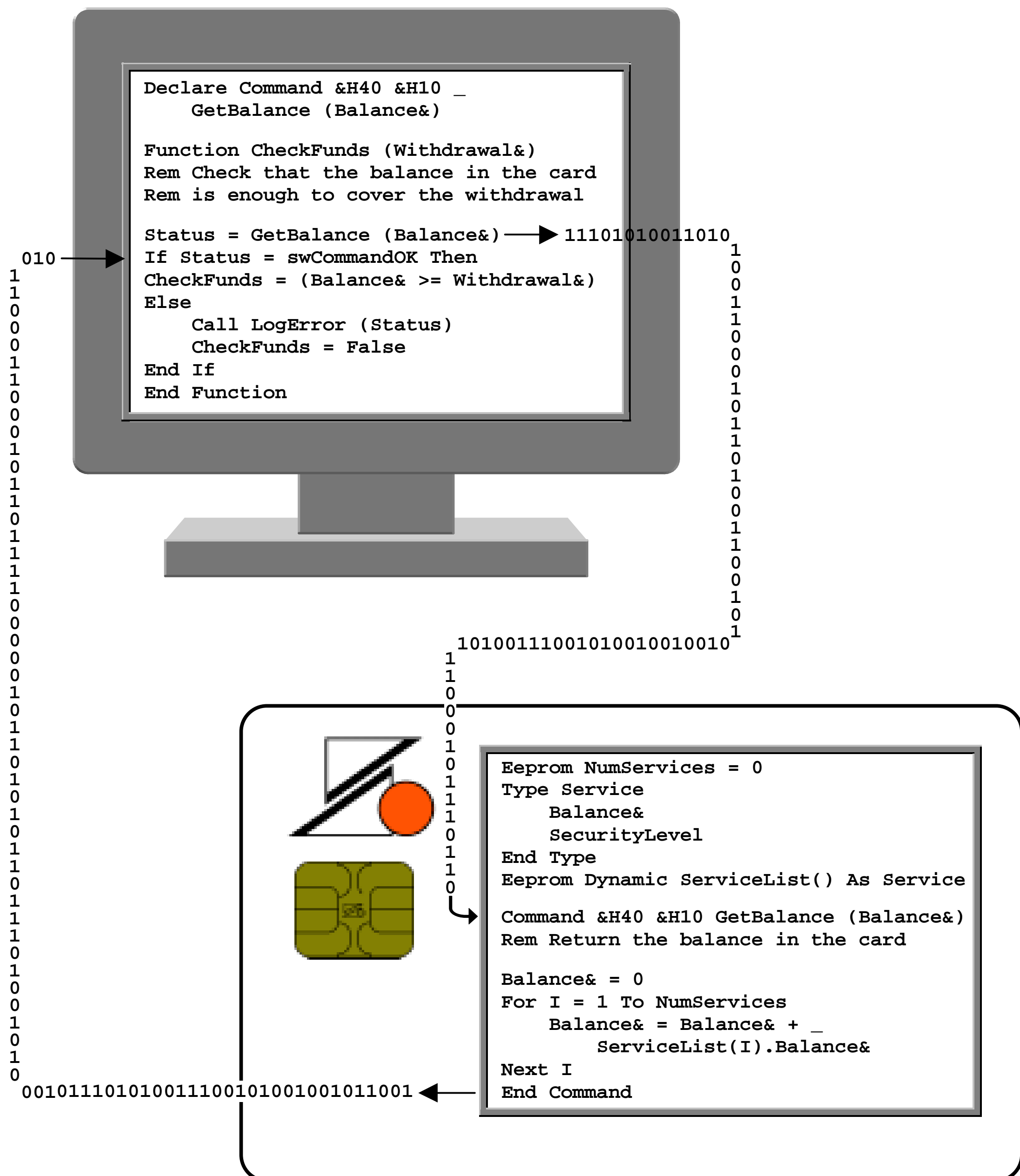
BasicCard



The ZeitControl BasicCard Family

ZeitControl
cardsystems GmbH

The ZeitControl BasicCard Family

Compact BasicCard

Enhanced BasicCard

Professional BasicCard

MultiApplication BasicCard

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Overview

Like most computer hardware, the price of smart cards is steadily decreasing, while performance and capacity are improving all the time. You can now buy a fully-functional computer, the size of your thumb-nail, for just a euro or two. However, before the BasicCard arrived, the cost of developing software for smart cards was out of all proportion to the cost of the hardware. A typical development project might take six months and cost a quarter of a million euros. This was a major barrier to the widespread use and acceptance of smart cards.

But now you can program your own smart card in an afternoon, with no previous experience required. If you can program in Basic, you can design and implement a custom smart card application. With ZeitControl's BasicCard, the development cycle of writing code, downloading, and testing takes a few minutes instead of weeks.

This document describes ZeitControl's BasicCard family: the Compact BasicCard, the Enhanced BasicCard, and Professional BasicCard, and the MultiApplication BasicCard. A BasicCard contains 256-1768 bytes of RAM, and 1-31 kilobytes of user-programmable EEPROM. The EEPROM contains the user's Basic code, compiled into a virtual machine language known as P-Code (the Java programming language uses the same technology). The user's permanent data is also stored in EEPROM, either as Basic variables, or in the BasicCard's directory-based file system. The RAM contains run-time data and the P-Code stack.

The smallest BasicCard, the Compact BasicCard, contains 1 kilobyte of EEPROM. How much Basic code can you squeeze into this card? While no exact figure can be given, our experience suggests a ratio of about 10-20 bytes of P-Code to every statement of Basic code. Assuming on average one statement every two lines (for comments and blank lines), this works out at 100-200 lines of source code. Some Professional BasicCards contain over 30 times as much EEPROM. The MultiApplication BasicCard contains 31 kilobytes of EEPROM, allowing several sizeable Applications in a single card.

To create P-Code and download it to the BasicCard, you need ZeitControl's BasicCard support software. This software is *free of charge,* and can be downloaded at any time from ZeitControl's BasicCard page on the Internet (www.BasicCard.com). The support software runs under Microsoft® Windows® 98 or later. With this support package, you can test your software even if you don't have a card reader, by simulating the BasicCard in the PC. The package contains a fully-functional Multiple Debugger, that can run Terminal and BasicCard programs simultaneously. So you can try out your idea for a smart card application without it costing you a cent.

The Smart Card Environment

Obviously, programming a smart card is not the same as programming a desktop computer. It has no keyboard or screen, for a start. So how does a smart card receive its input and communicate its output? It talks to the outside world through its bi-directional I/O contact. Communication takes place at 9600 baud or more, according to the T=0 and T=1 protocols defined in ISO/IEC standards 7816-3 and 7816-4. But this is completely invisible to the Basic programmer – all you have to do is define a command in the card, and program it like an ordinary Basic procedure. Then you can call this command from a ZC-Basic program running on the PC. Again, the command is called as if it was an ordinary procedure.

The BasicCard operating system takes care of all the communications for you. It will even encrypt and decrypt the commands and responses if you ask it to. All you have to do is specify a different two-byte ID for each command that you define. (If you are familiar with **ISO/IEC 7816-4**: *Interindustry commands for interchange*, you will know these two bytes as **CLA** and **INS**, for Class and Instruction.)

Here is a simple example. Suppose you run a discount warehouse, and you are issuing the BasicCard to members to store pre-paid credits. You will want a command that returns the number of credits left in the card. So you might define the command GetCustomerCredits, and give it an ID of &H20 &H02 (&H is the hexadecimal prefix):

```
Eeprom CustomerCredits ' Declare a permanent Integer variable
Command &H20 &H02 GetCustomerCredits (Credits)
    Credits = CustomerCredits
End Command
```

You can call this command from the PC with the following code:

```
Const swCommandOK = &H9000
Declare Command &H20 &H02 GetCustomerCredits (Credits)
Status = GetCustomerCredits (Credits)
If Status <> swCommandOK Then GoTo CancelTransaction
```

The value &H9000 is defined in **ISO/IEC 7816-4** as the status code for a successful command. This value is automatically returned to the caller unless the ZC-Basic code specifies otherwise. The return value from a command should always be checked, even if the command itself has no error conditions – for instance, the card may have been removed from the reader.

It's as simple as that. Of course, there is a lot more going on below the surface, but you don't have to know about it to write a BasicCard application.

Technical Summary

All BasicCard families (Compact, Enhanced, Professional, and MultiApplication) contain:

- a full implementation of the **T=1** block-level communications protocol defined in **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*, including chaining, retries, and WTX requests;
- a command dispatcher built around the structures defined in **ISO/IEC 7816-4**: *Interindustry commands for interchange* (**CLA INS P1 P2** [**Lc IDATA**] [**Le**]);
- built-in commands for loading EEPROM, enabling encryption, etc.;
- a Virtual Machine for the execution of ZeitControl's P-Code;
- code for the automatic encryption and decryption of commands and responses, using the **AES**, **DES**, or **SG-LFSR** symmetric-key algorithm.

Enhanced BasicCards contain in addition:

- a directory-based, DOS-like file system;
- IEEE-compatible floating-point arithmetic.

The functionality of the Enhanced BasicCard family can be further extended using Plug-In Libraries.

Professional BasicCards contain all the above, plus:

- a Public-Key algorithm (**RSA** or **EC**);
- a full implementation of the **T=0** byte-level communications protocol defined in **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*;
- the **SHA-1** Secure Hash Algorithm.

The *MultiApplication BasicCard* (and some Professional BasicCards) contain all the above, plus cryptographic algorithms **EAX** (for Authenticated Encryption) and **OMAC** (for Message Authentication) and the **SHA-256** Secure Hash Algorithm.

The data sheet on the next two pages contains details of available BasicCards versions, and the cryptographic algorithms that they support.

Development Software

The **ZeitControl MultiDebugger** software support package consists of:

- **ZCPDE**, the Professional Development Environment;
- **ZCMDTERM** and **ZCMDCARD**, debuggers for Terminal programs and BasicCard programs;
- **ZCMBASIC**, the compiler for the ZC-Basic language;
- **ZCMSIM**, for low-level simulation of Terminal and BasicCard programs;
- **BCLOAD**, for downloading P-Code to the BasicCard;
- **KEYGEN**, a program that generates random keys for use in encryption;
- **BCKEYS**, for downloading cryptographic keys to the Compact and Enhanced BasicCards.

BasicCard Versions

Compact BasicCard

Version	*EEPROM*	*RAM*	*Protocol*	*Encryption*	*Floating-Point Support*	*File System*
ZC1.1	**1K**	**256 bytes**	**T=1**	**SG-LFSR**	**None**	**No**

Enhanced BasicCard

Version	*EEPROM*	*RAM*	*Protocol*	*Encryption*	*Extras*	*FP Support*	*File System*
ZC3.1	**2K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.2	**4K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.31	**8K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.4	**16K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.5	**6K**	**256 bytes**	**T=1**	**DES**	**EC-FSA**[1]	**Full**	**Yes**
ZC3.6	**14K**	**256 bytes**	**T=1**	**DES**	**EC-FSA**[1]	**Full**	**Yes**
ZC3.7	**2K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.8	**4K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**
ZC3.9	**8K**	**256 bytes**	**T=1**	**DES**		**Full**	**Yes**

[1] **EC-FSA**: Fast Signature Algorithm for Elliptic Curve Cryptography

Plug-In Libraries for the Enhanced BasicCard: **EC-161, AES, SHA-1, IDEA**

Professional BasicCard[1]

Version	*PK Algorithm*	*EEPROM*	*RAM*	*Protocol*	*Encryption*	*Extras*	*FP Support*	*File System*
ZC4.5A	**RSA**	**30K**	**1K**	**T=0, T=1**	**AES**	**SHA-1**	**Partial**[2]	**Yes**
ZC4.5D	**RSA**	**30K**	**1K**	**T=0, T=1**	**DES**	**SHA-1**	**Partial**[2]	**Yes**
ZC5.4	**EC-167**	**16K**	**1K**	**T=0, T=1**	**AES & DES**	**SHA-1**	**Full**	**Yes**
ZC5.5	**EC-211**	**31K**	**1.7K**	**T=0, T=1**	**EAX/OMAC/ AES/DES**	**SHA-256**	**Full**	**Yes**

[1] See **Professional and MultiApplication BasicCard Datasheet** for more information

[2] **Single**-to-**String** conversion not supported

MultiApplication BasicCard[1]

Version	*PK Algorithm*	*EEPROM*	*RAM*	*Protocol*	*Encryption*	*Extras*	*FP Support*	*File System*
ZC6.5	**EC-211**	**31K**	**1.7K**	**T=0, T=1**	**EAX/OMAC/ AES/DES**	**SHA-256**	**Full**	**Yes**

[1] See **Professional and MultiApplication BasicCard Datasheet** for more information

Algorithms and Protocols

Public-Key Algorithms

Name	*Description*	*Key size*	*Reference*
RSA	Rivest-Shamir-Adleman algorithm	1024 bits	IEEE P1363: Standard Specifications for Public Key Cryptography
EC-211	Elliptic Curve Cryptography over the field GF(2^{211})	211 bits	
EC-167	Elliptic Curve Cryptography over the field GF(2^{167})	167 bits	
EC-161	Elliptic Curve Cryptography over the field GF(2^{168})	161 bits	

Symmetric-Key Algorithms

Name	*Description*	*Key size*	*Reference*
EAX	Encryption with Authentication for Transfer (using **AES**)	128/192/ 256 bits	EAX: A Conventional Authenticated-Encryption Mode[1] M. Bellare, P. Rogaway, D. Wagner
OMAC	One-Key CBC-MAC (using **AES**)	128/192/ 256 bits	OMAC: One-Key CBC MAC[1] Tetsu Iwata and Kaoru Kurosawa Department of Computer and Information Sciences, Ibaraki University 4–12–1 Nakanarusawa, Hitachi, Ibaraki 316-8511, Japan
AES	Advanced Encryption Standard	128/192/ 256 bits	Federal Information Processing Standard FIPS 197
DES	Data Encryption Standard	56/112/168 bits	ANSI X3.92-1981: Data Encryption Algorithm
SG-LFSR	Shrinking Generator – Linear Feedback Shift Register	64 bits	D. Coppersmith, H. Krawczyk, and Y. Mansour, The Shrinking Generator, Advances in Cryptology – CRYPTO '93 Proceedings, Springer-Verlag, 1994
IDEA	International Data Encryption Algorithm	128 bits	X. Lai, On the Design and Security of Block Ciphers, ETH Series in Information Processing, v. 1, Konstanz: Hartung-Gorre Verlag, 1992

[1] These documents are available at http://csrc.nist.gov/CryptoToolkit/modes/proposedmodes/

Data Hashing Algorithms

Name	*Description*	*Reference*
SHA-256	Secure Hash Standard	Federal Information Processing Standard FIPS 180-2
SHA-1	Secure Hash Algorithm, revision 1	

Communication Protocols

Name	*Description*	*Reference*
T=0	Byte-level transmission protocol	ISO/IEC 7816-3: Electronic signals and transmission protocols
T=1	Block-level transmission protocol	

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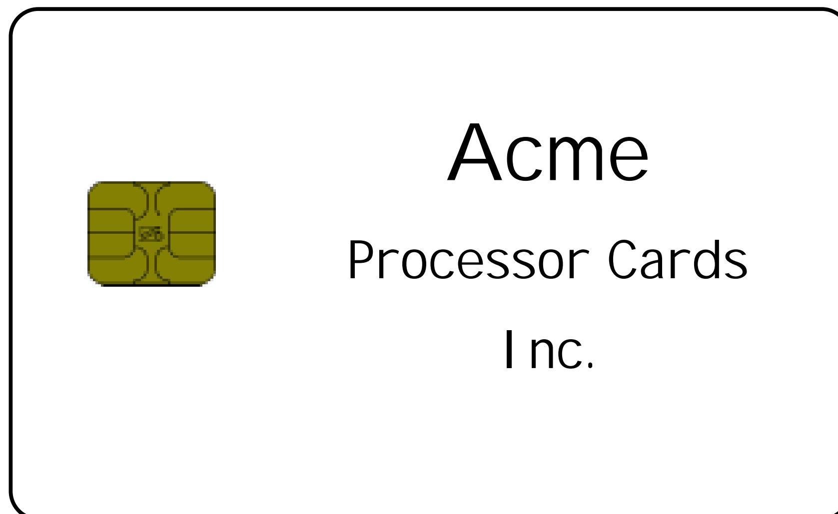
Part I

User's Guide

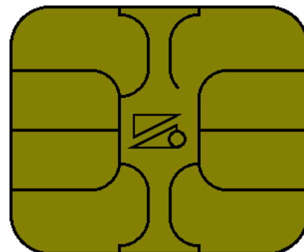
1. The BasicCard

1.1 Processor Cards

A processor card looks like this:



Most of this is just plastic. The important part is the metallic contact area:

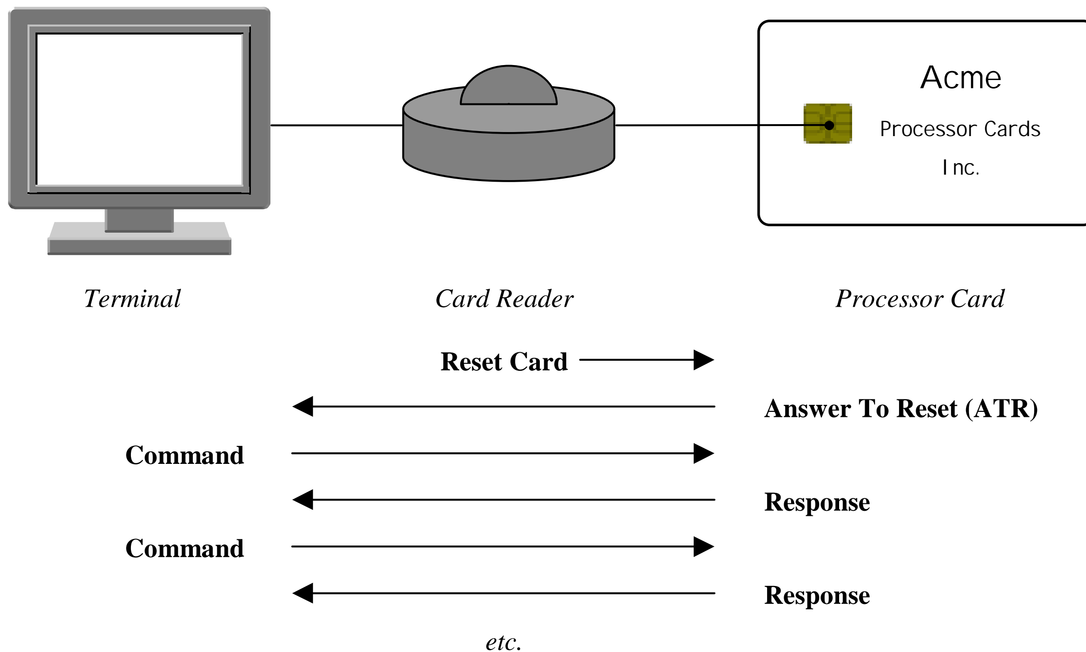


This area has the same layout as a standard telephone card. However, a telephone card contains only memory, while a processor card contains a CPU as well – in effect, a complete miniature computer. A typical processor card today might contain 16-64 kilobytes of ROM (Read-Only Memory) for the operating system machine code, 8-32 kilobytes of EEPROM (Electrically Erasable, Programmable Read-Only Memory) for the data in the card, and 256-2048 bytes of RAM (Random Access Memory). The EEPROM is the 'hard disk' of the card – data written to EEPROM retains its value when the card is powered down.

The single most important aspect of processor card design is security. That's what processor cards are for. If I want to make telephone calls for free, I can buy the equipment to make my own telephone cards – but the reward is not proportional to the effort required (not to mention the risk of detection). But if those telephone cards contained real money, instead of just telephone credits, there would be plenty of people working on making illegal copies.

So for cards that contain so-called *electronic cash* that can be spent like real money, a processor card is required. The processor protects access to the memory, using tamper-proof hardware design coupled with high-security software algorithms.

Communication with a processor card is by means of a *command-response* protocol. When a card is inserted in the reader, a command-response session is initiated:



The processor card is the passive partner in this exchange. After sending the Answer To Reset, it does nothing until it receives a command from the Terminal. Then after sending the response to this command, it waits passively for the next command, and so on. The command-response protocol used by most processor cards is defined in the **ISO** standard documents **ISO/IEC 7816-3**: *Electronic signals and transmission protocols* and **ISO/IEC 7816-4**: *Interindustry commands for interchange*. These documents are summarised in **Chapter 8: Communications**.

1.2 Programmable Processor Cards

Until recently, programming a processor card was a major undertaking. The following skills were involved:

- Assembly language programming. Although ‘C’ compilers were available for some processor cards, it was not possible to write the whole operating system in ‘C’.
- Byte-level communication protocols, such as the **T=0** protocol.
- Block-level communication protocols at the command-response level.
- Programming at the hardware level for writing to EEPROM.
- Security algorithms. You had to write your own.

You would also need a complex (and expensive) development environment. And on top of everything, after submitting your program to the chip manufacturer, you would have to wait for two or three months, while it was burned into ROM in several thousand chips, before you could test it in a real card.

However, the situation has improved. Programmable processor cards are now available. The heart of a programmable processor card is its P-Code interpreter. You write a program for the card, in Java or Basic (the two languages currently available on the market). This is compiled into so-called P-Code, which is a machine-independent language that looks like machine code. The P-Code is downloaded to the card, where it is executed by the interpreter. And if your code doesn’t work first time, you can download a new version into the same card. So the development cycle is closer to what most programmers are used to.

1.3 BasicCard Features

The BasicCard is a programmable processor card, with a P-Code interpreter optimised for executing programs written in Basic. It was designed with four criteria in mind at all times. It had to be:

Inexpensive The development software is *free of charge* – you can download the latest version from our web site at any time at www.BasicCard.com. And most versions of the BasicCard cost less than half as much as other currently-available programmable processor cards.

Easy to program Everybody can program in Basic – or if they can't, they can pick it up in an afternoon. That's all you need to program the BasicCard. A command from the Terminal to the BasicCard is defined and called just like a Basic function. The file system in the BasicCard looks just like a regular diskette. Encryption has been made as simple as possible to implement – you just turn it on or off. And EEPROM data is read and written just like RAM data.

Secure State-of-the-art cryptographic algorithms are available for all BasicCard types:

Professional and MultiApplication BasicCards

- public-key cryptography: **RSA**, or **EC** over GF(2^{167}) or GF(2^{211})
- **AES** Advanced Encryption Standard and **DES** Data Encryption Standard
- Secure Hash Algorithm **SHA-1** or **SHA-256**
- Provably secure modes of operation **EAX** for Authenticated Encryption and **OMAC** for Message Authentication (BasicCards **ZC5.5** and **ZC6.5** only)

Enhanced BasicCard

- **DES** Data Encryption Standard
- Plug-In Libraries: **AES**, **SHA-1**, **EC** over GF(2^{168}), and the **IDEA** International Data Encryption Algorithm

Compact BasicCard

- the Shrinking Generator algorithm designed by D. Coppersmith, H. Krawczyk, and Y. Mansour – see **9.10 The SG-LFSR** Algorithm for details

The security of the BasicCard implementation is enhanced by our cryptographic key generation program – see **6.9.4 The Key Generator KEYGEN.EXE**.

ISO-compliant In the ZC-Basic programming language, defining your own **ISO**-compliant command is as easy as declaring a function. Just as importantly, **ISO**-defined commands, such as **SELECT FILE** and **READ RECORD**, can be programmed in ZC-Basic. So you can implement your own **ISO** card, or call an existing **ISO** card from a ZC-Basic Terminal program. See **8.5 Commands and Responses** for more information.

The operating systems in all BasicCards contain the following features:

- A full implementation of the **T=1** communications protocol defined in **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*, including chaining, retries, and WTX requests. The Professional and MultiApplication BasicCards contain the **T=0** protocol as well.

  These protocols define the structure and duration of the bits and bytes that constitute the messages in a command-response session. See **8.3 The T=0 Protocol** and **8.4 The T=1 Protocol** for more information.

- Pre-defined commands for downloading programs and data to the BasicCard, enabling automatic encryption, etc.

  These commands are described in **8.7 Pre-Defined Commands**.

- A Virtual Machine for the execution of ZeitControl's P-Code.

  The compiler **ZCMBASIC** compiles ZC-Basic source code into P-Code, an intermediate language that can be thought of as the machine code for a Virtual Machine. (The Java programming language uses the same technology, although the P-Code instruction set is not the same.) The P-Code is downloaded to the card using the **BCLOAD** Card Loader program. Then the Virtual Machine in the BasicCard executes the P-Code instructions at run-time.

1.4 BasicCard Programs

1.4.1 Applications

BasicCard programs are written in the ZC-Basic language, which is a modern procedure-oriented Basic, with special features for the processor card environment. It is described in **Chapter 3: The ZC-Basic Language**.

A BasicCard program is specified in a single source file (which may, however, include other source files). This file will typically have a **.BAS** extension. It consists of a set of Commands, with associated files and data.

Single-application BasicCards (Compact, Enhanced, and Professional) can contain only a single Application; all Commands in the Application's Command set have Read and Write access to all the associated files and data.

A MultiApplication BasicCard can contain up to 128 different Applications, each with its own Command set and associated data. Associated data is accessible only by its own Application. Files, however, can be accessed for Reading or Writing by any Application that has the necessary permission.

1.4.2 Image Files

The compiler can create a ZeitControl Image File (with **.IMG** extension) from your BasicCard program source file. This image file can then be downloaded to a BasicCard; or it can be run in the **ZCMSIM** P-Code interpreter together with a Terminal Program – see **6.9.2 The P-Code Interpreter ZCMSIM.EXE** for details.

1.4.3 Debug Files

If the BasicCard Application is to be run in the **ZCMDCARD** BasicCard debugger, the compiler must create a ZeitControl Debug File (with **.DBG** extension). This is simply a ZeitControl Image File with symbolic debugging information included. Image files and debug files are described in **Chapter 11: Output File Formats**.

1.4.4 Card Program Files

The **ZCMDCARD** BasicCard debugger works with simulated BasicCards. A simulated card is described by a Card Program File, with extension **.ZCC**. This file contains the simulated EEPROM, which retains its contents between program runs, and various other data, such as source filename of each Application, the BasicCard version, and compiler options. A single source file may be the basis for several Card Program files, each running the same program, but with different data stored in simulated EEPROM.

1.5 BasicCard Program Layout

A BasicCard program consists of *initialisation code* and *procedure definitions*. Programs for the Enhanced, Professional, and MultiApplication BasicCards can also contain optional *file definition sections*.

1.5.1 Initialisation Code

The first block of code that is not contained inside a procedure definition is *initialisation code*. In a single-application BasicCard, this initialisation code gets executed when the first user-defined command is called from the Terminal. In the MultiApplication BasicCard, an Application's initialisation code is executed whenever the Application is selected.

Initialisation code is not required, but it can be useful for certain things; for instance, checking that the card has not been cancelled by the issuer, or that the expected files and directories are present.

1.5.2 Procedure Definitions

ZC-Basic has three types of procedure: subroutines, functions, and commands. Each procedure is self-contained – nested procedure definitions are not allowed, and **GoTo** and **GoSub** statements can only transfer control to labels within the current procedure. Subroutines and functions are familiar to Basic programmers – a subroutine is a block of code that can be called from other procedures, and a function is a subroutine that returns a value. The command, however, is special to ZC-Basic; it is the mechanism by which the Terminal program communicates with the BasicCard program.

According to the **ISO** standard document **ISO/IEC 7816-4**: *Interindustry commands for interchange*, each command is assigned a unique two-byte ID. This is all the ZC-Basic programmer needs to know about ISO standards. For the curious, these two bytes are known as **CLA** and **INS** (for Class and Instruction); the full command-response protocol defined in the standard is described in **8.5 Commands and Responses**. The two-byte ID must be supplied between the **Command** keyword and the name of the command. Here is an example (**&H** is the hexadecimal prefix):

```
Command &H80 &H10 GetCustomerName (Name$)
    Name$ = CustomerName$
End Command
```

Then whenever the BasicCard receives a command from the Terminal with **CLA = &H80** and **INS = &H10**, the operating system in the card automatically executes the **GetCustomerName** command.

A command behaves like a cross between a function and a subroutine: it is defined like a subroutine (as above), but called like a function (see **2.2 Terminal Program Layout**). The BasicCard operating system fills in the return value that gets passed back to the Terminal program. This return value consists of the two status bytes **SW1** and **SW2** defined in **ISO/IEC 7816-4**. The return value of a command should always be checked; for instance, the card may have been removed from the reader, or the reader may have lost power for some reason. If **SW1 = &H90** and **SW2 = &H00**, or if **SW1 = &H61**, then the command completed successfully. Otherwise a problem has occurred that prevented successful execution of the command.

These two status bytes are available as pre-defined variables in the BasicCard, so you can define your own error codes. For convenience of access, the two-byte **Integer** variable **SW1SW2** is also defined. For instance:

```
Eeprom Balance As Long : Rem Declare permanent (Eeprom) variable
Const InsufficientCredit = &H6F00
Command &H80 &H20 DebitAccount (Amount As Long)
    If Balance < Amount Then
        SW1SW2 = InsufficientCredit
    Else
        Balance = Balance - Amount
    End If
End Command
```

Notes:

- You don't need to specify **SW1** and **SW2** if the command completes successfully. They are set to **&H90** and **&H00** before the command is called.
- If you specify values for **SW1** and **SW2** other than the two indicators of successful completion (**SW1SW2 = &H9000** or **SW1 = &H61**), the operating system throws away the response data and just returns the two status bytes to the Terminal program. (This is in accordance with **ISO/IEC 7816-4**.) In the Professional and MultiApplication BasicCards, you can override this behaviour – see **3.3.4 The #Pragma Directive** and **7.10.8 SW1-SW2 Processing** for details.
- Your own **SW1-SW2** error codes can take any values. However, for **ISO** compliance, or if you are programming a Professional BasicCard that uses the **T=0** protocol, the high nibble of **SW1** must be **6**, i.e. **SW1 = &H6***X*. You should also avoid assigning new meanings to ZC-Basic's own error codes. ZC-Basic's error codes are listed in **8.6 Status Bytes SW1 and SW2**; you can avoid any clashes if you use **SW1 = &H6B** or **&H6F** (except **SW1-SW2=&H6F00**).

1.5.3 File Definition Sections

The Enhanced, Professional, and MultiApplication BasicCards contain a Windows®-like file system, with directories organised in a tree structure. There are several ways to access BasicCard files and directories.

- From within the BasicCard itself, files can be created, read, and written with exactly the same statements that you would use in a Basic program running under DOS or Windows®. There are also some special statements for setting access conditions on files and directories, to restrict access from Terminal programs and from other Applications. These access conditions can depend on cryptographic keys, user passwords, etc.
- From a Terminal program, the BasicCard looks just like a diskette, with the special drive name "**@:**". If the access conditions permit it, you can create, read, and write files and directories in the BasicCard as if it was a floppy disk.
- You can initialise directory structures and files in a BasicCard program with File Definition Sections – see **4.11 File Definition Sections**. In a MultiApplication BasicCard program, a File Definition Section can also contain Component definitions and Application Loader commands. See **5.4 Application Loader Definition Section** for more information.

1.5.4 Permanent Data

Most BasicCard applications will contain permanent data, that retains its value while the BasicCard is powered down. Permanent data is stored in EEPROM (Electrically Erasable, Programmable Read-Only Memory). In most BasicCards, you can store permanent data in files; but it is often simpler (and in the Compact BasicCard it is compulsory) to store permanent data in **Eeprom** variables, particularly if the length of the data is fixed. An example of an **Eeprom** variable was given in the previous section:

```
Eeprom Balance As Long : Rem Declare permanent (Eeprom) variable
```

The variable **Balance** declared here can be read or written just like a regular variable. **Eeprom** strings and arrays can also be declared. This can be a very convenient way of storing permanent data, in all types of BasicCard. Note, however, that in the MultiApplication BasicCard, **Eeprom** data can only be accessed by the Application that declares it; data to be shared between Applications must be file-based.

Writing to EEPROM can take up to 6 milliseconds, so the possibility is always present that the card will lose power in the middle of the write operation. The Enhanced, Professional, and MultiApplication BasicCards automatically log all EEPROM write operations, to enable them to recover in the event of power loss. The Compact BasicCard has no such recovery mechanism, so EEPROM data may be left in an inconsistent state. In the Compact BasicCard, therefore, important **Eeprom** data should be duplicated to protect against possible corruption if the card is powered down during an EEPROM write operation. For example:

```
Eeprom Balance As Long : Rem A very important piece of data
Eeprom ShadowBalance As Long
Eeprom Committed = False

Command &H80 &H30 ChangeBalance (NewBalance As Long)
    ShadowBalance = NewBalance
    Committed = True
    Balance = ShadowBalance
    Committed = False
End Command
```

Then in the initialisation code:

```
If Committed Then
    Balance = ShadowBalance
    Committed = False
End If
```

This technique guarantees that **Balance** will never be left in an inconsistent state.

Note: In the Compact BasicCard, power loss during memory allocation can lead to corruption of the EEPROM heap. For this reason, we recommend that you avoid **ReDim** statements and assignment of

variable-length strings in all Compact BasicCard code that may be executed after the card is issued to the end user.

1.6 The Compact BasicCard

A single version of the Compact BasicCard is available:

BasicCard ZC1.1 Contains 1K of user-programmable EEPROM. Available since June 1998.

The Compact BasicCard is no longer being manufactured, and is only available as long as stocks last.

1.7 The Enhanced BasicCard

The original Enhanced BasicCard – the *Series 2* Enhanced BasicCard – is no longer supported. The current Enhanced BasicCard is the *Series 3* Enhanced BasicCard:

BasicCard ZC3.1 Contains 2K of user-programmable EEPROM. Available in large quantities only – contact ZeitControl for details.

BasicCard ZC3.2 Contains 4K of user-programmable EEPROM. Available in large quantities only – contact ZeitControl for details.

BasicCard ZC3.3 Contains 8K of user-programmable EEPROM. Available since December 1999.

BasicCard ZC3.31 Functionally identical to **BasicCard ZC3.3**.

BasicCard ZC3.4 Contains 16K of user-programmable EEPROM. Available since December 1999.

BasicCard ZC3.5 Contains 6K of user-programmable EEPROM, and the Elliptic Curve Fast Signature Algorithm (**EC-FSA**). Available since February 2000.

BasicCard ZC3.6 Contains 14K of user-programmable EEPROM, and the Elliptic Curve Fast Signature Algorithm (**EC-FSA**). Available since February 2000.

The two **EC-FSA** cards contain a proprietary algorithm that can generate a 161-bit Elliptic Curve signature in 1.2 seconds.

BasicCard ZC3.7 New 2K version, equivalent to **BasicCard ZC3.1**.

BasicCard ZC3.8 New 4K version, equivalent to **BasicCard ZC3.2**.

BasicCard ZC3.9 New 8K version, equivalent to **BasicCard ZC3.3**.

These three new versions were required due to hardware changes in the chip, but the functionality is unchanged.

1.8 The Professional BasicCard

All Professional BasicCards contain a built-in public-key cryptography algorithm: **ZC4.x** series cards support the **RSA** algorithm, and **ZC5.x** series cards support the **EC-167** algorithm (Elliptic Curve cryptography over the finite field GF(2^{167}), as defined in IEEE standard P1363).

The minor version number (the **x** in **ZC4.x** and **ZC5.x**) indicates that the amount of user-programmable EEPROM in the card is approximately 2^{X} kilobytes.

Currently available Professional BasicCards:

Version	*User-programmable EEPROM*	**T=0**	**T=1**	**EAX**	**OMAC**	**AES**	**DES**	**RSA**	**EC**	**SHA**
ZC4.5A	30K	✓	✓			✓		✓		**SHA-1**
ZC4.5D	30K	✓	✓				✓	✓		**SHA-1**
ZC5.4	16K	✓	✓			✓	✓		**EC-167**	**SHA-1**
ZC5.5	31K	✓	✓	✓	✓	✓	✓		**EC-211**	**SHA-256**

From time to time, new versions of the Professional BasicCard will appear, and new features will be added to existing cards. See the **Professional and MultiApplication BasicCard Datasheet** on ZeitControl's BasicCard web site www.BasicCard.com for the most up-to-date information.

The version number of the card, along with its software revision number, is returned by the card as an ASCII string in the response to the **GET STATE** command (see **8.7.3 The GET STATE Command**).

1.9 The MultiApplication BasicCard

Version **ZC6.5** is the only MultiApplication BasicCard currently available:

Version	*User-programmable EEPROM*	**T=0**	**T=1**	**EAX**	**OMAC**	**AES**	**DES**	**EC-211**	**SHA-256**
ZC6.5	31K	✓	✓	✓	✓	✓	✓	✓	✓

See **Chapter 5: The MultiApplication BasicCard** for more information.

2. The Terminal

2.1 The Terminal Program

The ZC-Basic language was designed with the BasicCard in mind. But it can also run in a PC, with or without a card reader attached to the serial port. You can write a stand-alone ZC-Basic program to do your monthly accounts, or to help you solve crosswords, or whatever you like.

A ZC-Basic program that runs on a PC is referred to in this documentation as the **Terminal** program. Usually it will communicate with one or more ZC-Basic programs running in (real or simulated) BasicCards – the **BasicCard** programs.

The compiler can create executable files, image files, and debug files from a Terminal program source file – see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE** for details.

2.1.1 Executable Files

The compiler can create standard executable files (files with **.EXE** extension), that will run as programs in a DOS box under Windows®. Such programs can communicate with a real or simulated BasicCard. Such programs are not self-modifying, so they can't execute **Write Eeprom** statements (see **2.2.4 Permanent Data** below).

Command-line parameters passed to the executable file can be accessed from ZC-Basic in the pre-defined string array **Param$ (1 To nParams)** – see **3.21.10 Pre-Defined Variables**.

2.1.2 Image Files

For more flexibility during program development, the compiler can also create a ZeitControl Image File (with **.IMG** extension) from your Terminal program source file. The **ZCMSIM** P-Code interpreter can then run this Terminal program together with a BasicCard program running in a real or simulated BasicCard – see **6.9.2 The P-Code Interpreter ZCMSIM.EXE** for details.

2.1.3 Debug Files

The compiler can also produce Debug Files (with **.DBG** extension), which are ZeitControl Image Files with debugging information included. These files are used by the **ZCMDTERM** Terminal Program debugger. Image files and debug files are described in **Chapter 11: Output File Formats**.

2.1.4 Terminal Program Files

The **ZCMDTERM** Terminal Program debugger saves the data for a given Terminal Program in a Terminal Program file, with **.ZCT** extension. This file contains the source filename, the compiler options, and various other data.

2.2 Terminal Program Layout

A Terminal program consists of the *main procedure* and *procedure definitions*. BasicCard commands are declared in *command declarations*, after which they can be called just like functions.

The Terminal program is executed by ZeitControl's P-Code interpreter, in one of three ways:

- as a stand-alone executable file (**.EXE**) created by the compiler;
- by the **ZCMSIM** P-Code interpreter, from an Image File (**.IMG**);
- by the **ZCMDTERM** Terminal Program debugger, from a Debug File (**.DBG**).

The P-Code interpreter can run BasicCard programs simultaneously in the PC in simulated BasicCards, or it can communicate with genuine BasicCards via a card reader – a ZeitControl Chip-X® or CyberMouse® card reader connected to a serial port or a USB port, or any other PC/SC-compatible card reader.

2.2.1 The Main Procedure

The *main procedure* starts at the first statement that is not contained inside a procedure definition, and ends at the start of the next procedure definition (or the end of the source file). The Terminal program begins execution at the first statement in the main procedure, and continues until it reaches the end of the main procedure, or until an **Exit** statement is executed.

2.2.2 Procedure Definitions

Procedure definitions in the Terminal program consist of functions and subroutines, exactly like a regular Basic program. Each procedure is self-contained – nested procedure definitions are not allowed, and **GoTo** and **GoSub** statements can only transfer control to labels within the current procedure.

2.2.3 Command Declarations

Before you can call a BasicCard command, you must declare it, so that the ZC-Basic compiler knows the two ID bytes of the command, and the types of the command parameters. Apart from the two ID bytes, a command declaration looks like a subroutine declaration. Here are declarations of the three example commands from **1.5 BasicCard Program Layout**:

```
Declare Command &H80 &H10 GetCustomerName (Name$)
Declare Command &H80 &H20 DebitAccount (Amount As Long)
Declare Command &H80 &H30 ChangeBalance (NewBalance As Long)
```

Calling these commands is just like calling a function:

```
Status = GetCustomerName (Name$)
If Status <> &H9000 And (Status And &HFF00) <> &H6100 Then
    Print "GetCustomerName: Status = &H"; Hex$ (Status)
    GoTo Retry
End If
```

You should always check the return value, even if the command itself has no error conditions, in case a communication problem has occurred (such as the card being removed from the reader). If you prefer, you can use the pre-defined variables **SW1**, **SW2**, and **SW1SW2**, which contain the status bytes from the most recently called command:

```
Call GetCustomerName (Name$)
If SW1SW2 <> &H9000 And SW1 <> &H61 Then
    Print "GetCustomerName: Status = &H"; Hex$ (SW1SW2)
    GoTo Retry
End If
```

See **8.6 Status Bytes SW1 and SW2** for a list of ZC-Basic status codes. The file `BasicCardPro\Inc\Commands.Def` defines these status codes in **Const** statements, so you can refer to &H9000 and &H61 as **swCommandOK** and **sw1LeWarning** respectively if you include this file in your program – see **3.3.1 Source File Inclusion**. Alternatively, you can call the subroutine **CheckSW1SW2()**, which is defined in the file COMMERR.DEF. If a communications error has occurred, this subroutine prints a suitable error message and exits.

2.2.4 Permanent Data

ZC-Basic contains a very convenient mechanism for the reading and writing of permanent data in the BasicCard: you just declare data of storage type **Eeprom**, and the BasicCard operating system does the rest. Although the Terminal program contains no genuine EEPROM data, this useful feature is available in Terminal programs as well, if they were loaded from a ZeitControl Image File (or Debug File). **Eeprom** data in a Terminal program is written back to the image file in two circumstances:

2. The Terminal

1. On program exit, if the appropriate options were specified:
   - in the **ZCMDTERM** Terminal Program debugger, checking the **Save Terminal EEPROM** entry in the **Terminal Program Options** dialog box;
   - with the **–W** parameter on the **ZCMSIM** command line (see **6.9.2 The P-Code Interpreter ZCMSIM.EXE**).
2. When the Terminal program executes a **Write Eeprom** statement (see **3.21.7 Saving Eeprom Data**).

Note: The **Write Eeprom** statement is only valid if the Terminal program is running in the **ZCMSIM** P-Code interpreter or the **ZCMDTERM** Terminal Program debugger. Programs containing **Write Eeprom** statements can't be compiled into executable files.

3. The ZC-Basic Language

The ZC-Basic programming language is a fully functional, modern Basic, with function and subroutine calls, user-defined data types, file I/O, and pre-processor directives. In addition, it has some special features for the smart card environment, including command definition and invocation, I/O encryption, and file access control.

In this chapter, the following conventions are observed:

- ZC-Basic keywords are printed in **bold text**.
- Statement fields that must be supplied by the programmer are printed in *italic text*.
- Programming examples are printed in **`fixed-width bold text`**.
- Optional statement fields are enclosed in [square brackets].
- Alternatives are separated by a vertical bar and enclosed in braces, e.g. { **ByVal | ByRef** }.

File I/O in ZC-Basic is described in **Chapter 4: Files and Directories**.

3.1 The Source File

A ZC-Basic Application must consist of a single compilation unit – there is no linking stage. This lets the compiler work out the storage requirements of the whole program, so that it can use the limited RAM as efficiently as possible. You may, however, split your source into several files and **#Include** them all in a master source file.

The source consists of *lines*, which may be logically extended with the line continuation character '_' (underscore). Each line consists of *statements*, separated from each other with '**:**' (colon). A comment character ''' (single quote) causes the rest of the line to be ignored (unless it occurs inside a string). The **Rem** keyword may also be used to introduce a comment, but it is only allowed at the beginning of a statement. For instance:

```
X = 0           '     Comment introduced by comment character
                Rem   OK to use Rem on its own line...
Y = 0 : Z = 0 : Rem   ...but here we need the colon
```

3.2 Tokens

At the lowest level, a source program consists of a sequence of *tokens*. There are four kinds of token: constants, identifiers, reserved words, and special symbols. Except for string constants, tokens may not contain spaces or tabs.

A constant can be an integer, a floating-point number, or a string. Integer constants are decimal by default; the prefixes **&O** (or just **&**) and **&H** denote octal and hexadecimal constants respectively. Integer constants have the range –2147483648 to +2147483647.

If a constant contains a decimal point or an exponent (E or e), it is a floating-point constant. ZC-Basic supports only single-precision floating-point numbers. Floating-point numbers are stored in IEEE denormalised format, with an 8-bit exponent and a 23-bit mantissa. This gives a precision of 7 decimal places, and a range of 1.401298E–45 to 3.402823E+38.

A string constant is any sequence of printable characters enclosed in double quotes '**"**'. To include non-printable characters in a string constant, use **Chr$()**; the double quote itself is **Chr$(34)**. For example:

```
X$ = Chr$(34) + "STRING" + Chr$(34) + Chr$(10) ' 10 = new line
```

The special syntax **Chr$**($c_1$, c_2, ..., c_n), where c_i are all constants between 0 and 255, is an abbreviation for

Chr$**($c_1$) + **Chr$(c_2) + ... + **Chr$**($c_n$)

This defines a constant string consisting of the characters c_1 through c_n.

3. The ZC-Basic Language

Variables, procedures, etc. must be given names, or *identifiers*. In ZC-Basic, an identifier consists of letters (**A-Z**, **a-z**) and digits (**0-9**), followed by an optional type character (@, **%**, **&**, **!**, **$**). It may be any length. An identifier must start with a letter. The type character specifies the data type of a function or variable, as follows:

Character:	@	%	&	!	$
Data type:	**Byte**	**Integer**	**Long**	**Single**	**String**

If a type character is not present, the default type is **Integer** (but you can change this default behaviour with **DefByte**, **DefLng** etc – see **3.22.2 DefType Statement**). Case is not significant in ZC-Basic, so **ABC**, **AbC**, and **abc** are considered identical. An identifier must not clash with a *reserved word*, which is a word with a pre-defined meaning.

Here is a list of the reserved words in ZC-Basic:

Abs	**Access**	**And**	**Append**	**ApplicationID**
As	**Asc**	**At**	**ATR**	**Base**
Binary	**ByRef**	**Byte**	**ByVal**	**Call**
CardInReader	**CardReader**	**Case**	**Certificate**	**ChDir**
ChDrive	**Chr$**	**Close**	**Cls**	**Command**
Const	**CurDir**	**CurDrive**	**Declare**	**DefByte**
DefInt	**DefLng**	**DefSng**	**DefString**	**DES**
Dim	**Dir**	**Disable**	**Do**	**Dynamic**
Eeprom	**Else**	**ElseIf**	**Enable**	**Encryption**
End	**EOF**	**Erase**	**Exit**	**Explicit**
File	**For**	**FreeFile**	**Function**	**Get**
GetAttr	**GoSub**	**GoTo**	**Hex$**	**If**
Implicit	**InKey$**	**Input**	**Integer**	**Is**
Key	**Kill**	**LBound**	**LCase$**	**Left$**
Len	**Let**	**Line**	**Lock**	**Log**
Long	**Loop**	**LTrim$**	**Mid$**	**MkDir**
Mod	**Name**	**Next**	**Not**	**On**
Open	**Option**	**Or**	**Output**	**OverflowCheck**
PcscCount	**PcscReader**	**Polynomials**	**Print**	**Private**
Public	**Put**	**Random**	**Randomize**	**Read**
ReDim	**Rem**	**ResetCard**	**Return**	**Right$**
RmDir	**Rnd**	**Rol**	**RolB**	**Ror**
RorB	**RTrim$**	**Seek**	**Select**	**SetAttr**
Shared	**Shl**	**Shr**	**ShrL**	**Single**
Space$	**Spc**	**Sqrt**	**Static**	**Step**
Str$	**String**	**String$**	**Sub**	**Tab**
Then	**Time$**	**To**	**Trim$**	**Type**
UBound	**UCase$**	**Unlock**	**Until**	**Val!**
Val&	**ValH**	**WEnd**	**While**	**Write**
WTX	**Xor**			

In addition to constants, identifiers, and reserved words, the following special symbols are recognised:

(	Left parenthesis	)	Right parenthesis	_	Underscore (line continuation)
+	Plus	-	Minus	'	Single quote (comment character)
*	Multiply	/	Divide	#	Pre-processor directive or file number
,	Comma	:	Colon	"	Double quote (string delimiter)
=	Equals	<>	Not equals	.	Full stop or Period
<	Less than	>	Greater than	;	Semi-colon
<=	Less than or equal to	>=	Greater than or equal to		

3.3 Pre-Processor Directives

Pre-processor directives are instructions to the **ZCMBASIC** compiler. For instance, they tell the compiler which lines of source code to compile, and whether these lines should be written to the list file if a listing is requested. They can also be used to specify various command-line parameters in the source code itself – in this case, the compiler accepts the first occurrence of the parameter, so directives in the source code are overridden by parameters on the command line.

A pre-processor directive begins with the hash character '#', which must be the first character on the input line (excluding spaces and tabs).

3.3.1 Source File Inclusion

The directive

#Include *filename*

causes the named file to be included and compiled as if it was part of the source file itself. Included files can themselves contain **#Include** directives, nested to any depth. If *filename* contains any space characters, it must be enclosed in double quotes ("*filename*"); otherwise the quotes are optional. The compiler looks for the file in the following directories:

- first, the directory of the including file;
- next, directories specified in **–I** parameters, in the order that they appear in the command line (see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE**);
- next, the current directory;
- next, directories specified in the Windows® Registry variable "**HKEY_CURRENT_USER\Software\ZeitControl\BasicCardPro\ZCINC"**;
- finally, directories specified in the **ZCINC** environment variable.

The **ZCINC** Windows® Registry variable can be set from the **ZCPDE** Professional Development Environment, via menu item **Options|Environment|Compiler**.

3.3.2 Constant Definition

The statement

Const *constantname=expression* [,*constantname=expression*,...]

defines one or more constants. *expression* can be an integer, floating point, or string constant.

3.3.3 Library Inclusion

The directive

#Library *filename*

loads a ZeitControl Plug-In Library for the Enhanced BasicCard. See **Chapter 7: System Libraries** for a list of currently available libraries. The compiler looks for the **#Library** file in the same directories as it looks for **#Include** files – see **3.3.1 Source File Inclusion** for details.

Notes:

- ZeitControl provides a definition file *library***.def** for each library file *library***.lib**. The definition file contains the appropriate **#Library** directive, along with all the required declarations. You should normally just **#Include** this definition file, rather than loading the library yourself with a **#Library** directive.
- Terminal programs, and Professional and MultiApplication BasicCard programs don't need the **#Library** directive, as they use a different mechanism for loading Libraries – see **3.13.2 System Library Procedures**.

3.3.4 The #Pragma Directive

Various card-specific options can be selected using the **#Pragma** directive. At the time of writing, the following options are available in some or all cards:

Protocol Specification

#Pragma ATR (*ATR-Spec*)

where *ATR-Spec* defines the **ATR** (Answer To Reset) that the card sends on reset. See **3.20.1 Customised ATR** for the format of *ATR-Spec*.

In the MultiApplication BasicCard, protocol selection is implemented via the reserved file "**ATR**" – see **5.3.1 ATR File** for details.

For compatibility with earlier source code, the following options are still accepted by the compiler:

Old Version	*New Version*
#Pragma InverseConvention	**#Pragma ATR (Inverse)**
#Pragma [**T=0,**] [**T=1**]	**#Pragma ATR** ([**T=0,**] [**T=1**])
#BWT *n*	**#Pragma ATR (BWT** = *n*)
Declare ATR = *string*	**#Pragma ATR (HB** = *string*)

SW1-SW2 = &H9XXX Allowed

#Pragma Allow9XXX

Normally, if **SW1-SW2 <> &H9000**, and **SW1 <> &H61**, then **ODATA** is not sent – see **8.5 Commands and Responses**. You can override this behaviour in some BasicCards with this option: if **SW1-SW2** has the form **&H9***XXX*, then **ODATA** is sent in the response. This behaviour is enabled for every command. See **7.10.8 SW1-SW2 Processing** for an alternative method.

At the time of writing, this option is available in Professional BasicCards **ZC5.4** (from Revision B) and **ZC5.5** (all revisions), and in MultiApplication BasicCard **ZC6.5**.

Catch Undefined Commands

In the MultiApplication BasicCard, if a Default Application is defined, it can be configured to catch all commands that the currently selected Application doesn't recognise. Enable this option with

#Pragma CatchUndefinedCommands

in the source code of the Default Application. See **5.2.3 Catching Undefined Commands** for more information.

3.3.5 Conditional Compilation

Sections of code can be included or excluded according to the values of constants defined earlier (or on the compiler command line):

#If *condition1*
    code block 1
[**#ElseIf** *condition2*
    code block 2]
[**#ElseIf** *condition3*
    code block 3]
. . .
[**#Else**
    code block n]
#EndIf

where *condition1, condition2,...* are constant numerical expressions, which may include symbols defined in **Const** statements or on the compiler command line (with the "**–D***symbol*" parameter – see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE**). *Code block i* is compiled if *condition i* is the first non-zero condition.

Instead of testing the value of a numerical expression, you can test whether a constant symbol has been defined:

> **#IfDef** *symbol1*
> *code block 1*
> [**#ElseIfDef** *symbol2*
> *code block 2*]
> [**#ElseIfDef** *symbol3*
> *code block 3*]
> **. . .**
> [**#Else**
> *code block n*]
> **#EndIf**

The directives **#IfNotDef** and **#ElseIfNotDef** have the opposite sense to directives **#IfDef** and **#ElseIfDef** respectively.

#EndIf has the alternative form **#End If** (with a space) for compatibility with the Basic **End If** statement.

See also **3.3.13 Pre-Defined Constants**.

3.3.6 Listing Directives

You can cause sections of code (or complete included files) to be omitted from the listing file with the directive

> **#NoList**

The **#NoList** directive is cancelled by **#List**.

3.3.7 Card State

By default, a single-application BasicCard is switched to state **TEST** after a ZC-Basic program is downloaded. You can override this with the **#State** directive:

> **#State** { **LOAD | PERS | TEST | RUN** }

This is equivalent to the command-line parameter **–S***state* (see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE**).

3.3.8 Number of Open File Slots

Each open file in a ZC-Basic program is assigned an *open file slot*. The maximum number of files that can be opened simultaneously is equal to the number of open file slots:

Terminal Program	*MultiApplication BasicCard*	*Professional BasicCard*	*Enhanced BasicCard*
32	**10**	**4**	**2**

In the Professional and Enhanced BasicCards, this number can be overridden with the **#Files** directive:

> **#Files** *nFiles*

with 0 <= *nFiles* <= 16. This number includes files opened in the BasicCard program *and* BasicCard files opened from a Terminal program. The amount of RAM used by the file system is (6 * *nFiles* + 7) bytes (unless *nFiles* is zero, in which case no file system is installed, so no RAM is required).

3.3.9 Stack Size

The **#Stack** directive specifies the size of the P-Code stack:

> **#Stack** *stack-size*

This is equivalent to the compiler command-line parameter **–S***stack-size* (see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE**). If no stack size is specified, the compiler works out for itself how big the stack should be.

3.3.10 Heap Size

In a MultiApplication BasicCard program, the **#Heap** directive specifies the size of the Application heap:

#Heap *heap-size*

This is equivalent to the compiler command-line parameter **–H***heap-size* (see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE**).

The Application heap contains the Application's **Eeprom** strings and **Eeprom** dynamic arrays. If no heap size is specified, the heap is made just big enough to contain the strings and arrays that are initialised in the source code. If the source code contains uninitialised **Eeprom** strings or dynamic arrays, but no **#Heap** directive is present, the compiler issues an appropriate warning.

3.3.11 Message Directive

You can output a message at any point during compilation with

#Message *message*

The message is printed to the screen, and compilation continues unaffected.

3.3.12 Error Directive

You can define your own compiler error messages with the **#Error** directive. For instance:

```
#If MaxLineLength > 80
  #Error MaxLineLength too big (max 80)
#EndIf
```

Then if anybody tries to compile the program with **MaxLineLength** defined as 100, say, the compiler will issue the error message "**#Error MaxLineLength too big (max 80)**" and stop compilation.

3.3.13 Pre-Defined Constants

According to the target machine type, one of the following constants is pre-defined by the compiler (and has the value 1):

TerminalProgram	**CompactBasicCard**	**EnhancedBasicCard**
ProfessionalBasicCard	**MultiAppBasicCard**	

For instance:

```
#IfNotDef EnhancedBasicCard
  #Error This program must be compiled for the Enhanced BasicCard!
#EndIf
```

In BasicCard programs, the constants **CardMajorVersion** and **CardMinorVersion** are also defined. For instance, in a program compiled for the Enhanced BasicCard ZC3.5, they take the values 3 and 5 respectively.

3.4 Data Storage

All variables in a ZC-Basic program belong to one of four *data storage* classes**:** **Eeprom**, **Public**, **Static**, or **Private**.

3.4.1 Eeprom data

EEPROM is the BasicCard's equivalent of a hard disk. It retains its contents while the card is powered down in the customer's pocket. EEPROM contains your ZC-Basic program (compiled into P-Code), directories and files (in the Enhanced BasicCard), and all permanent variables (such as the customer's name or the credit balance in the card). For example:

```
Eeprom CustomerName$ = "" ' We don't know customer's name yet
Eeprom Balance& = 500     ' Free 5-euro bonus for new members
```

If you don't specify an initial value, the data will be initialised to zero. This initialisation takes place when the program (P-Code and data) is downloaded to the card.

Eeprom data has global scope – it can be accessed by all procedures in the program.

3.4.2 Public and Static data

The RAM data area contains **Public** and **Static** data, that retains its value as long as the BasicCard remains powered up in the card reader (or until another Application is selected in the MultiApplication BasicCard). **Public** data has global scope; **Static** data has local scope – it can only be accessed by the procedure that declared it.

Public and **Static** data can be initialised, just like **Eeprom** data. The initialisation takes place whenever the card is powered up (or in the MultiApplication BasicCard, whenever the Application is selected).

3.4.3 Private data

Data declared in a procedure as **Private** exists only until the procedure returns. It is allocated on the P-Code stack every time the procedure is called. It has local scope. **Private** data can be initialised with constant values:

```
Private LoopCounter = 100
```

This initialisation takes place every time the procedure is called. Uninitialised **Private** data is set to zero when the procedure is called.

You don't have to declare every variable before you use it. If the compiler meets a variable name that it doesn't recognise, it implicitly declares it as **Private** and issues a warning message – unless you have overridden this behaviour with the **Option Explicit** statement (see **3.22.4 Explicit Declaration of Variables and Arrays**), or by declaring the procedure itself **Static** (see **3.12 Procedure Definition**).

3.5 Data Types

ZC-Basic supports the following data types:

Byte 1-byte unsigned integer. Range: 0 to 255.

Integer 2-byte signed integer. Range: –32768 to +32767.

Long 4-byte signed integer. Range: –2147483648 to +2147483647.

Single 4-byte single-precision floating-point number (denormalised IEEE format: 1 sign bit, 8-bit exponent, and 23-bit mantissa with implied msb=1 unless exponent is zero). Precision: 7 decimal digits. Range: +/–1.401298E–45 to +/–3.402823E+38.

String Character string, up to 254 bytes long. Requires *n+3* bytes of storage, where *n* is the length of the string – a 2-byte pointer to an (*n+1*)-byte (length, data) pair.

String*n Fixed-length string, **n** bytes long, where **n** is a constant between 1 and 254. Requires **n** bytes of storage.

You may also define your own data types – see **3.8 User-Defined Types**.

Note: The **Single** data type is not supported in the Compact BasicCard. You may store **Single** data in the Compact BasicCard, but you can't perform floating-point arithmetic operations or string conversions.

3.6 Arrays

An array in ZC-Basic can belong to any of the four data storage classes (**Eeprom**, **Public**, **Private**, **Static**), and its elements may be of any type (**Byte**, **Integer**, **Long**, **Single**, **String**, **String*n**, or a user-defined type). It may have up to 32 dimensions, and may contain up to 16K of data. In Compact and Enhanced BasicCard programs, the upper and lower bounds for each dimension are subject to the constraints:

–32 <= *lower bound* <= 31 and *lower bound* <= *upper bound* <= *lower bound* + 1023

All arrays are either **Dynamic** or Fixed. The upper and lower bounds of a **Fixed** array must be constant expressions, and can't be changed. The bounds of a **Dynamic** array can be any integer expression, and the array can be re-sized at any time with a **ReDim** statement. However, the number of dimensions of a **Dynamic** array can't be changed.

If any of the subscripts in an array access is out of bounds, a run-time P-Code error is generated.

The **ReDim** statement has the following syntax:

ReDim *array* (*bounds* [**,** *bounds***, . . .**]) [**As** *type*] [**,** *array* (*bounds* [**,** *bounds***, . . .**]) [**As** *type*]**, . . .**]

array — If *array* has already been declared, it must be a **Dynamic** array, and one *bounds* specifier must be present for each dimension. (In this case, **As** *type* is not required, but if present it must match the type as originally declared.) If *array* has not yet been declared, then the **ReDim** statement does double duty as a data declaration statement. In other words, the statement

ReDim *array* (*bounds* [**,** *bounds***, . . .**]) [**As** *type*]

is expanded to

Dim Dynamic *array* ([**, , . . .**]) [**As** *type*]
ReDim *array* (*bounds* [**,** *bounds***, . . .**])

(The **Dim** statement is described in **3.7 Data Declaration**.)

bounds — The *bounds* specifier gives the upper and lower bounds for each dimension, in the form [*lower-bound* **To**] *upper-bound.* If *lower-bound* is not given, it defaults to 0, unless otherwise specified in an **Option Base** statement (see **3.22.3 Array Subscript Base**).

An array can be cleared with the **Erase** statement:

Erase *array* [**,** *array***, . . .**]

If *array* is **Fixed**, all its elements are set to zero. If *array* is **Dynamic**, its data area is freed. In either case, if the elements of *array* are of type **String**, they are all freed.

3.7 Data Declaration

Data items and arrays are declared and initialised in a *data declaration statement.* A data declaration statement consists of a sequence of data declarations separated by commas. Data may optionally be initialised with constant values:

storage-class [**Dynamic**] *data-declaration* [=*initial-value*] [**,** *data-declaration* [=*initial-value*]**, . . .**]

storage-class — This can be **Eeprom**, **Public**, **Private**, or **Static**. The keyword **Dim** is also allowed; outside a procedure, **Dim** is a synonym for **Public**, and inside a procedure, it has the same meaning as **Private** (or **Static** in a procedure declared as **Static**).

Dynamic — If the **Dynamic** keyword is present, then all arrays declared in the statement are **Dynamic** arrays.

data-declaration — This field takes one of two forms:

1. For scalar (non-array) data, *data-declaration* has the form

name [**As** *type*] [**At** *address*]

The type of the variable *name* is determined as follows:

- by *type* if [**As** *type*] is present;
- otherwise, by the last character of *name* if it belongs to the following list:

Character:	@	%	&	!	$
Data type:	**Byte**	**Integer**	**Long**	**Single**	**String**

- otherwise, by the initial character of *name*, as specified in the most recent **DefType** statement (see **3.22.2 DefType Statement**).

By default, all initial characters are assigned to **Integer** type in ZC-Basic, as if by the statement **DefInt A–Z**.

The address of the variable *name* is automatically assigned by the compiler, unless overridden by [**At** *address*]. If present, *address* takes the form *var*[+*constant*], where *var* is the name of a previously declared variable. The new variable must be entirely contained within the previously-declared variable.

2. If an array is being declared, *data-declaration* has the form

array (*bounds* [**,** *bounds***, . . .**]) [**As** *type*]

The type of the elements of the array is determined as described above for scalar variables. The form of the bounds specifier is described in the previous section under **ReDim**. There is an additional possibility – the empty array syntax:

array ([**, . . .**]) [**As** type]

This declares a **Dynamic** array, while deferring the allocation of the array to a later time. The following example declares empty **Dynamic** arrays **A1**, **A2**, and **A3** with one, two, and three dimensions respectively:

```
Dim A1()
Dim A2(,)
Dim A3(,,)
```

Otherwise, *array* is **Dynamic** if (i) the **Dynamic** keyword was specified; or (ii) any of its bounds is non-constant.

If no initialisation data is present, the data item or array is initialised to zero (or empty strings in the case of **String** data). In ZC-Basic, any type of data may be initialised, with two exceptions: **Dynamic** arrays with non-constant initial bounds, and **Private Dynamic** arrays. Initialisation data must be constant. If an array is initialised, the data must be specified in the order of the array elements, with the leftmost subscript varying the fastest (‘column-major’ order). For instance, the following example initialises each element of a 2x2 **String** array to contain an ASCII description of itself:

```
Option Base 1 ' Set lower bound of arrays to 1
Private X$(2,2) = "X$(1,1)", "X$(2,1)", "X$(1,2)", "X$(2,2)"
```

If the end of the initialisation data is reached before the array has been filled, the rest of the array is initialised to zero (or empty strings for a **String** array).

Fixed-length **String*n** data can be initialised in two ways: as a string, or as a list of bytes. These two ways can be combined, but the string must be the last data item in the list. For example:

```
Eeprom S1 As String*5 = "ABC" ' Padded with two NULL bytes
Public S2 As String*3 = &H81, &H82, &H83
Private S3 As String*7 = 3, 4, "XYZ"
Rem   This is equivalent to:
Rem       Private S3 As String*7 = 3, 4, 88, 89, 90, 0, 0
```

3.8 User-Defined Types

ZC-Basic supports the user definition of structured data types:

Type *type-name*
member-name [**As** *type*] [**,** *member-name* [**As** *type*]**, . . .**]
member-name [**As** *type*] [**,** *member-name* [**As** *type*]**, . . .**]
. . .
End Type

type-name and *member-name* are regular identifiers. The *type* of each member can be **Byte**, **Integer**, **Long**, **Single**, **String*n**, or another user-defined type. It may not be an array, or a **String** of variable length. The total size of all the members must not exceed 254 bytes.

If *var* is a variable or array element of type *type-name,* then the members of *var* are referred to using the syntax *var***.***member-name* (as in the ‘C’ programming language). For example:

```
Type Point: X!, Y!: End Type ' Character '!' => type Single...
Type Rectangle
    Area As Single ' ...or the type can be declared explicitly
    TopLeft As Point
    BottomRight As Point
End Type

Sub Area (R As Rectangle)
    Width! = R.BottomRight.X! - R.TopLeft.X!
    Height! = R.BottomRight.Y! - R.TopLeft.Y!
    R.Area = Width! * Height!
End Sub
```

A user-defined type can be copied as a unit, with a single assignment statement:

```
Public UnitSq As Rectangle = 0,0,0,1,1 ' BottomRight = (1.0,1.0)
Call Area (UnitSq) ' Fill in the Area
Public RA(10) As Rectangle
For I = 1 To 10 : RA(I) = UnitSq : Next I
```

Variables or array elements of the same user-defined type can be compared for equality using = and <> (but the comparison operators < , > , <= , and >= are not allowed).

3.9 Expressions

An *expression* is built up by applying *operations* to *terms*. For example:

```
X + 5         ' Apply '+' (addition) to terms X and 5
A(I) * Rnd    ' Apply '*' (multiplication) to terms A(I) and Rnd
S$ + "0"      ' Apply '+' (concatenation) to terms S$ and "0"
```

A term can be one of the following:

- A constant: the type of a constant term is **Byte**, **Integer**, or **Long** (depending on the value of the constant) for whole-number expressions, **Single** for floating-point expressions, and **String** for string constants.
- A scalar variable, an array element, or a member of a variable or array element of user-defined type.
- A function call. This can be a user-defined function or command, or a built-in function (such as **Abs**, **Sqrt**, **LBound**, **Chr$**, or **CurDir**).
- An array name, with no parentheses (or an empty pair of parentheses). This returns the address of the data area of the array, so that you can check whether a dynamic array has been allocated or not. For instance:

```
Eeprom Dynamic A() ' Declare an Integer array
...
If A = 0 Then Redim A (10) ' or 'If A() = 0...'
```

An expression has one of the following types: **Byte**, **Integer**, **Long**, **Single**, **String**, *boolean*, or *user-defined*. A boolean expression is an expression of type **Integer** that is the result of a comparison; it takes the value **True** (–1) or **False** (0). Normally a boolean expression is treated the same as an **Integer** expression; any exceptions are noted below.

3.9.1 Numerical Expressions

If *expr1* and *expr2* are numerical expressions (i.e. expressions of type **Byte**, **Integer**, **Long**, **Single**, or boolean), the following operations are allowed, grouped in descending order of priority:

Group	Expression	Meaning
Group 1	– *expr1*	Unary minus
	+ *expr1*	Unary plus (has no effect)
Group 2	**Not** *expr1*	Bitwise complement
Group 3	*expr1* * *expr2*	Multiplication
	expr1 / *expr2*	Division
	expr1 **Mod** *expr2*	Remainder
Group 4	*expr1* + *expr2*	Addition
	expr1 – *expr2*	Subtraction
Group 5	*expr1* **Shl** *expr2*	Shift Left
	expr1 **Shr** *expr2*	Shift Right (arithmetical, with sign preserved)
	expr1 **ShrL** *expr2*	Shift Right Logical (with sign bit cleared)
	expr1 **Rol** *expr2*	Rotate Left
	expr1 **Ror** *expr2*	Rotate Right
	expr1 **RolB** *expr2*	Rotate Byte Operand Left
	expr1 **RorB** *expr2*	Rotate Byte Operand Right
Group 6	*expr1* < *expr2*	**True** if *expr1* is less than *expr2*
	expr1 <= *expr2*	**True** if *expr1* is less than or equal to *expr2*
	expr1 > *expr2*	**True** if *expr1* is greater than *expr2*
	expr1 >= *expr2*	**True** if *expr1* is greater than or equal to *expr2*
Group 7	*expr1* = *expr2*	**True** if *expr1* is equal to *expr2*
	expr1 <> *expr2*	**True** if *expr1* is not equal to *expr2*
Group 8	*expr1* **And** *expr2*	Bitwise **And**
Group 9	*expr1* **Xor** *expr2*	Bitwise exclusive-or
Group 10	*expr1* **Or** *expr2*	Bitwise **Or**

The priority of an operator determines the order of the operations. For instance, **3 + –5 * 7** is evaluated as **3 + ((–5) * 7)** , and **A Or B And C** is evaluated as **A Or (B And C)**.

Numerical Operators

Groups 1, 3, and 4 are the *numerical operators*. The type of the resulting expression is determined as follows:

- If *expr1* or *expr2* is **Single**, then the other is converted to **Single** if necessary; the resulting expression if of type **Single**.
- Otherwise, if *expr1* or *expr2* is **Long**, then the other is converted to **Long** if necessary; the resulting expression if of type **Long**.
- Otherwise, *expr1* and *expr2* are converted to **Integer**; the resulting expression is of type **Integer**.

Note: Even if *expr1* and *expr2* are both **Byte** expressions, they are converted to **Integer** before any operation is performed. (This means that the only expressions of type **Byte** are those consisting of a single term.)

Shift/Rotate Operators

The *shift/rotate operators* in Group 5 are currently available in Terminal programs, Professional BasicCard **ZC5.5**, and MultiApplication BasicCard **ZC6.5**. *expr2* is treated as an unsigned **Integer** (so, for instance, *expr1* **Shl** *expr2* will always be zero if *epxr2* < 0 or *expr2* > 31). These operators never generate an overflow error.

Comparison Operators

Groups 6 and 7 are the *comparison operators*. Exactly the same conversions are applied as for the numerical operators, but the type of the resulting expression is boolean.

Bitwise Operators

Groups 2, 8, 9, and 10 are the *bitwise* operators. Bitwise operations are never performed on **Single** expressions; if *expr1* or *expr2* is **Single**, it is converted to **Long** before a bitwise operation is performed. If both *expr1* and *expr2* are of boolean type, then the result is also of boolean type.

There is a special rule concerning the evaluation of expressions of boolean type:

> If *expr1* and *expr2* are both of boolean type, and one of the expressions
>
> *expr1* **And** *expr2*   *expr1* **Or** *expr2*
>
> occurs in the program, then *expr2* is not evaluated if the value of the whole expression can be deduced from the value of *expr1* alone.

In other words:

- if *expr1* is **False**, then “*expr1* **And** *expr2*” is always **False** as well, so *expr2* is not evaluated;
- if *expr1* is **True**, then “*expr1* **Or** *expr2*” is always **True** as well, so *expr2* is not evaluated.

This is important if the evaluation of *expr2* has any side-effects. For instance:

```
If X! = 0 Or F(1/X!) > 100 Then Goto 100
```

If **X!** is zero, then **1 / X!** is not evaluated (which would otherwise cause a run-time error), and the function **F** is not called (which might, for instance, have changed **Public** data).

3.9.2 String Expressions

If either *expr1* or *expr2* is of type **String**, then the other must be of type **String** as well: there are no mixed numerical/string operations. The following string operations are allowed:

Group 1	*expr1* + *expr2*	String concatenation
Group 2	*expr1* < *expr2*	**True** if *expr1* is less than *expr2*
	expr1 <= *expr2*	**True** if *expr1* is less than or equal to *expr2*
	expr1 > *expr2*	**True** if *expr1* is greater than *expr2*
	expr1 >= *expr2*	**True** if *expr1* is greater than or equal to *expr2*
Group 3	*expr1* = *expr2*	**True** if *expr1* is equal to *expr2*
	expr1 <> *expr2*	**True** if *expr1* is not equal to *expr2*

The resulting expression is of **String** type after string concatenation (Group 1), and of boolean type after string comparison (Groups 2 and 3). The comparison operations in Group 2 are performed by finding the first characters that differ in the two strings, and comparing their ASCII values. In ASCII, all lower-case letters are greater than all upper-case letters, so for instance “abc” is greater than “XYZ”. For case-insensitive comparison, use **UCase$** or **LCase$** to convert both arguments to the same case. For example:

```
If UCase$(S1$) > UCase$(S2$) Then T$ = S1$: S1$ = S2$: S2$ = T$
```

3.9.3 Expressions of User-Defined Type

The only operation allowed on user-defined types is comparison for equality:

Group 1	*expr1* = *expr2*	**True** if *expr1* is equal to *expr2*
	expr1 <> *expr2*	**True** if *expr1* is not equal to *expr2*

The resulting expression is of boolean type.

3.10 Assignment Statements

An assignment statement has the form

[**Let**] *var* = *expression*

where *var* is a scalar variable, or an array element, or a member of a variable or array element of user-defined type. The **Let** keyword is optional. The following rules apply:

- If *var* has numerical type (**Byte**, **Integer**, **Long**, or **Single**), then *expression* must have numerical type.
- If *var* has type **String** or **String*n**, then *expression* must have type **String**.
- If *var* has a user-defined type, then *expression* must have the same user-defined type.

There are four special string assignment statements:

[**Let**] **Mid$** **(***string*, *start* [, *length*]**)** = *expression*
[**Let**] **Left$** **(***string*, *length***)** = *expression*
[**Let**] **Right$** **(***string*, *length***)** = *expression*
[**Let**] *string* **(***n***)** = *expression*

Mid$ overwrites *length* characters of *string* with the value *expression*, starting from position *start*. (The first character in the string has position 1.) A value of *start* less than 1 results in a run-time error; a value of *start* greater than the length of *string* is not an error, but no characters are copied. If *length* is absent, or if *start*+*length* is greater than the length of *string*, the whole of rest of the string is overwritten.

Left$ overwrites the first *length* characters of *string* with the value *expression*. If *length* is greater than the length of *string*, the whole of *string* is overwritten.

Right$ overwrites the last *length* characters of *string* with the value *expression*. If *length* is greater than the length of *string*, the whole of *string* is overwritten.

In ZC-Basic, *string* **(***n***)** is shorthand for **Mid$** **(***string*, *n*, 1**)**. So the last statement in the above list assigns the first character of *expression* to the *n*th character of *string*.

In the first three string assignment statements, only the first *length* characters of *expression* are copied into *string*. If *length* is greater than the length of *expression*, then the destination sub-string is filled out with NULL characters (i.e. ASCII zeroes).

3.11 Program Control

3.11.1 Exit Statements

An **Exit** statement jumps out of an enclosing block of code, according to the type of the statement:

Exit For	Jumps to the statement following the innermost current **For**-loop.
Exit While	Jumps to the statement following the innermost current **While**-loop.
Exit Do	Jumps to the statement following the innermost current **Do**-loop.
Exit Case	Jumps to the statement following the next **End Select**.
Exit Sub	Returns from a subroutine to the calling procdedure.
Exit Function	Returns from a function to the calling procdedure.
Exit Command	Returns from a BasicCard command to the caller in the Terminal program.
Exit	Exits the program. **Exit** in a Terminal program returns to the operating system; **Exit** in a BasicCard program returns to the caller in the Terminal program. *Note:* The **Exit** statement (with no parameters) exits the program immediately, without freeing **Private** strings and arrays. This is not a problem in the Terminal program, but it can cause **pcOutOfMemory** errors in subsequent commands in a BasicCard program, until the card is reset. So you should only use such an **Exit** statement in a BasicCard program if you detect an error condition that prevents the card from continuing the command-response session.

3.11.2 Labels

There are two types of label in ZC-Basic: named labels, and line numbers. A named label is an identifier followed by a colon. A line number is simply a decimal number, which may or may not be followed by a colon. A label, of either type, may only be accessed from within the procedure that defines it. Label names and line numbers must be unique within each procedure, but the same name or line number can be used in two different procedures.

3.11.3 GoTo

The simplest program control statement is the **GoTo** statement:

> **GoTo** *label*
> **. . .**
> *label***:**

The program continues execution at the statement following *label*.

Note: You can't use **GoTo** to jump from one procedure to another.

3.11.4 GoSub

A procedure can call its own private subroutines with the **GoSub** statement. Such a private subroutine is not a procedure; it has no parameters, and no data of its own. It is simply a part of the procedure that defines it. It returns with the **Return** statement:

> **GoSub** *label*
> **. . .**
> *label***:**
>   *subroutine-code*
> **Return** [*return-label*]

If *return-label* is specified in the **Return** statement, the subroutine returns there; otherwise it returns to the statement following the **GoSub** call.

3.11.5 If-Then-Else

The **If** statement executes code depending on the value of a conditional expression:

> **If** *condition* **Then**
>   *code block*
> **End If**

The full form of the **If-Then-Else** block is as follows:

> **If** *condition1* **Then**
>   *code block 1*
> [**ElseIf** *condition2* **Then**
>   *code block 2*]
> [**ElseIf** *condition3* **Then**
>   *code block 3*]
> **. . .**
> [**Else**
>   *code block n*]
> **End If**

Each condition is a numerical expression. *code block i* is executed if *condition i* is non-zero (true). If all the conditions are zero (false), then *code block n* is executed.

If there are any statements on the same line after the **Then** of the initial **If**-statement, then this is a *single-line* **If**-statement. In this case, the **If-Then-Else** block is terminated not with **End If**, but with the end of the line. (This is the only place in the ZC-Basic language where a colon is not equivalent to an end of line.) For instance:

```
If X = 0 Then GoTo 100
If X < 0 Then X = 0 : ElseIf X > 50 Then X = 50
```

This is equivalent to

```
If X = 0 Then
  GoTo 100
End If

If X < 0 Then
  X = 0
ElseIf X > 50 Then
  X = 50
End If
```

3.11.6 For-Loop

The **For**-loop executes a block of code a specified number of times:

> **For** *loop-var* = *start* **To** *end* [**Step** *increment*]
> [*code block*]
> [**Exit For**]
> [*code block*]
> **Next** [*loop-var*]

loop-var — A numerical variable, used to count the number of times the **For**-loop has been executed.

start — A numerical expression, the initial value of *loop-var*.

end — A numerical expression. The **For**-loop terminates when *loop-var* passes this value. More precisely:
If *increment* >= 0, then the **For**-loop terminates when *loop-var* > *end.*
If *increment* < 0, then the **For**-loop terminates when *loop-var* < *end.*

increment — The amount by which *loop-var* is incremented after each execution of the **For**-loop. If [**Step** *increment*] is absent, *increment* takes the value 1.

The **Exit For** statement breaks out of the **For**-loop to the statement following the **Next** instruction.

loop-var is optional in the **Next** statement (but it can be useful as a reminder if the loop is large).

If **For**-loops are nested, the **Next** statement can specify more than one loop variable. For example:

```
For I = 1 To 10: For J = 1 To 10: A(I,J) = 0 : Next I, J
```

Any **Exit For** statement, even in the innermost loop, breaks out to the statement following the **Next** statement. So the following example prints only the value **11**:

```
For I = 1 To 2 : For J = 1 To 2
  Print 10*I + J : Exit For
Next I, J
```

However, this example prints **11** and **21**:

```
For I = 1 To 2 : For J = 1 To 2
  Print 10*I + J : Exit For
Next J : Next I
```

Note: This distinction was not observed by the compiler prior to Version 4.62; the first example behaved just like the second. If your program relies on this behaviour, change any such **Next I, J** statements to the form **Next J: Next I**.

3.11.7 While-Loop and Do-Loop

The **While**-loop is executed as long as *condition* is non-zero:

> **While** *condition*
> [*code block*]
> [**Exit While**]
> [*code block*]
> **Wend**

The **Do**-loop has more flexibility:

> **Do** [{**While | Until**} *condition*]
> [*code block*]
> [**Exit Do**]
> [*code block*]
> **Loop** [{**While | Until**} *condition*]

The optional [{**While | Until**} *condition*] may appear at the beginning or the end of the **Do**-loop, but not both. If it appears at the end, then the loop is always executed at least once. If neither is present, then the loop is executed endlessly until left by some other means (such as **Exit Do** or **GoTo**).

3.11.8 Select Case

Select Case executes one of several blocks of code, depending on the value of a test expression:

> **Select Case** *test-expression*
> **Case** *case-test* [**,** *case-test***, . . .**]
> [*code block*]
> [**Exit Case**]
> [*code block*]
> **Case** *case-test* [**,** *case-test***, . . .**]
> [*code block*]
> [**Exit Case**]
> [*code block*]
> **. . .**
> [**Case Else**
> [*code block*]
> [**Exit Case**]
> [*code block*]]
> **End Select**

test-expression An expression of any type (numerical, **String**, or user-defined)

case-test This takes one of three forms:

expression	**True** if *test-expression* = *expression*
expr1 **To** *expr2*	**True** if *expr1* <= *test-expression* <= *expr2*
[**Is**] *op expr*	**True** if *test-expression op expr*, where *op* is one of the six comparison operators: < <= > >= = <> The **Is** keyword is optional.

If *test-expression* is of user-defined type, only the first of these three forms is valid.

The **Select Case** statement executes the code following the first **Case** statement that contains a *case-test* that is **True**. If more than one such **Case** statement exists, only the first is executed. If no such **Case** statement exists, then the code following the **Case Else** statement is executed (and if there is no **Case Else** statement, none of the code in the **Select Case** block is executed). The **Exit Case** statement jumps to the statement following **End Select**.

3.11.9 Computed GoTo and Computed GoSub

You can jump to one of a list of labels depending on the value of a test expression:

On *expression* { **GoTo** | **GoSub** } *label1* [**,** *label2***, . . . ,** *labeln*]

expression — An expression of type **Integer**. If it is equal to *r*, with 1 <= *r* <= *n*, then **GoTo** *labelr* or **GoSub** *labelr* is executed. If *expression* < 1 or *expression* > *n*, execution proceeds with the following statement.

3.12 Procedure Definition

A ZC-Basic program consists mainly of procedure definitions. Each procedure is either a **Subroutine**, a **Function**, or a **Command**. The **Private** and **Static** variables declared in a procedure belong to that procedure alone, and can't be accessed from other procedures (such variables are said to have local scope); **Public** and **Eeprom** variables can be accessed from all procedures (they have global scope).

3.12.1 Subroutine

The simplest procedure type is the subroutine. A subroutine returns no value to the caller, except through its arguments. A subroutine definition is as follows:

[**Static**] **Sub** *proc-name* ([*param-def***,** *param-def***, . . .**])
    [*procedure code*]
    [**Exit Sub**]
    [*procdedure code*]
End Sub

Static — If the **Static** keyword is present in the definition, undeclared variables in the procedure have **Static** storage class, instead of **Private**.

param-def — [{**ByVal** | **ByRef**}] *param-name*[()] [**As** *type*], where *param-name* is a variable name by which the parameter is accessed in *procedure-code*. See **3.15 Procedure Parameters** for a full discussion of parameters.

3.12.2 Function

A **Function** is a **Subroutine** that returns a value to the caller. A function definition is as follows:

[**Static**] **Function** *proc-name* ([*param-def***,** *param-def***, . . .**]) [**As** *type*]
    [*procedure code*]
    [*proc-name* = *expression*]
    [**Exit Function**]
    [*procedure code*]
End Function

Static — If the **Static** keyword is present in the definition, undeclared variables in the procedure have **Static** storage class, instead of **Private**.

param-def — [{**ByVal** | **ByRef**}] *param-name*[()] [**As** *type*], where *param-name* is a variable name by which the parameter is accessed in *procedure-code*. See **3.15 Procedure Parameters** for a full discussion of parameters.

The return type of the function is determined as if *proc-name* were a variable name: from "**As** *type*" if present; otherwise from the last character in *proc-name* if it is a type character (**@**, **%**, **&**, **!**, or **$**); otherwise from the first character in *proc-name*. (The type characters are defined in **3.2 Tokens**.) A function can have any return type that is not an array.

Inside the function, *proc-name* behaves like a **Private** variable. It is initialised to zero when the function is called, and its value is returned to the caller when the function exits.

3.12.3 Command

A command is defined like a subroutine, but you must specify the two ID bytes (**CLA** and **INS**) by which the command will be invoked:

[**Static**] **Command** [*CLA*] [*INS*] *proc-name* ([*PreSpec*,] [*param-def*, *param-def*, **. . .**] [**,** *PostSpec*])
[*procedure code*]
[**Exit Command**]
[*procdedure code*]
End Command

Static If the **Static** keyword is present in the definition, undeclared variables in the procedure have **Static** storage class, instead of **Private**.

CLA The 'Class' byte. All the pre-defined commands in the BasicCard have **CLA=&HC0**, so you should normally avoid this value for your own commands, unless you specifically want to override a pre-defined command. If *CLA* is not present, **CLA** must be present in *PreSpec*.

INS The 'Instruction' byte. The compiler accepts any value; but in a card that uses the **T=0** protocol, this byte must be even, and the top nibble may not be **6** or **9**. If *INS* is not present, **INS** must be present in *PreSpec*.

PreSpec Pre-parameter specification. It may contain the following terms, in the following order, and separated by commas:

CLA=*constant*	An alternative way of specifying **CLA**
INS=*constant*	An alternative way of specifying **INS**
Lc=0	Only relevant under the **T=0** protocol

In a Professional BasicCard using the **T=0** protocol, **Lc=0** defines the command as having no incoming data – a **Case 2** command in the terminology of **8.3.2 APDU Transmission by T=0**. You only need to use this if:

- you are implementing a pre-existing **T=0** command specification; or
- you want to minimise **T=0** communications overhead to improve performance.

param-def [{**ByVal** | **ByRef**}] *param-name*[()] [**As** *type*], where *param-name* is a variable name by which the parameter is accessed in *procedure-code*. See **3.15 Procedure Parameters** for a full discussion of parameters.

PostSpec Post-parameter specification, only relevant under the **T=0** protocol. You only need to use this if:

- you are implementing a pre-existing **T=0** command specification; or
- you want to minimise **T=0** communications overhead to improve performance.

It may take one of two forms:

Disable Le
Input Le

Disable Le defines the command as having no outgoing data – a **Case 3** command in the terminology of **8.3.2 APDU Transmission by T=0**.

Input Le is used to distinguish the two sub-cases of **Case 4** commands – *Case 4S.2* and *Case 4S.3* in **8.3.6 Case 4: Incoming and Outgoing Data**. In *Case 4S.2* commands, **ResponseLength** is specified by the Terminal program in the **Le** parameter, so the Terminal program must send **Le** before the command is executed; in *Case 4S.3* commands, the BasicCard decides for itself what **ResponseLength** should be. **Input Le** defines the command as a *Case 4S.2* command.

Notes:

1. The special syntax "[**Static**] **Command Else** *proc-name* ([*param-def*, *param-def*, **. . .**])" defines a *default command* in the card, that is called when the BasicCard receives a command with unrecognised *CLA* and *INS*.
2. In some cards (currently **ZC5.5** from **REV E**, and **ZC6.5** all revisions), if the Application contains a subroutine **ClaInsFilter**(), this subroutine is called whenever a command is received, before the BasicCard operating system looks for a match for **CLA** and **INS**. If you modify **CLA** or **INS** in this subroutine, the card will behave as if the modified values had been received.
3. A **Command** parameter may not be an array.

4. A **Command** definition is only valid in a BasicCard program; it is not allowed in a Terminal program.
5. If a **Command** parameter is a variable-length string, it must be the last (or only) parameter in the list. In the Compact BasicCard, the compiler must know how long this string can be, so that it can make sure the P-Code stack is large enough; you can specify a maximum length for the string with the special syntax:

   param-name <= *maxlen*

   For example:

   ```
   Command &H20 &H00 SetUserName(UserID, Name$<=25)
   ```

   In the absence of this special syntax, *maxlen* defaults to 40. (Other BasicCards use a more flexible mechanism, and the length of the string is limited only by the requirement that the total parameter list be no larger than 255 bytes. So this special syntax is not required.)

3.13 Procedure Declaration

The compiler can't process a procedure call unless it knows what kinds of parameters the procedure accepts. It knows this if the procedure has already been defined:

```
Function Square (X!) As Single
  Square = X! * X!
End Function

Sub S()
  Y! = Square (5.5)     ' OK - Square already defined
End Sub
```

But the compiler won't accept the following:

```
Sub S()
  Y! = Square (5.5)     ' Error - Square not defined yet
End Sub

Function Square (X!) As Single
  Square = X! * X!
End Function
```

To call a procedure before it is defined, you must provide a *procedure declaration* that tells the compiler what it needs to know. A procedure declaration starts with the word **Declare**:

Declare Sub *proc-name* ([*param-def*, *param-def*, **. . .**])
Declare Function *proc-name* ([*param-def*, *param-def*, **. . .**]) [**As** *type*]
Declare Command [*CLA*] [*INS*] *proc-name* **(**[*PreSpec*,] [*param-def*, *param-def*, **. . .**] [**,** *PostSpec*]**)**

If a declaration and a definition of the same procedure occur in the program, then they must match. More precisely:

- for a **Function**, the return type in the declaration must match the return type in the definition;
- for a **Command**, *CLA* and *INS* must be the same in the declaration and the definition;
- the types of the parameters must match exactly;
- the parameter-passing method (**ByVal** or **ByRef**) must be the same for each parameter.

However, the names of the parameters don't need to match. Parameter names in a procedure declaration are just place-holders; the only restriction is that they may not be reserved words (see **3.2 Tokens** for a list of reserved words). For example:

```
Declare Function Square (Z!) As Single

Sub S()
  Y! = Square (5.5)           ' OK - Square declared
End Sub

Function Square (X!) As Single ' OK – matches declaration
  Square = X! * X!
End Function
```

3.13.1 Command Declarations

A **Command** declaration has the following general form:

Declare Command [*CLA*] [*INS*] *proc-name* **(**[*PreSpec***,**] [*param-def***,** *param-def***, . . .**] [**,** *PostSpec*]**)**

The *param-def* fields are the same as in **Function** and **Sub** declarations. The *PreSpec* and *PostSpec* fields are available for users who need precise control over the **T=0** and **T=1** Command APDU parameters; otherwise they are not required.

CLA — The 'Class' byte. All pre-defined commands in the BasicCard have **CLA=&HC0**, so you should normally avoid this value for your own commands, unless you want to override a pre-defined command. If *CLA* is not present, **CLA** must be present in *PreSpec*, either here or in the procedure call – see **3.14.3 Calling a Command**.

INS — The 'Instruction' byte. The compiler accepts any value; but in a card that uses the **T=0** protocol, this byte must be even, and the top nibble may not be **6** or **9**. If *INS* is not present, **INS** must be present in *PreSpec*, either here or in the procedure call – see **3.14.3 Calling a Command**.

PreSpec — Pre-parameter specification. This field may contain any of the following terms, in the following order, and separated by commas:

CLA=*constant*
INS=*constant*
P1=*constant*
P2=*constant*
P1P2=*constant*
Lc=*constant*

Each *constant* is a **Byte** expression, except **P1P2**, which is an **Integer**. See **8.5 Commands and Responses** for definitions of these terms.

PostSpec — Post-parameter specification. If present, this field takes one of the following forms:

Le=*constant*
Disable Le

Here, *constant* is a **Byte** expression; **Disable Le** specifies that **Le** is absent from the command. See **8.5 Commands and Responses** for a definition of **Le**.

3.13.2 System Library Procedures

In Terminal programs, and Professional and MultiApplication BasicCard programs, Library procedures are called via the **SYSTEM** instruction. They are declared as follows:

Declare Sub *SysCode SysSubcode proc-name* **(**[*param-def***,** *param-def***, . . .**]**)**
Declare Function *SysCode SysSubcode proc-name* **(**[*param-def***,** *param-def***, . . .**]**)** [**As** *type*]

SysCode — The System Library identifier, a **Byte** between **&HC0** and **&HFF**.
SysSubcode — The procedure sub-code, any **Byte** value.

3.14 Procedure Calls

3.14.1 Calling a Subroutine

The recommended way to call a subroutine is

Call *procedure-name* ([[{**ByVal** | **ByRef**}] *expression***,** [{**ByVal** | **ByRef**}] *expression***, . . .**])

The expressions in the list must match the parameters in the subroutine declaration (or definition) in number and type. (See **3.15 Procedure Parameters** below for a fuller explanation.) If the subroutine takes no parameters, then the parentheses are optional:

Call *procedure-name* [()]

Alternatively, ZC-Basic accepts the older subroutine call syntax (with parentheses not allowed):

procedure-name [[{**ByVal** | **ByRef**}] *expression***,** [{**ByVal** | **ByRef**}] *expression***, . . .**]

3.14.2 Calling a Function

A **Function** call returns a value, that can be used as a term in an expression. For example:

```
X! = X! + Square (X!+1)
```

A **Function** can also be called just as if it were a **Subroutine**, in which case the return value is simply discarded.

3.14.3 Calling a Command

A **Command** is called as if it were a **Function** – although it is defined as if it were a **Subroutine**. The reason for this is that the Terminal program automatically returns the command status word (**SW1–SW2**) as if it were the return value of a function. This command status word should always be checked, as it is possible that communications were disrupted for some reason before the command could be successfully completed in the BasicCard.

A **Command** call has the following general form:

var = *command-name* ([*PreSpec***,**] *arg-list* [**,** *PostSpec*])

where the *arg-list* field is the same as in **Function** and **Sub** calls. The *PreSpec* and *PostSpec* fields are available for users who need precise control over the **T=0** and **T=1** Command APDU parameters; otherwise they are not required.

PreSpec — Pre-parameter specification. This field may contain any of the following terms, in the following order, and separated by commas:

CLA=*expr*
INS=*expr*
P1=*expr*
P2=*expr*
P1P2=*expr*
Lc=*expr*

Each *expr* is a **Byte** expression, except **P1P2**, which is an **Integer**. See **8.5 Commands and Responses** for definitions of these terms.

PostSpec — Post-parameter specification. If present, this field takes one of the following forms:

Le=*expr*
Disable Le

Here, *expr* is a **Byte** expression; **Disable Le** specifies that **Le** is absent from the command. See **8.5 Commands and Responses** for a definition of **Le**.

An alternative method of calling a command:

Call *command-name* ([*PreSpec***,**] *arg-list* [**,** *PostSpec*])

In this case, the command status word is available in the pre-defined variables **SW1**, **SW2**, and **SW1SW2**.

3.15 Procedure Parameters

3.15.1 Parameter Passing

In traditional Basic, procedure parameters are passed *by value* or *by reference*. Passing by value means that the procedure receives its own copy of the parameter; any changes it makes to this copy are lost when the procedure returns. Passing by reference means that the address (or 'reference') of the parameter is passed to the procedure; knowing its address, the called procedure can change the value of a variable in the calling procedure.

In general, ZC-Basic can't do this, because the BasicCard can't change the value of a variable in the Terminal program directly. However, it uses a *write-back* mechanism to achieve the same effect (and it retains the keywords **ByVal** and **ByRef**, although they are not strictly accurate). With the exception of **String** and array parameters, all parameters are passed by value (in the traditional sense); the value of each parameter is pushed onto the P-Code stack before the procedure is called. The parameters are then referenced like **Private** variables in the called procedure, and can be read or written directly. Then when the procedure returns to the caller, any parameters that were passed **ByRef** are copied back from the stack into their original locations.

By default, all parameters are passed **ByRef** (in the ZC-Basic sense). If the **ByVal** keyword is specified in the procedure definition or declaration, then the following parameter is passed by value, and not written back when the procedure returns. (The **ByRef** keyword is also allowed here, although it is superfluous.) The parameter-passing method specified in the procedure definition or declaration can be overridden for a particular procedure call by specifying **ByVal** or **ByRef** in front of a parameter. (Here **ByRef** is not superfluous if the parameter was specified as **ByVal** in the procedure definition or declaration.)

For the write-back mechanism to be invoked for a given parameter, the parameter-passing method must be **ByRef**, and the expression in the procedure call must be an *assignable* expression – an expression that can appear on the left-hand side of an assignment statement. If you don't want a variable to be changed by a called procedure, you can specify **ByVal**, or you can enclose the variable in parentheses (which is a valid expression, but not an assignable expression). An example may make this clearer:

```
Declare Sub S (X, ByVal Y, ByRef Z) ' 'ByRef' redundant here
Private A, B, C
Call S (A, B, C)                    ' A and C can change
Call S (ByVal A, ByRef B, C)        ' B and C can change
Call S (A+1, B, (C))      ' Nothing can change - 'A+1' and '(C)'
                          ' are not assignable expressions
```

For information on the maximum total size of a parameter list, see **3.23.1 Parameter Size Limits**.

3.15.2 String Parameters

There is an important difference between parameters of type **String** and parameters of type **String*n**. The former occupy 3 bytes on the P-Code stack, the latter occupy **n** bytes. So you should where possible use **String** parameters rather than **String*n** parameters. However, a variable-length string parameter to a **Command** is only allowed if it is the last (or only) parameter; any other string parameters must be of fixed-length **String*n** type.

Note: You can pass a fixed-length string in a **String** parameter, or a variable-length string in a **String*n** parameter; the compiler performs the necessary conversions. The parameter type only determines how the string is passed to the procedure.

For more information on **String** parameters, see **3.23.3 String Parameter Format**.

3.15.3 Array Parameters

An array parameter takes up just two bytes on the P-Code stack (the address of the array descriptor is passed to the procedure – see **3.23.2 Array Descriptor Format**).

An array parameter is specified in a procedure definition or declaration by a pair of parentheses after the parameter name:

param-name() [**As** *type*]

The parentheses must be empty. To pass an array parameter in a procedure call, the array name is sufficient; an empty pair of parentheses after the array name is optional. The type of the array must match exactly the type of the parameter. For example:

```
Declare Sub S (A() As Integer) ' Parentheses required here
Dim X (10) As Integer, Y (20) As Long
Call S (X)    ' OK
Call S (X())  ' Also OK - parentheses optional in call
Call S (Y)    ' Error - Y is Long array, not Integer array
```

The number of dimensions of the array is checked at run-time. The following code will compile, but will generate a run-time error:

```
Declare Sub S (A() As Integer)
Dim X (5, 5, 5)
Call S (X)
...
Sub S (A() As Integer)
A (2, 2) = 0 ' Run-time error - parameter X has 3 dimensions
```

3.15.4 Parameters of User-Defined Type

A parameter of user-defined type is passed to a procedure by pushing every member onto the P-Code stack. The P-Code stack occupies precious RAM, so you should avoid passing large user-defined types as procedure parameters. Otherwise, a parameter of user-defined type behaves just like a parameter of numerical type.

3.16 Built-in Functions

3.16.1 Numerical Functions

Abs(*X*) Returns the absolute value of *X* (that is to say, *X* or –*X*, whichever is positive). The type of the result is the type of *X*, unless *X* is **Byte**, in which case **Abs**(*X*) has type **Integer**.

Rnd Returns a random number of type **Long**: –2147483648 <= **Rnd** <= 2147483647. See **3.18 Random Number Generation**.

Sqrt(*X*) Returns the square root of *X*. The result is of type **Single**.

3.16.2 Array Functions

LBound(*array* [, *dim*])
UBound(*array* [, *dim*]) These two functions return the lower and upper bounds of subscript *dim* in the given array. If *dim* is not present, the lower or upper bound for the first subscript is returned. The result is of type **Integer**.

3.16.3 String Functions

string (*n*) Returns a string of length 1, containing the *n*th character of *string*. (The first byte of the string has position 1.) It is shorthand for **Mid$**(*string*, *n*, 1).

Asc(*string*) Returns the ASCII value of the first character of *string*, as a **Byte**.

Chr$(*char-code*) Returns a string of length 1, containing the ASCII character with the given *char-code*. The special syntax **Chr$**($c_1$, c_2, ..., c_n), where c_i are all constants between 0 and 255, is short for **Chr$**($c_1$) + **Chr$**(c_2) + ... + **Chr$**($c_n$).

Hex$(*val*) Returns a string containing the hexadecimal representation of the **Long** number *val*.

Left$(*string*, *len*) Returns the first *len* bytes of *string*.

LCase$(*string*) Returns *string* with all upper-case letters converted to lower-case.

Len(*string*) Returns the length of *string*, as a **Byte**.

LTrim$(*string***)** — Returns *string* with leading spaces and NULL bytes removed.

Mid$(*string***,** *start***[,** *len***])** — Returns *len* bytes of *string*, starting from position *start*. (The first byte of the string has position 1.) If *start* **>** **Len(***string***)**, the empty string is returned. If *start* + *len* **>** **Len(***string***)** , or if *len* is absent, then the whole of *string* from position *start* is returned. If *start* **<=** **0** or *len* **<** **0**, a run-time error is generated.

Right$(*string***,** *len***)** — Returns the last *len* bytes of *string*.

RTrim$(*string***)** — Returns *string* with trailing spaces and NULL bytes removed.

Space$(*len***)** — Returns a string containing *len* space characters (ASCII 32).

Str$(*val***)** — Returns a string containing the decimal representation of *val*. If *val* is of type **Single**, its value is given to 7 significant figures. *Note:* If *val* is of type **Single**, use of this statement in an Enhanced BasicCard program will reduce the amount of user-programmable EEPROM available – see **3.23.5 Single-to-String Conversion** for details.

String$(*len***,** *char***)** — Returns a string consisting of *len* characters with ASCII value *char*. If *char* is itself a string, then the returned string consists of *len* copies of the first character of *char*.

Trim$(*string***)** — Returns *string* with leading and trailing spaces and NULL bytes removed.

UCase$(*string***)** — Returns *string* with all lower-case letters converted to upper-case.

Val&(*string***[,** *len***])** — Returns the decimal number represented by *string*, as a **Long** value. If *len* is present, it must be a variable (not an array element). This variable is set to the number of characters used.

Val!(*string***[,** *len***])** — Returns the decimal number represented by *string*, as a **Single** value. If *len* is present, it must be a variable (not an array element). This variable is set to the number of characters used. *Note:* Use of this statement in an Enhanced BasicCard program will reduce the amount of user-programmable EEPROM available – see **3.23.5 Single-to-String Conversion** for details.

ValH(*string***[,** *len***])** — Returns the hexadecimal number represented by *string*, as a **Long** value. If *len* is present, it must be a variable (not an array element). This variable is set to the number of characters used.

3.16.4 Encryption Functions

Note: These functions are not available in the Compact BasicCard.

Key(*keynum***)** — Returns key number *keynum* as a string. If no such key exists, a zero-length string is returned. This function may also appear on the left of an assignment statement:

Key(*keynum***) =** ***string***

In the MultiApplication BasicCard, this function is not available; keys can only be accessed via **COMPONENT** System Library procedures.

In the Terminal program, **Key** is a pre-defined, **Static** array of strings: **Key(0 To 255) As String**. In the Enhanced and Professional BasicCards, only keys declared in **Declare Key** statements can be accessed, and the length of each key is fixed; see **3.17.3 Key Declaration** for details.

DES(*type***,** *key***,** *block$***)** — Performs a single DES block encryption or decryption operation, returning the result as an 8-byte string. *key* is either a key number from 0 to 255, or a string containing a cryptographic key. *block$* is a string at least 8 bytes long. See **3.17.7 DES Encryption Primitives** for more information. Professional BasicCard **ZC4.5A** does not support this function.

Certificate(*key***,** *data***)** — Returns a **DES**-based cryptographic certificate of *data*, as an 8-byte string. *key* is either a key number from 0 to 255, or a string containing a

cryptographic key. See **3.17.8 Certificate Generation** for more information.

3.16.5 Other Functions

Len(*variable*) Returns the size, in bytes, of a scalar variable (arrays are not allowed).

Len(*type*) Returns the size of a data type (e.g. **Integer**, or a user-defined type).

3.17 Encryption

The BasicCard contains a sophisticated mechanism for the encryption and decryption of commands and responses. For full details of the algorithms, see **Chapter 9: Encryption Algorithms**.

3.17.1 Implementing Encryption in the MultiApplication BasicCard

Encryption and key handling are necessarily more complex processes in a MultiApplication environment than in a single-application environment. See **Chapter 5: The MultiApplication BasicCard** for more information.

3.17.2 Implementing Encryption in a Single-Application BasicCard

To implement the encryption mechanism for single-application BasicCard commands:

1. Use the **KEYGEN** program to generate a key file, containing cryptographic keys (and primitive polynomials for the **SG-LFSR** algorithm if you are programming for the Compact BasicCard).
2. Include the generated key file in both the Terminal program and the BasicCard program.
3. Include the file **COMMANDS.DEF** in the Terminal program, to define the **StartEncryption**, **ProEncryption**, and **EndEncryption** commands.
4. In the Terminal program, turn automatic encryption on and off as follows:

   Compact and Enhanced BasicCards:

   > **Call StartEncryption (P1**=*algorithm*, **P2**=*keynum*, **Rnd)**
   > **Call EndEncryption()**

   Professional BasicCard:

   > **Call ProEncryption (P1**=*algorithm*, **P2**=*keynum*, **Rnd**, **Rnd)**
   > **Call EndEncryption()**

   Or, if you don’t know the card type in advance:

   > **Call AutoEncryption (***keynum*, *keyname$***)**
   > **Call EndEncryption()**

   The **AutoEncryption** subroutine is defined in **COMMANDS.DEF**. The algorithm is selected according to the key length and the card type. The *keyname$* parameter is the pathname of the key, and is only required for the MultiApplication BasicCard. For use with single-application BasicCards, this parameter can be empty:

   > **Call AutoEncryption (***keynum*, “”**)**

That’s all you have to do. An example program is provided in **9.13 Encryption – a Worked** Example.

The program running in the BasicCard will usually want to know whether encryption is currently in force. It can check this through the pre-defined variables **Algorithm** and **KeyNumber**, which contain the two parameters **P1** and **P2** that were passed in the most recent **StartEncryption** command. If encryption is not in force, both these variables have the value zero.

3.17.3 Key Declaration

In a Terminal program or a single-application BasicCard program, the **Declare Key** statement declares a cryptographic key (the **KEYGEN** program outputs its keys as **Declare Key** statements in the key file):

Declare Key *keynum* [(*length* [**,** *counter*])] [= *b1*, *b2*, *b3*, . . .]

keynum — The key number, by which the key can be specified (for example, in a **StartEncryption** command). It can take any value from 0 to 255, except in Enhanced BasicCard programs, where 255 is not allowed.

length — The length of the key. If absent, the key length defaults to 8 bytes. If an initial value field (*b1*, *b2*, *b3*, . . .) is present, and no length is specified, the key length is set to the number of bytes in the initial value field. (If the length is specified, the initial value field is padded with zeroes to the required length.)

Note: In the Compact BasicCard, all keys must be 8 bytes long.

counter — The error counter for the key (0 <= *counter* <= 15). If *counter* is zero, the key is initially disabled. If *counter* is absent, the error counter for the key is initially inactive. See **3.17.6 Key Error Counter** for details.

Note: the *counter* parameter is allowed in all programs, but it is ignored in Terminal programs and Compact BasicCard programs. This allows the same key file to be used in all programs in an application.

b1, *b2*, *b3*, . . . — The initial value of the key. If no initial value is provided, the key is initialised to zeroes. The key may be changed later, in one of three ways:

- with **Key(***keynum***) =** *string*, except in a Compact BasicCard program (see **3.16.4 Encryption Functions**);
- with the **Read Key File** statement in a Terminal program (see **3.17.5 Run-Time Key Configuration**);
- with the **BCKEYS** program in a Compact or Enhanced BasicCard (see **6.9.5 The Key Loader BCKEYS.EXE**).

3.17.4 Polynomial Declaration

The encryption algorithm described in **9.10 The SG-LFSR** Algorithm requires two primitive polynomials, of degree 31 and 32. (This is the encryption algorithm used by the Compact BasicCard.) You don't need to know what a primitive polynomial is, because the **KEYGEN** program generates them for you, and outputs them to the key file as a **Declare Polynomials** statement:

Declare Polynomials = *PolyA&*, *PolyS&*

PolyA& A primitive polynomial of degree 31, the generator of the Linear Feedback Shift Register **A**.

PolyS& A primitive polynomial of degree 32, the generator of the Linear Feedback Shift Register **S**.

The polynomials may be initialised at compile time, or later – with the **Read Key File** statement in a Terminal program, or with the **BCKEYS** program in a BasicCard.

3.17.5 Run-Time Key Configuration

The Terminal program can load keys and/or polynomials from a key file at run-time, with the statement

Read Key File *filename*

If this command fails, the File System variable **FileError** contains a non-zero error code indicating the reason for the failure – see **4.12 The Definition File FILEIO.DEF** for a list of error codes.

Except in Compact and MultiApplication BasicCard programs, keys can also be accessed as strings via the **Key(***keynum***)** function. See **3.16.4 Encryption Functions** for details.

3.17.6 Key Error Counter

In the Enhanced, Professional, and MultiApplication BasicCards, each cryptographic key has an error counter. If the error counter for a particular key is active, it limits the number of times that a Terminal program can attempt to guess the key. For example, suppose the error counter for key *keynum* has an initial value of 10. Whenever the BasicCard receives a command that is encrypted with key *keynum*:

- if the encryption is invalid, the error counter is decremented, and the BasicCard returns the status code **SW1-SW2 = swRetriesRemaining**+*X* (&H63C0+*X*), where *X* is the new value of the error counter. When the error counter reaches zero the key is disabled, until an **Enable Key** command is executed in the BasicCard program (see below);
- if the encryption is valid, the error counter is reset to its initial value (in this case, 10);
- if the key is disabled (i.e. the error counter is already zero), the BasicCard responds with status code **SW1-SW2 = swKeyDisabled** (&H6614).

So the Terminal program is given 10 chances, after which no more commands encrypted with key *keynum* are accepted.

In an Enhanced or Professional BasicCard, there are two commands for setting a key's error counter:

Enable Key *keynum* [(*counter*)]

Enables the key. If *counter* is present, the error counter for the key is activated, and its initial value is set to **Max** (*counter*, 15). If *counter* is absent, or equal to 255, the error counter is deactivated (i.e. the key will remain enabled regardless of how many times a command is badly encrypted with the key).

Disable Key *keynum*

Disables the key, until a subsequent **Enable Key** command is executed.

Notes:

1. This error counter mechanism only applies to the encryption of commands. Even if a key is disabled, it can always be used from within a single-application BasicCard program. ZC-Basic functions that use cryptographic keys are listed in **3.16.4 Encryption Functions**.
2. In a MultiApplication BasicCard program, the **WriteComponentAttr** System Library procedure is used to enable and disable keys.

3.17.7 DES Encryption Primitives

DES message encryption and decryption is based on the six block encryption primitives $\mathbf{E_K}$, $\mathbf{D_K}$, $\mathbf{EDE2_K}$, $\mathbf{DED2_K}$, $\mathbf{EDE3_K}$, and $\mathbf{DED3_K}$, as defined in **9.1 The DES Algorithm**. In Terminal programs, and all BasicCards with **DES** support, these primitives are available to the ZC-Basic programmer via the **DES** function:

result$ = **DES(***type***,** *key***,** *block$***)**

type The type of primitive, as follows:

+1 or **+56:**	$\mathbf{E_K}$(*block*)	**Single DES** encryption (8-byte key required)
–1 or **–56:**	$\mathbf{D_K}$(*block*)	**Single DES** decryption (8-byte key required)
+3 or **+112:**	$\mathbf{EDE2_K}$(*block*)	**Triple DES-EDE2** encryption (16-byte key required)
–3 or **–112:**	$\mathbf{DED2_K}$(*block*)	**Triple DES-EDE2** decryption (16-byte key required)
+168:	$\mathbf{EDE3_K}$(*block*)	**Triple DES-EDE3** encryption (24-byte key required)
–168:	$\mathbf{DED3_K}$(*block*)	**Triple DES-EDE3** decryption (24-byte key required)

Cards that support the **Triple Des-EDE3** algorithm (currently, Professional BasicCard **ZC5.5** and MultiApplication BasicCard **ZC6.5**) accept all values; other cards accept only ±1 and ±3. (The values 56, 112, and 168 denote the number of significant bits in the key.)

key Either a key number from 0 to 255, or a string containing a cryptographic key.

block$ A string containing, as its first 8 bytes, the block to encrypt or decrypt. If shorter than 8 bytes, P-Code error **pcBadStringCall** (&H0D) is generated.

result$ The 8-byte result of the DES encryption or decryption function.

3.17.8 Certificate Generation

The Terminal program, and all BasicCards with **DES** support, can generate "digital certificates" using cryptographic keys. A digital certificate is an electronic verification of a piece of data. Suppose you have a network of dealers, who can unload cash credits from the cards that you issue to your customers, in return for goods and services that they provide. At the end of the week, they come to you to exchange these electronic cash credits for real money. How can you be sure that the dealers are honest?

Digital certificates are the answer. To unload credits from a customer's card, the dealer sends a message saying "I am dealer number *A*, and I want *B* credits". The customer's BasicCard will have its own ID number *C*, and it can maintain a transaction counter *D*, which it increments after each transaction. The BasicCard program puts these four numbers *A*, *B*, *C*, and *D* together into a string or a user-defined variable, and generates a certificate using a secret key not known to the dealer or the customer. This certificate is then returned to the dealer, who shows it to you to claim reimbursement for the credits. You can write a Terminal program to check that *A*, *B*, *C*, and *D* really do generate the correct certificate with the secret key. And because the key is known only to you and the BasicCard, you know that the dealer hasn't forged the certificate.

To generate a certificate:

S$ = **Certificate(***key***,** *data***)**

where *key* is a key number from 0 to 255 or a string containing a cryptographic key, and *data* is the data to be verified – either an expression of type **String**, or a fixed-length variable or array element. Depending on the key length, this generates a **Triple DES-EDE3** certificate (24-byte key; cards **ZC5.5** and **ZC6.5** only), or a **Triple DES-EDE2** certificate (16-byte key), or a **Single DES** certificate (8-byte key). The result, *S$*, is always 8 bytes long. The certificate generation algorithm is described in **9.3 Certificate Generation Using DES**.

3.18 Random Number Generation

The **Rnd** built-in function returns a 4-byte random number. The Terminal and the various BasicCards have different mechanisms for random number generation.

3.18.1 The Terminal

The Terminal program initialises its random number generator with a seed based on the system clock. This ensures that the **Rnd** function returns a different sequence every time a program runs. You can override this behaviour with the **Randomize** command:

Randomize *seed*

where *seed* is any expression of type **Long** or **String**.

You might want to do this for the following reasons:

- to generate a predictable sequence of random numbers while developing a program, to make debugging easier;
- to use a more unpredictable seed than the system clock, for better security.

Note: The default behaviour of the random number generator is good enough for the encryption algorithms used in communication with the BasicCard – these algorithms don't depend critically on the unpredictability of the initial values **RA** and **RB** (see **8.7.11 The START ENCRYPTION Command** for details). However, they do depend critically on the secrecy of the keys used, and for this purpose we provide a high-quality random number generation mechanism in the **KEYGEN** program (see **6.9.4 The Key Generator KEYGEN.EXE**).

3.18.2 The Compact and Enhanced BasicCards

Each Compact and Enhanced BasicCard has a unique serial number burnt into its memory. The first time in its life that the BasicCard generates a random number, this serial number is used as the seed. The seed is then updated and stored in EEPROM for the next random number generation. This ensures that:

- each BasicCard generates a different sequence of random numbers;
- a given BasicCard doesn't generate the same sequence each time it is reset.

The **Randomize** command is not available in the BasicCard.

Note: The BasicCard simulators in the **ZCMSIM** and **ZCMDCARD** programs do generate the same sequence of random numbers each time they run. This is because they have no access to a unique serial number to seed the generation mechanism. But when the program is downloaded to a genuine BasicCard, the random number sequence will become unpredictable.

3.18.3 The Professional and MultiApplication BasicCards

These BasicCards have a hardware random number generator, so the **Rnd** function returns a truly random number.

3.19 Error Handling

If the P-Code interpreter in the BasicCard detects a run-time error, such as arithmetic overflow or insufficient memory, it calls the **ErrorHandler** procedure. If there is no procedure with this name in the program, it exits with the status code **SW1 = sw1PCodeError** (&H64). **SW2** contains the P-Code error code (see **8.6.2 BasicCard P-Code Interpreter** for a list of these error codes). The **ErrorHandler** procedure may perform clean-up operations, but it cannot cause execution to be resumed at the statement that caused the error. The pre-defined variable **PCodeError** contains the P-Code error code.

In the Enhanced, Professional, and MultiApplication BasicCards, the address of the instruction where the error occurred is passed to the **ErrorHandler** procedure as an **Integer** parameter, so you can access it by declaring e.g.

Sub ErrorHandler (PC As Integer)

3.20 BasicCard-Specific Features

3.20.1 Customised ATR

When the BasicCard is reset, it provides information about itself by means of the **ATR** (Answer To Reset). The **ATR** contains technical information about the communication parameters that the card uses, followed by up to fifteen bytes (the 'Historical Characters') by which the card can identify itself. For example, the Historical Characters in the Enhanced BasicCard are of the form "**BasicCard ZC***vvv*", where *vvv* is the firmware version number of the card. See **8.2 Answer To Reset** for more information on the **ATR**.

In a single-application BasicCard program, you can override the card's built-in ATR with the following pre-processor directive:

#Pragma ATR (*ATR-Spec***)**

To override the default **ATR** in a MultiApplication BasicCard, create a file in the Root Directory with the name "**ATR**" (see **5.3.1 ATR File**), and initialise the file contents with a statement of the form:

ATR (*ATR-Spec***)**

In both cases, *ATR-Spec* is a comma-separated list of communication parameters, some of which take values:

param [= *val*] [, *param* [= *val*] , ...]

The following parameters are supported; for the meanings of these parameters, see **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*:

General Parameters

Direct or **Inverse**	Character coding convention
T=0 and/or **T=1**	The protocols supported by the card

T=15	Forces **T=15** to change the way the extra guard time is calculated
HB = *string*	Historical Bytes

Global Interface Parameters

FI = *val* or **F** = *val*	Clock rate conversion factor
DI = *val* or **D** = *val*	Baud rate adjustment factor
N = *val*	Extra guard time
TA2 = *val*	Specific mode byte
XI = *val*	Clock stop indicator
UI = *val*	Class indicator
GI = *val* or **G** = *val*	Clock factor

T=0 *Parameters*

WI = *val*	Work waiting time in tenths of a second

T=1 *Parameters*

IFSC = *n*	Information field size for the card
CWI = *val* or **CWT** = *val*	Character waiting time
BWI = *val* or **BWT** = *val*	Block waiting time
CRC or **LRC**	Error detection code

Most of these parameters affect only the content of the ATR – they are ignored by the card itself. The exceptions are **Inverse**, which at the time of writing is supported by BasicCards **ZC5.4**, **ZC5.5**, and **ZC6.5**; and **T=0**/**T=1**, which are supported by all Professional and MultiApplication BasicCards.

Alternatively, you can specify the **ATR** as a sequence of bytes, with the statement

Declare Binary ATR = *data*

Here *data* must have a total length <= 31. Use this feature with care, as an invalid ATR can make the card unusable. You should at the very least try out the ATR in a simulated BasicCard before testing it in a real card.

Certain cards expect a flag byte as the last byte (which doesn't count towards the 31-byte length restriction). Examples of valid ATR's can be found in the file **BasicCardPro\Inc\ATRList.def**, supplied with the distribution kit. Unless you know exactly what you are doing, you should only use this statement with data supplied by ZeitControl.

3.20.2 Application ID

The BasicCard has a pre-defined command **GET APPLICATION ID** (see **8.7.10 The GET APPLICATION ID Command**). You can use this command to check that the BasicCard in the card reader contains your application. To configure an Application ID:

Declare ApplicationID = *data*

data	Any sequence of **Byte** and **String** constants, with a total length <= 127.

3.20.3 Enabling and Disabling Encryption Algorithms

In a single-application BasicCard, you can enable or disable individual encryption algorithms:

{**Enable** | **Disable**} **Encryption** [*AlgorithmID* [, *AlgorithmID*, . . .]]

AlgorithmID The ID of an encryption algorithm. If no algorithm is specified, all available algorithms are enabled or disabled. The following algorithms (defined in COMMANDS.DEF) can be enabled or disabled:

Compact BasicCard

AlgSgLfsr	**&H11**	**SG-LFSR**
AlgSgLfsrCrc	**&H12**	**SG-LFSR** with CRC-16

Enhanced BasicCard

AlgSingleDes	**&H21**	**Single DES**
AlgTripleDes	**&H22**	**Triple DES**

Professional BasicCard

AlgSingleDesCrc	**&H23**	**Single DES** with CRC-32
AlgTripleDesEDE2Crc	**&H24**	**Triple DES-EDE2** with CRC-32
AlgTripleDesEDE3Crc	**&H25**	**Triple DES-EDE3** with CRC-32
AlgAes128	**&H31**	**AES** with 128-bit key
AlgAes192	**&H32**	**AES** with 192-bit key
AlgAes256	**&H33**	**AES** with 256-bit key
AlgEaxAes128	**&H41**	**EAX** with **AES-128**
AlgEaxAes192	**&H42**	**EAX** with **AES-192**
AlgEaxAes256	**&H43**	**EAX** with **AES-256**
AlgOmacAes128	**&H81**	**OMAC** with **AES-128**
AlgOmacAes192	**&H82**	**OMAC** with **AES-192**
AlgOmacAes256	**&H83**	**OMAC** with **AES-256**

For maximum security, you should disable any encryption algorithms that you don't plan to use.

Notes:

- This command is executed when the program is compiled, and it lasts for the lifetime of the card. Algorithms can't be enabled or disabled at run-time.
- Different Professional BasicCards support different combinations of the twelve algorithms listed above.

3.20.4 Asking the Terminal for More Time

The BasicCard has a **BWT** (Block Waiting Time) of 1.6 seconds (Compact) or 12.8 seconds (all other card types) – see **8.4 The T=1 Protocol** for more information. If a command is going to take longer than this to complete, it must request more time, otherwise the caller will time out (but see **3.21.9 Giving the Card More Time**). It does this with a **WTX** (Waiting Time Extension) statement:

WTX *BWT-units*

BWT-units Any expression of type **Byte**: the number of multiples of **BWT** requested. **WTX** requests are not cumulative – each request cancels all previous requests.

Note: Some card readers treat 255 as a special value. If in doubt, don't use this value – use 254 instead.

In the **T=0** protocol, the *BWT-units* parameter is ignored, and a single **NULL** byte (**&H60**) is sent. This resets the **WWT** (Work Waiting Time) time-out period – see **8.3 The T=0 Protocol** for more information.

3.20.5 Pre-Defined Variables

The BasicCard operating system has a number of internal variables that can be accessed from the ZC-Basic language. Most of these have to do with communications – see **Chapter 8: Communications** for details. The following are all **Public** variables (in RAM) of type **Byte**:

CLA	Class byte – first byte of two-byte **CLA INS** command identifier.
INS	Instruction byte – second byte of two-byte **CLA INS** command identifier.
P1	Parameter 1 of 4-byte **CLA INS P1 P2** command header.
P2	Parameter 2 of 4-byte **CLA INS P1 P2** command header.
Lc	Length of **IDATA** field in command.
Le	Expected length of **ODATA** field in response (supplied by caller).
ResponseLength	Actual length of **ODATA** field in response (supplied by called command).
SW1	First status byte in response field **SW1-SW2**.
SW2	Second status byte in response field **SW1-SW2**.
Algorithm	ID of currently active encryption algorithm. Commands can check this byte to ascertain whether an appropriate encryption mechanism is in force. If no encryption

	is currently active, **Algorithm** is zero. See **3.20.3 Enabling and Disabling Encryption Algorithms** for a list of algorithm IDs.
KeyNumber	(Single-application BasicCards only) The number of the cryptographic key being used by the currently active encryption algorithm. If no encryption is currently active, **KeyNumber** is zero (but zero is also a valid key number, so you should not use **KeyNumber** to check whether encryption is active – use **Algorithm** for this purpose).
PCodeError	If a run-time error occurs, and the program contains a subroutine with the name **ErrorHandler**, then this subroutine is called. The error code is available to the **ErrorHandler** subroutine in the variable **PCodeError**.
FileError	The most recent error code generated by the file system (Enhanced and Professional BasicCards only).

The following **Integer** variables are defined:

P1P2	Concatenation of **P1** and **P2**.
SW1SW2	Concatenation of **SW1** and **SW2**.
LibError	The most recent library procedure error (only the Professional and MultiApplication BasicCards pre-define this variable – an Enhanced BasicCard program declares it in the *library*.**def** file).
SMKeyCID	(MultiApplication BasicCard only) The Component ID of the Key being used by the currently active encryption/authentication algorithm as a result of a **START ENCRYPTION** command. If none is currently active, **SMKeyCID** is zero.
ExtAuthKeyCID	(MultiApplication BasicCard only) The Component ID of the Key used in the most recent **EXTERNAL AUTHENTICATE** command, if successful.
VerifyKeyCID	(MultiApplication BasicCard only) The Component ID of the Key used in the most recent **VERIFY** command, if successful.

3.21 Terminal-Specific Features

3.21.1 Screen Output

Screen output uses the **Cls** and **Print** statements in conjunction with the four pre-defined variables **FgCol**, **BgCol**, **CursorX**, and **CursorY** (see **3.21.10 Pre-Defined Variables**).

The **Cls** command clears the screen, and sets **CursorX** and **CursorY** to 1:

Cls

The **Print** statement:

Print [*field* | *separator*] [*field* | *seperator*] **. . .**

field	Any **Byte**, **Integer**, **Long**, **Single**, or **String** expression	
separator	'**;**' (semi-colon)	Leaves the output column unchanged.
	'**,**' (comma)	Advances the output column to the next output field (an output field is 14 characters wide).
	Spc(*n*)	Prints *n* space characters.
	Tab(*n*)	Advances the output column to position *n*.

After the print statement, the cursor advances to the start of the next line, unless the last character is a separator. (So you can stay on the same output line by adding a semi-colon at the end of the command.)

3.21.2 Keyboard Input

InKey$ Returns a string containing 0, 1, or 2 bytes.

- 0 bytes: no character is waiting in the keyboard buffer.
- 1 byte: a regular ASCII key was pressed.

- 2 bytes: an extended-ASCII key was pressed. In this case, the first byte indicates which auxiliary keys were down (**&H01=Shift**, **&H02=Ctrl**, **&H04=Alt**), and the second byte contains the extended-ASCII code.

Line Input *X$* Reads a line from the keyboard into the string variable *X$*, until the carriage return key is pressed. Extended-ASCII keys are ignored.

Input *variable-list* Reads the variables in the list from the keyboard. If the list contains more than one variable, the user must separate the values with commas or spaces. This statement can also appear on the right-hand side of an assignment statement:

n = **Input** *variable-list*

This returns the number of variables in the list that were successfully input.

3.21.3 Communications

Three functions are provided for determining the status of the card reader and card. These functions return a status code in **SW1–SW2**, just like command calls:

CardReader [(*name$*)]

Attempts to detect a card reader via the configured serial port. If a string parameter is passed, the identification string of the card reader is returned. If the BasicCard is being simulated in the PC, the words “Simulated Card Reader” are returned in the *name$* parameter.

Status Codes in SW1-SW2:

swCommandOK	Card reader detected
swNoCardReader	Card reader not detected
swCardReaderError	Invalid response from card reader

CardInReader

Returns **swCommandOK** (&H9000) if a card is in the card reader.

Status Codes in SW1-SW2:

swCommandOK	Card is in card reader
swNoCardReader	Card reader not detected
swCardReaderError	Invalid response from card reader
swNoCardInReader	No card in reader

ResetCard [(*ATR$*)]

Attempts to reset the card, returning **swCommandOK** (&H9000) if the card responded with a valid Answer To Reset. If a string parameter is passed, the Historical Bytes of the Answer To Reset are returned. See also **3.20.1 Customised ATR**.

Status Codes in SW1-SW2:

swCommandOK	Valid Answer To Reset received
swNoCardReader	Card reader not detected
swCardReaderError	Invalid response from card reader
swNoCardInReader	No card in reader
swT1Error	**T=1** protocol error (see**8.4 The T=1 Protocol**)
swCardError	Invalid response from card
swCardTimedOut	Card failed to send an ATR within the prescribed time

3.21.4 PC/SC Functions

Two functions are provided for obtaining information about the PC/SC-compatible card readers configured in the system:

nReaders = **PcscCount**

Returns the number of configured PC/SC card readers, as an **Integer**.

Status codes in SW1-SW2:

swNoPcscDriver The PC/SC driver is not installed in the system.
swPcscError The PC/SC driver returned an unexpected error code.

ReaderName = **PcscReader (***ReaderNum***)**

Returns the name of PC/SC card reader *ReaderNum*, as a **String**. If *ReaderNum* is zero, the name of the default PC/SC reader is returned. To access PC/SC reader number *ReaderNum*, set the pre-defined variable **ComPort** to *ReaderNum*+100.

Status codes in SW1-SW2:

swNoCardReader *ReaderNum* is less than zero or greater than *nReaders*.
swNoPcscDriver The PC/SC driver is not installed in the system.
swPcscError The PC/SC driver returned an unexpected error code.

Note: To configure a default PC/SC reader, add the reader's name to the Windows® system registry, in the field "HKEY_CURRENT_USER\Software\ZeitControl\BCPCSC\Default" (you can do this with the Windows® system tool Regedit.Exe). If no such field is found, reader number 1 is the default.

3.21.5 I/O Logging

The **Open Log File** statement initiates the logging of all I/O between the Terminal program and the BasicCard program:

Open Log File *filename*

Previous contents of the log file are destroyed. If the file open fails, the pre-defined variable **FileError** is set to a non-zero value – see **4.12 The Definition File FILEIO.DEF** for error codes. The statement

Close Log File

ends I/O logging and closes the log file.

3.21.6 Date and Time

The string function **Time$** returns a 24-character string containing the current date and time in fixed format:

`"Ddd Mmm DD HH:MM:SS YYYY"` (for example: `"Wed Jul 07 15:50:35 2004"`).

3.21.7 Saving Eeprom Data

The statement

Write Eeprom [(*filename*)]

writes the permanent **Eeprom** data in the Terminal program to a disk file. If *filename* is not given, the data is written back to the original image file (or debug file). If the file couldn't be opened for any reason, the pre-defined variable **FileError** is set to a non-zero value – see **4.12 The Definition File FILEIO.DEF** for a list of error codes.

Note: The **Write Eeprom** statement is only valid if the Terminal program is running in the **ZCMSIM** P-Code interpreter or the **ZCMDTERM** Terminal Program debugger. Programs containing **Write Eeprom** statements can't be compiled into executable files.

3.21.8 Automatic Encryption

{ **Enable | Disable** } **Encryption**

The P-Code interpreter that runs the Terminal program monitors all commands to the BasicCard, watching for **START ENCRYPTION** and **END ENCRYPTION** commands. If it sees a well-formed **START ENCRYPTION** command that receives a valid response from the BasicCard, it automatically turns on encryption of commands and decryption of responses, until it sees an **END ENCRYPTION** command. If for any reason you want to disable this monitor, you can do it with a **Disable Encryption** command. You can turn the monitor back on at any time with **Enable Encryption**.

3.21.9 Giving the Card More Time

Sometimes the BasicCard needs more than the Block Waiting Time to execute a command. In principle, the card is responsible for requesting more time, which it does with a **WTX** statement – see **3.20.4 Asking the Terminal for More Time**. However, if you have a ZeitControl Chip-X® card reader, you can also override the default Block Waiting Time from the Terminal program with a **WTX** statement:

WTX *seconds*

seconds	Any expression of type **Byte**: the number of seconds to give the card before timing out. Unlike **WTX** requests in the BasicCard program, this time-out value remains in effect until explicitly cancelled (by **WTX 0**). If *seconds* is equal to 255, the card is given unlimited time to respond.

The Terminal program waits for a response from the card until *both* time-outs (those set by the BasicCard program and the Terminal program) have expired.

Note: This feature is only available if **ComPort** <= 4, and you are accessing a ZeitControl Chip-X® card reader via the serial port. The PC/SC standard interface, and the CyberMouse® card reader, do not support this feature. A more general way to increase time-outs is to adjust **WI** or **BWI** in the **ATR** – see **3.3.4 The #Pragma Directive** and **3.20.1 Customised ATR** for details.

3.21.10 Pre-Defined Variables

The Terminal P-Code interpreter contains the following **Public** pre-defined variables, of type **Byte**:

ComPort	The number of the COM port that the card reader is attached to. To specify PC/SC card reader number *n*, set **ComPort = *n***+100 (or **ComPort** = 100 for the default PC/SC reader – see **3.21.4 PC/SC Functions** for details). *Note:* The value of **ComPort** at program start-up is taken from the environment variable **ZCPORT**, if it exists; otherwise the Windows® Registry variable **ZCPORT** in the directory **HKEY_CURRENT_USER\Software\ZeitControl\BasicCardPro**, if it exists; otherwise it takes the value 1.
ResponseLength	The length of the **ODATA** field in the last response received from the card.
SW1	First byte of **SW1-SW2** status field in the last response received from the card.
SW2	Second byte of **SW1-SW2** status field in the last response received from the card.
Algorithm	ID of currently active encryption algorithm. Commands can check this byte to ascertain whether the appropriate encryption mechanism is in force. If no encryption is currently active, **Algorithm** is zero. See **3.20.3 Enabling and Disabling Encryption Algorithms** for a list of algorithm IDs.
PCodeError	If a run-time error occurs, and the program contains a subroutine with the name **ErrorHandler**, then this subroutine is called. The error code is available to the **ErrorHandler** subroutine in the variable **PCodeError**.
FgCol	Foreground colour for **Print** statements to the screen (0-15).
BgCol	Background colour for **Print** statements to the screen (0-15).
CursorX	X-coordinate of text cursor (1-80).
CursorY	Y-coordinate of text cursor (1-25).
FileError	The most recent error code generated by a file I/O operation.
nParams	Number of command-line parameters (see **6.9.2 The P-Code Interpreter ZCMSIM.EXE**).

Two **Integer** variables are defined:

KeyNumber	The number (for a single-application BasicCard) or the Component ID (for a MultiApplication BasicCard) of the cryptographic key being used by the currently active encryption algorithm. If no encryption is currently active, **KeyNumber** is zero (but zero is also a valid key number, so you should not use **KeyNumber** to check whether encryption is active – use **Algorithm** for this purpose).
SW1SW2	Concatenation of **SW1** and **SW2**.

Two **String** arrays are defined:

Param$(1 To nParams) Command-line parameters passed to the **ZCDOS** program (see **6.9.2 The P-Code Interpreter ZCMSIM.EXE**).

Key(0 To 255) Cryptographic keys.

3.22 Miscellaneous Features

This section lists all the ZC-Basic statements that are not covered in the preceding sections or in **Chapter 4: Files and Directories**.

3.22.1 Overflow Checking

{ **Enable** | **Disable** } **OverflowCheck**

Normally, if the result of an arithmetic operation is too big or too small to be represented in the target type, a P-Code error is generated. You can enable or disable this overflow checking with **Enable OverflowCheck** or **Disable OverflowCheck**. These statements are executed at run-time, and don't apply to the whole program. (So if you want to disable overflow checking for the whole program, then **Disable OverflowCheck** should appear in your initialisation code.)

Note: This statement only affects whole-number arithmetic (**Byte**, **Integer**, and **Long** data types). Floating-point overflow checking (**Single** data type) cannot be turned off.

3.22.2 DefType Statement

A **DefType** statement specifies the default type of variables, arrays, and functions that begin with a certain letter or range of letters:

{ **DefByte** | **DefInt** | **DefLng** | **DefSng** | **DefString** } *range* [**,** *range***, . . .**]

range Either a single letter, or a range of letters separated by a minus sign (e.g. **I–N**). The case of the letter(s) is not significant.

The initial setting is **DefInt A–Z**, i.e. all variables, arrays, and functions have type **Integer** by default.

3.22.3 Array Subscript Base

An array subscript range takes the form

[*lower-bound* **To**] *upper-bound*

If the optional *lower-bound* is missing, it defaults to **0**. You can change this default value with the **Option Base** command, which applies to all subsequent array declarations:

Option Base *subscript-base*

subscript-base Any constant expression. In the Compact and Enhanced BasicCards, it must satisfy –32 <= *subscript-base* <= +31.

Or you can specify that the lower bounds of array subscripts must always be explicitly declared, with

Option Base Explicit

3.22.4 Explicit Declaration of Variables and Arrays

By default, ZC-Basic allows implicit declaration of variables and arrays:

- If it meets a variable that it doesn't recognise in an expression or an assignment statement, it will treat it as a newly-declared variable. The type of the variable is determined from its name, as described in **3.7 Data Declaration**.
- If a **ReDim** statement contains an unrecognised array name, the compiler inserts an implicit **Dim** statement to declare the array.

The Basic programming language has always behaved this way. However, this can be dangerous, as it accepts mis-typed variable names as new variables. In the following example, this results in **TransactionState** ending with the value **1** instead of **13**:

```
TransactionState = 12
...
TransactionState = TransatcionState + 1
```

The compiler will issue a warning message whenever it implicitly declares a variable in this way. You can override this behaviour in two ways:

Option Explicit

This tells the compiler not to accept variables or array names that haven't been explicitly declared. It applies only to following code; preceding code can contain implicit declarations.

Option Implicit

This tells the compiler to accept implicitly-declared variables without issuing a warning message.

3.23 Technical Notes

3.23.1 Parameter Size Limits

The maximum total size of all the parameters in a procedure call is approximately 128 bytes. More precisely, the compiler checks that the sum of the following contributions is <= 128:

- the total size of all the fixed-length parameters (including **String*n**);
- 2 bytes for each parameter of array type;
- 3 bytes for each **String** parameter (or 2 bytes for the final **String** parameter to a **Command**);
- for a **Function**, the size of the return value (2 bytes if this is a **String**);
- 2 bytes for the return address (unless it's a **Command**);
- the frame overhead (2 bytes for the Compact and Enhanced BasicCards, otherwise 4 bytes).

See also Note 4 in **3.12.3 Command** for more on the final **String** parameter to a **Command**.

3.23.2 Array Descriptor Format

An array in ZC-Basic consists of a fixed-length *array descriptor*, and a *data area* (which is of variable length if the array is **Dynamic**). In a Compact or Enhanced BasicCard program, if an array has **n** dimensions, then its descriptor occupies **2*n + 4** bytes:

<table>
<tr><td colspan="3">Address of data area (0 if not allocated) (2 bytes)</td></tr>
<tr><td>Size of each element (1 byte)</td><td>D</td><td>n (7 bits)</td></tr>
<tr><td>LO(1) (6 bits)</td><td colspan="2">RANGE(1) (10 bits)</td></tr>
<tr><td>...</td><td colspan="2">...</td></tr>
<tr><td>LO(n) (6 bits)</td><td colspan="2">RANGE(n) (10 bits)</td></tr>
</table>

D This bit is **1** for **Dynamic** arrays, **0** for **Fixed** arrays.

LO(*i*) Lower bound for subscript(*i*): **–32 <= LO**(*i*) **<= 31.**

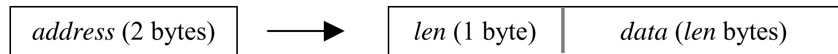
RANGE(*i*) Range for subscript(*i*): **0 <= RANGE**(*i*) **<= 1023.**

The upper bound of subscript(*i*) is equal to **LO**(*i*) + **RANGE**(*i*).

In Terminal programs, and Professional and MultiApplication BasicCard programs, **LO**(*i*) and **HI**(*i*) are 2-byte integers, so the descriptor occupies **4*n + 4** bytes.

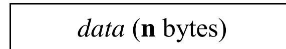
3.23.3 String Parameter Format

A variable of type **String** is a 2-byte pointer to a (*len*, *data*) pair:



This uses *len*+3 bytes of storage (but if *len* is zero, then *address* is zero too, so only 2 bytes are used).

A variable of type **String*n** requires just **n** bytes of storage:



A procedure parameter of type **String*n** also takes up **n** bytes on the P-Code stack.

However, a procedure parameter of type **String** is rather more complicated. Two requirements must be fulfilled:

- A procedure can change the value of a **String** variable passed as a parameter;
- A **String*n** variable can be passed as a **String** parameter.

So a **String** parameter takes up 3 bytes on the P-Code stack. If a fixed-length **String*n** variable was passed, then the first of these bytes contains the length **n** (0-254) and the next two bytes contain the address of the data. Otherwise, the first byte contains 255 (**&HFF**) and the next two bytes contain the address of the pointer (not the address of the data). So if the address of the data has to be changed because the string increases in length, the **String** variable can be updated to point to the new data. (By the way, this is the reason for the 254-byte length restriction on all strings.)

3.23.4 Memory Allocation in Single-Application BasicCards

The ZC-Basic compiler calculates the sizes of all the memory regions in RAM and EEPROM. Any memory left over is assigned to the two heaps, **RAMHEAP** and **EEPHEAP**. These regions are for run-time memory allocation. (See **10.4 Run-Time Memory** Allocation for the format of the allocated memory blocks.)

The ZC-Basic P-Code interpreter uses run-time memory allocation for three kinds of data: variable-length **String** data, **Dynamic** arrays, and files. Files and **Eeprom** data are allocated as **Permanent** blocks in **EEPHEAP**. Other data is allocated in **RAMHEAP** if there is room, but if not, it is allocated as **Temporary** blocks in **EEPHEAP**. All **Temporary** blocks are freed the next time the BasicCard is reset or the Terminal program is started. EEPROM writes require up to 6 milliseconds to complete, so a BasicCard program runs more slowly when it has to use **EEPHEAP** in this way.

See **5.2.4 Memory Allocation** for information on memory allocation in the MultiApplication BasicCard.

3.23.5 Single-to-String Conversion

The operating system in the Enhanced BasicCard consists of 17.7K of code; the chip, however, contains only 17K of ROM. The last 705 bytes contain the **Single**-to-**String** conversion routines. If an Enhanced BasicCard program requires these routines, the **ZCMBASIC** compiler automatically loads them into EEPROM (in the **STRVAL** region – see **10.1.2 The Enhanced BasicCard**). This means, of course, that the amount of EEPROM available for your code and data is reduced by 705 bytes.

If any of the following ZC-Basic statements occur in an Enhanced BasicCard program, this **STRVAL** region will be loaded:

- **Str$(***val***)** with a *val* parameter of type **Single**;
- **Val!(***string***)** (**String-**to-**Single** conversion);
- **Print** to file, with a parameter of type **Single**.

Some versions of the Professional BasicCard do not support **Single**-to-**String** conversion – see the **Professional BasicCard Datasheet** for details.

4. Files and Directories

4.1 Directory-Based File Systems

Everybody who owns a PC is familiar with directory-based file systems. Each disk drive has a special directory, called the *root directory*, which contains data files and sub-directories. These sub-directories themselves can contain data files and sub-directories, and so on. This determines a tree of directories, in which any directory in the tree can contain data files and sub-directories. The directory containing a given data file or sub-directory is called its *parent* directory. (*directory* is the traditional term, which is used throughout this chapter; Microsoft Windows® calls its directories *folders*.)

4.1.1 File and Directory Names

Under Windows®, filenames can be up to 255 characters long, and may contain any printable character (including the space character), except the following:

\	Backslash	/	Slash	:	Colon	*	Asterisk
?	Question mark	"	Double quote	<	Left angle-bracket	>	Right angle-bracket
|	Vertical bar						

Case is not significant when referring to an already existing file or directory. So if a file has the name "FILE.NAM", you can access it as "File.Nam" or "FiLe.nAm" or whatever. However, Windows® retains the case of the characters specified when the file was originally named. So if you create a file as "File.Nam" and then ask for a directory listing, Windows® lists it as "File.Nam".

4.1.2 Path Names

Each file and directory can be uniquely identified by a *full path name*. This consists of the disk drive name, followed by every sub-directory on the path from the root directory to the parent directory, followed by the name of the file or directory itself. The disk drive name is a letter A-Z followed by a colon, e.g. "`C:`" or "`A:`". (Lower-case letters may also be used to refer to disk drives, but a drive name returned by a ZC-Basic function will always be upper-case.) The drive name is immediately followed by a backslash character (this signifies the root directory); and subsequent directory names in the path are separated by backslash characters '\'. For example, a full path name might be "`C:\1997 Clients\Account Data`".

To save having to give the full path name every time, every disk drive in the system has a *current directory*, and the system as a whole has a *current drive*. If the disk drive name is missing from the front of a path name, the current drive is assumed. And if the first character after the disk drive name is not a backslash, then the chain of directories is followed starting from the current directory for the drive, instead of the root directory. Such a path name is called a *relative path name*. For instance, suppose the current drive is "`C:`", and the current directories for drives "`A:`" and "`C:`" are "`\Clients.97`" and "`\Programs\CPP`" respectively. Then the relative path names "`A:August\TOTALS.DAT`" and "`Headers\SUM.H`" expand to the full path names "`A:\Clients.97\August\TOTALS.DAT`" and "`C:\Programs\CPP\Hheaders\SUM.H`" respectively.

The directory names "`.`" and "`..`" have special meanings: "`.`" denotes the current position in the chain of directories, and "`..`" denotes the parent directory. So "`.\`" in a path has no effect, and "`..\`" goes back to the previous directory in the chain. For instance, in the previous example, the path name "`..\Basic\FILEIO.BAS`" expands to "`C:\Programs\CPP\..\Basic\FILEIO.BAS`", which is the same as "`C:\Programs\Basic\FILEIO.BAS`". The single-dot notation is useful when a directory is required as a parameter to a file system operation; for example, the ZC-Basic statement **`Name "..\FileList" As ".\"`** moves the file "`FileList`" from the parent directory to the current directory.

4.2 The BasicCard File System

The Enhanced, Professional, and MultiApplication BasicCards contain a directory-based file system, with the same file-naming rules as those described in the previous section for Windows® (except that the maximum length of a full path name is 254 characters). The BasicCard has one root directory, so path names don't begin with a disk drive name. With the exception of the commands **CurDrive**, **ChDrive**, and **SetAttr**, the ZC-Basic file and directory commands available to a BasicCard program are the same as those available to a Terminal program.

4.2.1 File Access from a Terminal Program

If the BasicCard allows it, files and directories in the card can be accessed from a Terminal program, just as if the card was a diskette. The card has the special drive name "`@:`". Suppose the BasicCard contains a file "`\Transport\Bus\Credits`". Then the full path name of this file from the point of view of the Terminal program is "`@:\Transport\Bus\Credits`". And if the Terminal program sets the current drive to "`@:`" and the current directory to "`\Transport`", it can refer to the file as simply "`Bus\Credits`". The full range of file and directory commands is available to the Terminal program for accessing BasicCard files and directories, subject to appropriate access being granted.

Each file or directory in the BasicCard has its own access conditions, specifying the circumstances under which the Terminal program is allowed read and write access.

If the card is a MultiApplication BasicCard, the access conditions also specify which Applications are allowed read and write access. For information on the MultiApplication BasicCard file security mechanism, see **5.1.3 Component Access Control**.

In a single-application BasicCard, these access conditions can be set and changed with **Lock** and **Unlock** statements. There are three types of access condition: **Read**, **Write**, and **Custom**. The following general rules apply to file and directory access in a single-application BasicCard:

- **Read** and **Write** access to all files and directories is available to the BasicCard program at all times.
- **Read** and **Write** access to all files and directories is available to the Terminal program as long as the BasicCard is in state **LOAD** or **PERS** (see **8.7.1 States of the BasicCard**).
- Otherwise, to access a file or directory from the Terminal program, **Read** access is required to all directories in the path from the root to the parent. To delete a file or directory, or to change its access conditions, **Write** access is required to the file or directory, and to its parent directory. (In particular, when the card is in state **TEST** or **RUN**, the Terminal program can never change the root directory's access conditions, because the root directory has no parent.)
- If a **Custom** lock is placed on a file or directory, it is locked against **Read** and **Write** access every time the card is reset. It can only be unlocked from within the BasicCard program, after which the file's regular **Read** and **Write** access conditions apply until the next reset. So you can write a command that unlocks a particular file if the Terminal program sends the correct PIN number, for instance.

The **Read** and **Write** access conditions on a file or directory can be:

- **Allowed** – access is allowed from the Terminal program;
- **Forbidden** – access is forbidden from the Terminal program; or
- **Keyed** – access is allowed only if encryption with the appropriate key is enabled.

Read and **Write** access conditions and key numbers can be set independently of each other. If access is **Keyed**, up to two keys can be specified – if encryption with either of the two keys is enabled, access is allowed. The encryption algorithm must be **Triple DES** for keys at least 16 bytes long, and **Single DES** for shorter keys. So to access a **Keyed** file from a Terminal program, you must first call **StartEncryption** with the appropriate algorithm and key number – see **3.17.1 Implementing Encryption**.

Note: The default access conditions on the root directory are **Read=Allowed** and **Write=Forbidden**.

4.2.2 Pre-Defined Files and Directories

In a BasicCard program, you can pre-define directories and data files using **Dir** and **File** statements. The compiler constructs the appropriate structures in EEPROM for downloading to the card. See **4.11 File Definition Section** for details.

4.2.3 Storage Requirements

In the BasicCard, data files and directories are stored in EEPROM. To make efficient use of the limited space available, you should know how much memory is used. A data file or directory allocates space for its header and its name; a data file owns data blocks as well:

- A directory header requires 13 bytes of EEPROM; a data file header requires 19 bytes.
- The name of a file or directory takes up *n*+2 bytes of EEPROM, where *n* is the number of characters in the name.
- Each data block in a data file uses *n*+4 bytes of EEPROM, where *n* is the block length specified when the file was created. (The default block length is 32 bytes.) These blocks are allocated automatically when data is written to a file. *Note:* Contiguous data blocks are merged if they are also contiguous in EEPROM; this saves the overhead of 4 bytes per block. So if you are creating a file that is going to be written to just once, you can achieve optimum EEPROM usage by specifying a block length of 1 byte.

As well as these EEPROM requirements, the file system in the Enhanced and Professional BasicCards uses (6 * *nFiles* + 7) bytes of RAM, where *nFiles* is the number of open file slots configured (see **3.3.8 Number of Open File Slots**).

4.3 File System Commands

This chapter describes all the file system commands available to the ZC-Basic programmer. There are three cases that the ZC-Basic *interpreter* must distinguish:

1. A Terminal program accessing the file system in the PC (disk drives "`A:`" through "`Z:`").
2. A Terminal program accessing the BasicCard file system (disk drive "`@:`").
3. A BasicCard program accessing its own BasicCard file system (no disk drive).

However, these cases all look the same to the ZC-Basic *programmer*. Apart from the disk drive names, there are no differences, unless explicitly noted in the command descriptions that follow.

After each command, its required access conditions are listed. These access conditions apply to a Terminal program (if the BasicCard is in state **TEST** or **RUN**), and to an Application running in the MultiApplication BasicCard. They don't apply to an Application running in a single-application BasicCard; such an Application has access to all files and directories.

All file system commands return a status byte in the pre-defined variable **FileError**. A zero value (**feFileOK**) indicates success. A non-zero value is an error code, and indicates the first error that occurred since this variable was last set to zero. (It is reset to zero every time a new command is received from the Terminal program; you may also set it to zero yourself if you want to continue after an error.) Error codes for each command are listed below.

As well as the error codes documented below under individual commands, there are some general error codes that apply to all commands:

feInvalidDrive — In cases 1 and 2 above (Terminal program), a disk drive name in a path was not a letter or "`@:`".

feBadFilename — A filename contains an invalid character, or is too long (see **4.1.1 File and Directory Names**).

feBadFilenum — A file number is out of range. In ZC-Basic, an open file is referred to by a file number. In a Terminal program, this number must be between 0 and 32 inclusive (with 0 indicating the screen or keyboard). In a BasicCard program, the number must be between 1 and the number of open file slots (see **3.3.8 Number of Open File Slots**).

feFileNotFound A file or directory specified in a path name does not exist.

feFileNotOpen The file number passed to the command is not associated with an open file. *Note:* This need not be the result of a programming error. If a Terminal program opens a file in the BasicCard, and then calls a BasicCard command, the BasicCard command can close all files unilaterally – including remotely-opened files – by using the **Close** command with no parameters. This is so that the BasicCard program can always find a free open file slot when it needs one.

feAccessDenied The access conditions on a file or directory do not allow the execution of the command.

feBadFileChain The file system in the BasicCard is corrupted.

feBadParameter An invalid parameter value was passed to the command.

feOutOfMemory The BasicCard has insufficient free EEPROM to execute the command.

feUnexpectedError An operating system command in the PC returned an unexpected error code when a file system function was called.

feCommsError In case 2 above (Terminal program accessing the BasicCard file system), the command failed because of a communications failure with the BasicCard. The status bytes describing the communications failure can be found in the pre-defined variables **SW1** and **SW2**.

feNoFileSystem The card has no file system installed, either because

- it's a Compact BasicCard; or
- no program has yet been downloaded to the card; or
- the file system was disabled with a **#Files 0** directive (see **3.3.8 Number of Open File Slots**).

Definitions of these error codes, as well as all the other constants that appear in this chapter, are contained in the file **FILEIO.DEF**. This file is supplied in the distribution kit, and is listed in **4.12 The Definition File FILEIO.DEF**.

4.4 Directory Commands

4.4.1 Creating a Directory

The **MkDir** command creates a new directory (but see also **4.11 File Definition Sections**):

MkDir *path*

path The path name of the new directory. A final backslash '\' is optional.

Access Conditions:

Write access to the parent directory is required. The **Read** and **Write** access conditions of the new directory are the same as those of the parent directory.

Error Codes:

feFileNotFound The parent directory does not exist.
feFileAlreadyExists A file or directory with the given path name already exists.
feNameTooLong The full path name of the directory would be longer than 254 characters.

4.4.2 Deleting a Directory

The **RmDir** command deletes an existing directory. The directory must be empty before it can be deleted:

RmDir *path*

path The path name of the directory. A final backslash '\' is optional.

Access Conditions:

Single-application BasicCard: **Write** access is required, both to the directory and to its parent directory.
MultiApplication BasicCard: **Delete** access is required (but not to the parent directory).

Error Codes:

feFileNotFound	The directory does not exist.
feNotDirectory	The file is a data file, not a directory. Use **Kill** to delete data files.
feDirNotEmpty	The directory is not empty, and therefore can't be deleted.

4.4.3 Setting the Current Directory

The **ChDir** command sets the current directory.

ChDir *path*

path The path name of the new current directory. A final backslash '\' is optional.

Note (Terminal programs only): If the path contains a disk drive name, the current directory for that disk drive is changed, but the current disk drive is *not* changed. Use **ChDrive** to change the current disk drive.

Access Conditions:

Read access to the directory is required.

Error Codes:

feFileNotFound	The directory does not exist.
feNotDirectory	The file is a data file, not a directory.

4.4.4 Retrieving the Current Directory

The **CurDir** function returns the path of the current directory as a **String**:

S$ = **CurDir** [(*drive*)]

drive The disk drive for which the current directory is requested. The first character must be a letter ('A-Z' or 'a-z'), or the character '@'. If absent, the current directory of the current disk drive is returned.

Note: The optional *drive* parameter is accepted only in Terminal programs.

Access Conditions:

No access conditions are required for this command.

Error Codes:

feInvalidDrive	The disk drive specified in the *drive* parameter does not exist.
feNameTooLong	The full path name of the current directory is longer than 254 characters (Terminal program only).

4.4.5 Renaming a File or Directory

The **Name** command renames a file or directory, or moves it to a new directory, or both. It cannot be used to move a file from one disk drive to another.

Name *OldPath* **As** *NewPath*

OldPath The old path name of the file or directory.

NewPath The new path name. If no backslash appears in *NewPath*, the file or directory is renamed without being moved. If *NewPath* ends with a backslash character '\', the file or directory is moved without being renamed.

Note: Under MS-DOS®, directories can be renamed, but not moved.

Access Conditions:

Write access is required (i) to the file or directory being renamed, (ii) to its parent directory, and (iii) to the destination directory if different from the current parent directory.

Error Codes:

feFileNotFound	The file specified in *OldPath* does not exist, or the directory specified in *NewPath* does not exist.
feFileAlreadyExists	The file specified in *NewPath* already exists.
feNameTooLong	The operation would result in a file or directory in the BasicCard with a full path name longer than 254 bytes.
feRenameError	One of the following error conditions: • *OldPath* is the root directory, which cannot be renamed. • *NewPath* and *OldPath* are on different disk drives. • An attempt was made to move a directory under MS-DOS®.
feRecursiveRename	The directory in *NewPath* is a sub-directory of *OldPath*, so the rename operation would result in an endless loop in the directory tree.

4.4.6 Searching for Files

Use the **Dir** command to search for files and directories matching a given wild-card specification. This has two forms:

nFiles = **Dir** (*filespec*)	Returns the number of matching files and directories, as an **Integer**.
file$ = **Dir** (*filespec***,** *n*)	Returns the name of the *n*th matching file or directory, as a **String**.

filespec	The path name of the file(s) to search for. The last component of the path may contain the wild-card characters '`?`' (matching any single character) and '`*`' (matching any sequence of zero or more characters). For example, "`A*`" finds all filenames that start with the character '`A`' or 'a', and "`*=?`" finds all filenames whose penultimate character is '`=`'.
n	The number of the matching file, 1 <= *n* <= *nFiles*.

Notes:

1. If *filespec* refers to a file or files in the PC, the first **Dir** command for a given *filespec* saves all the matching files in memory. This list is retained for future **Dir** commands of the second form that have the same *filespec* parameter (unless a ZC-Basic command intervenes that can change the directory contents). This is a major speed improvement in most cases. However, if another process changes the directory contents, ZC-Basic won't know about it, and will continue to use the original list. You can override this at any time and re-load the list from the disk, by calling a **Dir** command of the first form.
2. ZC-Basic uses the host operating system to match wild-card specifications in the PC. MS-DOS® and Windows® handle wild-card characters a little differently, due to the differences in what constitutes a valid filename, but "`*.*`" matches all files and directories in both systems.
3. The Enhanced BasicCard uses a case-insensitive matching algorithm that treats the full stop (period) character '`.`' no differently from any other character (unlike MS-DOS® and Windows®). However, as a special case, the wild-card string "`*.*`" matches all files and directories.

Access Conditions:

Read access to the parent directory is required.

Error Codes:

feBadFilename	*filespec* is not a valid path name (this error code is also returned if *filespec* contains wild-card characters in any component except the last).
feBadFilenum	*n* is less than 1 or greater than *nFiles*.

4.4.7 Setting the Attributes of a File or Directory

The **SetAttr** command sets the attributes of a file or directory:

SetAttr *filename***,** *attributes*

filename	The path name of the file or directory.
attributes	A bit map of the attributes to set. The attributes available depend on the host operating system. See **4.4.8 Retrieving the Attributes of a File or Directory** for details.

Note: This command is available in Terminal programs only.

Access Conditions:

Access conditions are not relevant for **SetAttr** – a BasicCard file has no attributes that can be changed.

Error Codes:

feRemoteFile	*filename* is a BasicCard file, so it has no attributes that can be changed.

4.4.8 Retrieving the Attributes of a File or Directory

The **GetAttr** command returns the attributes of a file or directory:

attributes = **GetAttr (** *filename***)**

filename The path name of the file or directory.

attributes A bit map of the attributes of the file or directory. The attributes that can be returned depend on the host operating system, as follows:

- The BasicCard file system supports two attributes:

faDirectory	Indicates that the file is a directory, and not a data file.
faCardFile	Indicates that the file or directory is in the BasicCard.

- MS-DOS® supports these two attributes, plus the following:

faReadOnly	Indicates a read-only file.
faHiddenFile	Indicates a hidden file.
faSystemFile	Indicates a system file.
faArchived	Indicates that file has been backed up since last changed.

- Microsoft Windows® supports all the above attributes, plus the following:

faNormal	Indicates that no other attribute bits are set.
faTemporary	Indicates that file is being used for temporary storage.

These constants are defined in the file FILEIO.DEF.

Access Conditions:

Read access is required to the parent directory (but not to the file itself).

4.4.9 Setting the Current Disk Drive

The **ChDrive** command sets the current disk drive.

ChDrive *drive*

drive	The disk drive for which the current directory is requested. The first character must be a letter ('A-Z' or 'a-z'), or the character '@'.

Note: This command is available in Terminal programs only.

Access Conditions:

No access conditions are required for this command.

Error Codes:

feInvalidDrive	The disk drive specified in the *drive* parameter does not exist.

4.4.10 Retrieving the Current Disk Drive

The **CurDrive** function returns the current disk drive as a single-character **String** containing an upper-case letter 'A-Z' or the character '@':

S$ = **CurDrive**

Note: This command is available in Terminal programs only.

Access Conditions:

No access conditions are required for this command.

4.5 Creating and Deleting Files

4.5.1 Creating a File

There is no special command to create a new file (but BasicCard files can be defined at compile time – see **4.11 File Definition Sections**). A file is created simply by opening a non-existent file for output, using the **Open** command (see **4.6.1 Opening a File**). A file can't be created in this way if *mode* is **Input** or *access* is **Read**.

4.5.2 Deleting a File

The **Kill** command deletes an existing file:

Kill *filename*

filename	The name of the file.

Access Conditions:

Single-application BasicCards: **Write** access is required, both to the file and to its parent directory.
MultiApplication BasicCard: **Delete** access is required (but not to the parent directory).

Error Codes:

feFileNotFound	The file does not exist.
feNotDataFile	The file is a directory, not a data file. Use **RmDir** to delete directories.
feFileOpen	The file can't be deleted, because it is currently open.

4.6 Opening and Closing Files

4.6.1 Opening a File

In traditional Basic, the programmer has to specify *filenum*, the number of the open file slot. But in the BasicCard file system, with open file slots shared between the BasicCard program and the Terminal program, the programmer can't always know which file slots are in use. So ZC-Basic allows an alternative form of the **Open** command, where the operating system automatically selects a free open file slot. (This is equivalent to calling **FreeFile** to select an open file slot, followed by a traditional **Open** command.)

Traditional form: **Open** *filename* [**For** *mode*] [**Access** *access*] [*lock*] **As** [#] *filenum* [**Len**=*recordlen*]

Alternative form: *filenum* = **Open** *filename* [**For** *mode*] [**Access** *access*] [*lock*] [**Len**=*recordlen*]

filename — The path name of the file to be opened.

mode — If *mode* is **Input**, **Output**, or **Append**, the file is opened for sequential I/O, in which all write operations take place at the end of the file. If *mode* is **Binary** or **Random**, write operations can take place anywhere in the file, overwriting existing data:

Input	Opens the file for sequential input.
Output	Opens the file for sequential output. Existing data is destroyed.

Append	Opens the file for sequential output and sets the file pointer to the end of the file. Existing data in the file is preserved.
Binary	Opens the file for random access by file position, using **Get** and **Put**.
Random	Opens the file for random access by record number, using **Get** and **Put**.

If the *mode* parameter is absent, its value depends on the *access* parameter: **Input** for **Access Read**, **Output** for **Access Write**, and **Append** for **Access Read Write**. If both *mode* and *access* are absent, *mode* defaults to **Input** and *access* defaults to **Read.**

access Specifies which types of operations will be executed on the file. It takes the value **Read**, **Write**, or **Read Write**.

- If *mode* is **Input**, then *access*, if present, must be **Read**.
- If *mode* is **Output**, then *access*, if present, must be **Write**.
- If *mode* is **Append**, then *access*, if present, must be **Write** or **Read Write**.
- If *mode* is **Binary** or **Random**, then *access* can take any value; it defaults to **Read Write**.

lock For a file in the PC, this parameter specifies whether the file can be opened simultaneously by other processes. For a file in the BasicCard, it specifies whether the file can be opened simultaneously from the Terminal program and the BasicCard program. It also determines whether a file can be opened simultaneously under different open file slots in the same program. The *lock* parameter can take the following values:

Shared	Allows simultaneous read and write operations by other processes.
Lock Read	Prevents simultaneous read operations by other processes.
Lock Write	Prevents simultaneous write operations by other processes.
Lock Read Write	Prevents simultaneous access by other processes (the default).

filenum The number of an open file slot, by which read and write operatons will be executed. In the Terminal program, *filenum* must be between 1 and 32 inclusive. In the BasicCard program, *filenum* must be 1 or 2, unless the number of open file slots has been configured with the **#Files** directive (see **3.3.8 Number of Open File Slots**).

recordlen Record length or block length.

- If the file is being created, this parameter specifies the size of its data blocks (see **4.2.3 Storage Requirements** for more information). If absent (or zero), the data block size for the new file is 32 bytes. If present, it must be <= 16381.
- If *access* is **Random**, this parameter specifies the record length of the file. This record length must be between 1 and 254 inclusive.

Access Conditions:

If the file already exists, the access conditions required depend on the *access* parameter: **Read**, **Write**, or **Read Write**. If the file is being created, **Write** access to the parent directory is required, and the **Read** and **Write** access conditions on the new file are the same as those of the parent directory.

Error Codes:

feFileNotFound	The file does not exist, and could not be created, because: • the parent directory does not exist; or • *mode* is **Input**; or • *access* is **Read**.
feNotDataFile	The file is a directory, not a data file.
feFileOpen	(Traditional form only) Open file slot number *filenum* is already in use.
feTooManyOpenFiles	(Alternative form only) There are no more free open file slots.
feTooManyCardFiles	(Terminal program only) An attempt was made to open a BasicCard file from a Terminal program, but there are no more free open file slots in the BasicCard.
feNameTooLong	(BasicCard file system only) The file can't be created, because its full path name would be longer than 254 characters.

feRecordTooLong	Either *access* is **Random**, and *recordlen* is greater than 254; or the file is being created, and *recordlen* is greater than 8191.
feBadParameter	Either *access* is **Random**, and *recordlen* is less than 1 (or absent); or the file is being created, and *recordlen* is less than 0.
feSharingViolation	The file is already open, and the required shared access is not available.

4.6.2 Closing Files

The **Close** command closes one or more files:

Close [[#] *filenum* [**,** [#] *filenum* **, . . .**]]

Note: If no parameters are supplied, all open files are closed. (But the P-Code interpreter automatically closes all files on program exit.) If the BasicCard program closes all open files in this way, even files that were opened from the Terminal program are closed. In this way, the BasicCard program can always find a free open file slot when it needs one.

4.7 Writing To Files

4.7.1 Writing to Sequential Files

If a file was opened for writing, with a *mode* parameter equal to **Output** or **Append**, it can be written to with a **Print** or **Write** command. All write operations take place at the end of the file.

The **Print** command outputs data to a sequential file in human-readable format. It has the same format as the **Print** command for displaying data on the screen (see **3.21.1 Screen Output**), except for the initial #*filenum* parameter:

Print #*filenum***,** [*field* | *separator*] [*field* | *seperator*] **. . .**

filenum	The *filenum* parameter to the **Open** command by which the file was opened.	
field	Any **Byte**, **Integer**, **Long**, **Single**, or **String** expression	
separator	'**;**' (semi-colon)	Leaves the output column unchanged.
	'**,**' (comma)	Advances the output column to the next output field (an output field is 14 characters wide).
	Spc(*n***)**	Prints *n* space characters.
	Tab(*n***)**	Advances the output column to position *n*.

A new-line character is added at the end, unless the last character is a separator. (So you can stay on the same output line by adding a semi-colon at the end of the command.)

Note: Use of this statement in an Enhanced BasicCard program with a parameter of type **Single** will reduce the amount of user-programmable EEPROM available – see **3.23.5 Single-to-String Conversion** for details.

The **Write** command writes data to a sequential file, in a binary format that is specific to ZC-Basic. If a sequence of values is written to a file with **Write** statements, then the same values can subsequently be read from the file using ZC-Basic **Input** statements (see **4.8.1 Reading from Sequential Files**).

Write [#] *filenum***,** *expression-list*

filenum	The *filenum* parameter to the **Open** command by which the file was opened.
expression-list	A list of expressions separated by commas. Expressions can be of numerical, string, or user-defined type.

Access Conditions:

The file must have been opened with the *access* parameter equal to **Write** or **Read Write**.

Error Codes:

feInvalidMode	The file was not opened with *mode* equal to **Output** or **Append**.
feInvalidAccess	The file was not opened with *access* equal to **Write** or **Read Write**.

4.7.2 Writing to Binary and Random Files

The **Put** command is used to write to files that were opened with *mode* equal to **Binary** or **Random**. The write operation takes place at the current file position, overwriting any existing data at that position. After the **Put** command, the current file position advances to the next character (for **Binary** files) or the next record (for **Random** files):

Put [#] *filenum*, [*pos*], *data*

filenum	The *filenum* parameter to the **Open** command by which the file was opened.
pos	A record number for **Random** files, and a character position for **Binary** files. If *pos* is not present ("**Put** [#] *filenum*, , *data*"), the variable is written to the current file position.
data	A variable or array element, or a **String** expression.

Access Conditions:

The file must have been opened with the *access* parameter equal to **Write** or **Read Write**.

Error Codes:

feInvalidMode	The file was not opened with *mode* equal to **Binary** or **Random**.
feInvalidAccess	The file was not opened with *access* equal to **Write** or **Read Write**.
feSeekError	*pos* is an invalid file position.

4.8 Reading From Files

4.8.1 Reading from Sequential Files

If a file was opened for reading, with a *mode* parameter equal to **Input** or **Append**, it can be read with a **Line Input** statement, an **Input** function, or an **Input** statement.

Line Input #*filenum*, *X$*	Reads a string from the file, up to the next new-line character or end-of-file, or until 254 characters have been read (the new-line character, if read, is discarded).
X$ = **Input** (*len*, [#] *filenum*)	The **Input** function reads a given number of characters from the file into a string.
Input #*filenum*, *variable-list*	The **Input** statement reads a list of variables from a file, expecting them in the format produced by a corresponding **Write** statement (see **4.7.1 Writing to Sequential Files**). This statement can also appear on the right-hand side of an assignment statement: *n* = **Input** #*filenum*, *variable-list* This returns the number of variables in the list that were successfully input.

filenum	The *filenum* parameter to the **Open** command by which the file was opened.
X$	A variable or array element of type **String**.
len	The number of characters to read.
variable-list	A list of variables or array elements, separated by commas.

Access Conditions:

The file must have been opened with the *access* parameter equal to **Read** or **Read Write**.

Error Codes:

feInvalidMode	The file was not opened with *mode* equal to **Input** or **Append**.
feInvalidAccess	The file was not opened with *access* equal to **Read** or **Read Write**.
feReadError	The end of file was reached before enough bytes were read.

4.8.2 Reading from Binary and Random Files

The **Get** command is used to read from files that were opened with *mode* equal to **Binary** or **Random**. The read operation takes place at the current file position. After the **Get** command, the current file position advances to the next character (for **Binary** files) or the next record (for **Random** files):

Get [#] *filenum***,** [*pos*]**,** *variable* [, *len*]

filenum	The *filenum* parameter to the **Open** command by which the file was opened.
pos	A record number for **Random** files, and a character position for **Binary** files. If *pos* is not present (e.g. "**Get** *filenum***, ,** *variable*"), the read operation takes place at the current file position.
variable	A variable or array element. If this is of type **String**, it must be followed by the *len* parameter; otherwise the *len* parameter must be absent.
len	The number of characters to read, in the case that *variable* is of type **String**.

Access Conditions:

The file must have been opened with the *access* parameter equal to **Read** or **Read Write**.

Error Codes:

feInvalidMode	The file was not opened with *mode* equal to **Binary** or **Random**.
feInvalidAccess	The file was not opened with *access* equal to **Read** or **Read Write**.
feSeekError	File position *pos* does not exist.
feReadError	The end of file was reached before enough bytes were read.

4.9 File Locking and Unlocking

The commands in this section are valid only for files in single-application BasicCards.

4.9.1 Setting Read and Write Access Conditions

The **Read** and **Write** access conditions of a file or directory are changed with the following commands:

Read Lock *filename* [**Key** = *k1* [**,** *k2*]]
Read Unlock *filename*

Write Lock *filename* [**Key** = *k1* [**,** *k2*]]
Write Unlock *filename*

Read Write Lock *filename* [**Key** = *k1* [**,** *k2*]]
Read Write Unlock *filename*

filename	The path name of the file or directory.
k1, *k2*	The key numbers required to access the file or directory.

- The **Lock** command with no parameters sets the **Read** and/or **Write** access conditions of the specified file or directory to **Forbidden**.
- The **Lock** command with *k1* or *k2* specified sets the **Read** and/or **Write** access conditions of the specified file or directory to **Keyed** – the file can't be read or written from the Terminal program unless DES encrpytion is currently active.
- The **Unlock** command sets the **Read** and/or **Write** access conditions of the specified file or directory to **Allowed**.

Access Conditions:

Write access is required to the file or directory, and to its parent directory.

Error Codes:

feNotRemoteFile	*filename* is not a BasicCard file or directory.

4.9.2 Setting and Unlocking a Custom Lock

If a file or directory has a **Custom** lock, it can't be read or written from a Terminal program unless the BasicCard program explicitly unlocks it. This allows access to a file or directory to be subject to any conditions, such as the presentation of a valid customer PIN number by the Terminal.

To set a **Custom** lock:

Lock *filename*

To unlock a **Custom** lock (BasicCard program only):

Unlock *filename*

Notes:

1. Once a **Custom** lock is set, it can never be permanently removed. A **Custom** lock is for ever.
2. If a **Custom** lock is unlocked, it can only be accessed from the Terminal program until the card is reset. After the card is reset, the BasicCard program must unlock the file or directory again before the Terminal program can access it.

Access Conditions:

For the "**Lock** *filename*" command, **Write** access is required to the file or directory, and to its parent directory. The "**Unlock** *filename*" command is not allowed in a Terminal program, so access conditions are not relevant.

Error Codes:

feNotRemoteFile	*filename* is not a BasicCard file or directory.
feTooManyCustomLocks	The maximum allowed number of **Custom** locks are already in place. (The implementation of the **Custom** lock mechanism in the Enhanced BasicCard limits the number of locked files to 125.)

4.9.3 Retrieving the Access Conditions on a File or Directory

The access conditions on a file or directory can be obtained with the **Get Lock** command:

Get Lock *filename*, *LockInfo*

filename — The path name of the file or directory.

LockInfo — A variable of user-defined type or a fixed-length string, at least seven bytes long. A suitable user-defined type **LockInfo** is defined in FILEIO.DEF:

```
Type LockInfo
  ReadLock As Byte
  WriteLock As Byte
  CustomLock As Byte
  ReadKey1@, ReadKey2@
  WriteKey1@, WriteKey2@
End Type
```

ReadLock and **WriteLock** can be **liAllowed**, **liForbidden**, **liKeyed1**, or **liKeyed2**. If **liKeyed1** or **liKeyed2**, then **ReadKey1@** etc. contain the appropriate key numbers.

CustomLock can be **liAllowed**, **liUnlocked**, or **liLocked**.

Access Conditions:

Read access is required to the parent directory.

Error Codes:

feNotRemoteFile	*filename* is not a BasicCard file or directory.

Note: Enhanced BasicCard versions ZC3.3, ZC3.4, ZC3.5, and ZC3.6 contain a bug in the file access code that can result in access being denied when it should be granted. This bug only occurs when a file

has a lock of type **liKeyed1**. To get round this bug, the compiler automatically converts all such locks to type **liKeyed2**, with a dummy key number 255 as the second key.

4.10 Miscellaneous File Operations

filenum = **FreeFile**	Returns a free *filenum* for use in a traditional **Open** statement. Returns –1 if no more file numbers are available, with error code **feTooManyOpenFiles**.
Seek [#] *filenum***,** *pos*	Sets the file pointer to position *pos* (of type **Long**) for the next read or write operation on file *filenum*. *pos* is a record number for files opened with *mode*=**Random**; otherwise it is a byte count. Records and bytes are numbered from 1. *Note:* If the file contains less than *pos*–1 bytes (or records), **Seek** fails with error code **feSeekError**, unless the file was opened for output in random access mode (*mode*=**Binary** or *mode*=**Random**, with **Write** access specified). In this case, the file is filled with zeroes to the required length.
Seek ([#] *filenum*)	Returns the read/write position for file *filenum*, as a **Long** value.
Len (#*filenum*)	Returns the length of file *filenum* in bytes, as a **Long** value.
EOF ([#] *filenum*)	Returns **True** if the end of file has been reached.

4.11 File Definition Sections

Using File Definition Sections, files and directories can be defined in the source code of the BasicCard program, to be created by the compiler. Files and directories so defined are downloaded to the BasicCard together with the BasicCard program itself. A File Definiton Section begins with a **Dir** command and ends with the matching **End Dir** command. It may occur anywhere in a BasicCard program; it may contain only File Definition statements, not regular ZC-Basic statements. A program may contain any number of File Definition Sections.

This section describes the statements available in single-application BasicCard programs. File Definition Sections in a MultiApplication BasicCard program can contain a much richer set of statements, including Component Definitions and Application Loader commands. See **5.4 Application Loader Definition Section** for more information.

4.11.1 Directory Definition

Dir *path*
    Lock Definitions
    File Definitions
    Sub-directory Definitions
End Dir

path	The path name of the directory. It may be a new directory or an existing directory.
Lock Definitions	**Lock** and **Unlock** statements for the *path* directory. These have the same format as the statements described in **4.9 File Locking and Unlocking**, but without the *filename* parameter.
File Definitions	Definitions of files contained in the *path* directory (see **4.11.2 File Definition**).
Sub-directory Definitions	Nested Directory Definitions, defining sub-directories of the *path* directory. Each nested Directory Definition must end with its own **End Dir** statement.

File Definitions and nested Directory Definitions may occur in any order.

4.11.2 File Definition

A File Definition may occur only inside a Directory Definition. It ends with the next **File** or **Dir** statement, or with the **End Dir** statement of the enclosing Directory Definition.

File *filename* [**Len** = *blocklen*]
Lock Definitions
Data Definitions
Input *inputfile*

filename The path name of the file.

blocklen The size of the new file's data blocks (see **4.2.3 Storage Requirements** for more information). If absent, *blocklen* defaults to 32. The special value **Len=0** sets the data block length to the length of the initial data, so that initially the file occupies exactly one data block.

Lock Definitions **Lock** and **Unlock** statements for the file. These have the same format as the statements described in **4.9 File Locking and Unlocking**, but without the *filename* parameter.

Data Definitions The initial data contained in the file. A Data Definition statement looks like this:

expr [**As** *type*] [(*repeat-count*)] [**,** *expr* [**As** *type*] [(*repeat-count*)]**, . . .**]

expr Any constant expression of numerical or string type.

type A data type. If absent, it defaults to the smallest data type that can contain *expr*. If *type* is a fixed-length string longer than *expr*, it is padded with NULL characters (ASCII zeroes) to the required length.

(*repeat-count***)** The number of copies of *expr* to store in the file.

Note: To store a new-line character in the data, use the constant 10.

Input *inputfile* Copies the contents of file *inputfile* byte-for-byte into the BasicCard file. The compiler looks for *inputfile* in the same directories as it looks for **#Include** files – see **3.3.1 Source File Inclusion** for details.

4.12 The Definition File FILEIO.DEF

```
Rem  FILEIO.DEF
Rem
Rem  Declarations for ZC-Basic File I/O

#IfNotDef FileioDefIncluded ' Prevent multiple inclusion
Const FileioDefIncluded = True

#IfDef CompactBasicCard
#Error File I/O is not suported in the Compact BasicCard!
#EndIf

Rem  FileError codes

Const feFileOK             = 0
Const feInvalidDrive       = 1
Const feBadFilename        = 2
Const feBadFilenum         = 3
Const feFileNotFound       = 4
Const feFileNotOpen        = 5
Const feOpenError          = 6
Const feSeekError          = 7
Const feReadError          = 8
Const feWriteError         = 9
Const feCloseError         = 10
Const feInvalidMode        = 11
```

```
Const feInvalidAccess       = 12
Const feRenameError         = 13
Const feAccessDenied        = 14
Const feSharingViolation    = 15
Const feFileAlreadyExists   = 16
Const feNotDataFile         = 17
Const feNotDirectory        = 18
Const feDirNotEmpty         = 19
Const feBadFileChain        = 20
Const feFileOpen            = 21
Const feNameTooLong         = 22
Const feRecordTooLong       = 23
Const feTooManyOpenFiles    = 24
Const feTooManyCardFiles    = 25
Const feCommsError          = 26
Const feRemoteFile          = 27
Const feNotRemoteFile       = 28
Const feRecursiveRename     = 29
Const feInvalidFromKeyboard = 30
Const feBadParameter        = 31
Const feOutOfMemory         = 32
Const feNoFileSystem        = 33
Const feUnexpectedError     = 34
Const feNotImplemented      = 35
Const feTooManyCustomLocks  = 36
Const feBadKeyFile          = 37

Rem  File Attribute bits

Const faDirectory  = &H0010
Const faCardFile   = &H0040

#IfDef TerminalProgram

Const faReadOnly   = &H0001
Const faHiddenFile = &H0002
Const faSystemFile = &H0004
Const faArchived   = &H0020
Const faNormal     = &H0080
Const faTemporary  = &H0100

#EndIf

#IfNotDef MultiAppBasicCard

Rem  LockInfo defined type, for GET LOCK statement

Type LockInfo
  ReadLock As Byte         ' liAllowed, liKeyed1, liKeyed2, or liForbidden
  WriteLock As Byte        ' liAllowed, liKeyed1, liKeyed2, or liForbidden
  CustomLock As Byte       ' liAllowed, liUnlocked, or liLocked
  ReadKey1@, ReadKey2@     ' Key number(s) for ReadLock
  WriteKey1@, WriteKey2@ ' Key number(s) for WriteLock
End Type

Rem  LockInfo constants

Const liAllowed   = 0
Const liKeyed1    = 1
Const liKeyed2    = 2
Const liForbidden = 3
Const liUnlocked  = 1
Const liLocked    = 2

#EndIf ' MultiAppBasicCard

#EndIf ' FileioDefIncluded
```

5. The MultiApplication BasicCard

The MultiApplication BasicCard **ZC6.5** is a natural extension of the single-application Professional BasicCard family. It was designed with two aims in mind:

- to retain the ease of programming that is such an attractive feature of the BasicCard;
- to allow multiple Applications to coexist in a single BasicCard without compromising their security.

These two aims have been achieved by retaining the ZC-Basic language essentially unchanged, with the additional concept of the Security Component.

5.1 Components

A Security Component (or Component for short) resembles a file, in that it has a name, resides in a directory, and can contain data. (In fact, in the MultiApplication BasicCard a file can be thought of as just another type of Component.)

5.1.1 Component Types

There are five Component types:

- **File** A data file or directory, just as in the Professional BasicCard.
- **ACR** Access Control Rule. An ACR defines the conditions by which a Component may be accessed. It is the only Component type that does not require a name.
- **Privilege** A Privilege can be granted to an Application (or to the Terminal program) to allow it access to a Component.
- **Flag** A Flag can be switched On or Off by an authorised Application, and then queried by an ACR to verify access conditions.
- **Key** A Key can be any length up to 255 bytes. When you create a Key, you specify the uses to which the key can be put (for example External Authentication), and the cryptographic algorithms that it may be used in (for example AES-128).

5.1.2 Component Properties

A Component name follows the same rules as a file name. Two Components in the same directory may have the same name if they are of different types. A Component may have *Attributes* and *Data*, which can be read and written separately if the requisite access conditions are satisfied. The format of a Component's Attributes and Data depends on its type, and on whether the Component is being created, written, or read. The various formats are described in the following sections.

Each Component has a unique two-byte Component ID, or CID, that is assigned by the BasicCard operating system when the Component is created. This ID is required as a parameter in a number of **COMPONENT** System Library procedures. This Library provides two procedures, **FindComponent** and **ComponentName**, for obtaining the CID of a Component from its name and vice versa.

The top four bits of a CID determine the type of the Component; the value ((CID **Shr** 8) **And** &HF0) is equal to one of the following constants, defined in the file COMPONNT.DEF:

ctFile	**&H10**
ctACR	**&H20**
ctPrivilege	**&H30**
ctFlag	**&H40**
ctKey	**&H70**

5.1.3 Component Access Control

Access to a Component is controlled according to its Access Control Rule, or ACR. The ACR specifies the conditions under which the various types of access are allowed. An ACR may be assigned to any Component; an ACR itself, being a Component, may also be protected with a (different) ACR.

The MultiApplication BasicCard defines five access types:

Read	Required to read a Component's data (or the contents of a directory)
Write	Required to write a Component's data (or to create a Component in a directory)
Execute	Required to select an Application
Delete	Required to delete a Component, or to write its attributes
Grant	Required to grant a Privilege to an Application (or to the Terminal program)

The conditions under which each access type is allowed may be separately specified. See **ACR Definition 5.4.5** for information on how to define an ACR in the source code of an Application; see **7.4 The COMPONENT Library** and **5.8.2 ACRs** for details on how to create an ACR dynamically at run-time.

5.2 Applications

From the point of view of the MultiApplication BasicCard, an Application is just an executable file. But from the point of view of the programmer, an Application will also contain various Components – data files, keys, ACR's etc. This section concentrates on the Application as an executable file; for information on how to bundle an Application with the Components that it needs, see **5.4 Application Loader Definition Section.**

5.2.1 Application Files

An Application file is an executable file, that contains compiled ZC-Basic code for the execution of commands. It must satisfy certain conditions:

- the first four bytes must be "**ZCAF**";
- it must be at least 37 bytes long;
- it must be allocated as a contiguous block of EEPROM.

In addition, if there exists an ACR in the Root directory with the name "**Executable**", then the file must satisfy this ACR.

An Application file contains compiled code for all the commands that the Application supports. It also contains the **Eeprom** data used by the Application. Such data is not shareable between Applications; if different Applications want to share data, they must use the File System. If an Application uses **Eeprom** strings or dynamic arrays, then it needs its own Heap, which also resides in the Application file.

An Application file can be created in one of two ways:

- with an **Application** *filename$* statement in the File Definition Section;
- with the "**–OA**" compiler command-line option.

The first option embeds the file in an Image file or Debug file for use by the Application Loader; the second option creates an Application file in the host computer (which can then be loaded "by hand").

5.2.2 Selecting an Application

When the MultiApplication BasicCard is reset, the operating system looks for an Application file in the Root directory with the name "**DefaultApp**". If such a file exists, it is selected, and becomes the *Current Application*. (If no such file exists, then there is initially no Current Application.) The Current Application is the Application file whose command table is searched when a command is received. If a match is found, then the code for the matched command is executed.

Subsequently, the Current Application can be changed by selecting a new Application. This is done by calling the System Library procedure **SelectApplication** (*filename$*), either from the Terminal program

or from within the card. If an Application selects another Application in this way, then the previous Application's code is no longer accessible, so code after the **SelectApplication** call will not get executed unless the Application selection fails for some reason.

To select an Application, **Execute** access is required to the Application file.

5.2.3 Catching Undefined Commands

If the card contains a Default Application (i.e. an executable file "**DefaultApp**" in the Root directory), it can be configured to catch undefined commands. This means that if a command is received that is not supported by the Current Application, then the Default Application's command table is searched for a match. If an undefined command is caught by the Default Application in this way, then the Current Applciation is closed, and the Default Application becomes the new Current Application.

To configure an Application to catch undefined commands:

```
#Pragma CatchUndefinedCommands
```

This statement is allowed in any Application, but it has no effect except in the Default Application.

5.2.4 Memory Allocation

The MultiApplication BasicCard has three types of heap for memory allocation:

- The Global Heap is for Files and Components, including Application Files. It occupies the whole of the available EEPROM in the card.
- Each Application has its own EEPROM Heap, which is an area in the Application File for the Application's **Eeprom String** variables and **Eeprom** dynamic arrays. Its size can be configured with the **#Heap** statement, or in the **ZCMDCARD** BasicCard Debugger.
- The RAM heap is for an Application's temporary (**Public** and **Private**) **String** variables and dynamic arrays. It is cleared on card reset, and whenever an Application is selected. Its size depends on the sizes of the Application's stack and fixed-length temporary data; the three regions **RAMHEAP**, **STACK**, and **RAMDATA** together occupy about 1100 bytes in MultiApplication BasicCard **ZC6.5**.

To see the exact lengths of an Application's EEPROM and RAM heaps, ask the compiler to generate a Map file. To find out the amount of free memory available in each heap, see **7.10.10 Free Memory**.

5.3 Special Files

Certain filenames have special meanings in the MultiApplication BasicCard.

5.3.1 ATR File

If a file with the name "**ATR**" exists in the Root Directory, its contents are used as the Answer To Reset, sent by the BasicCard whenever it is reset by the Terminal program. The complete ATR – protocol definition bytes and Historical Characters – must be included in the file, with a trailing flag byte. The special syntax

ATR (*ATR-Spec***)**

in a File Definition denotes a string constant that lets you specify the ATR in the same way as the **#Pramga ATR** directive – see **3.20.1 Customised ATR** for the format of *ATR-Spec*.

The following example configures a MultiApplication BasicCard to use the **T=0** protocol:

```
#Include ATRList.def

Dir "\" ' Root directory
  File "ATR" Lock Read: Always ' Make the file read-only
    ATR (T=0)
End Dir
```

Use this feature with care, as an invalid ATR can make the card unusable. You should at the very least try out the ATR in a simulated BasicCard before testing it in a real card.

5.3.2 Card ID File

If a file with the name "**CardID**" exists in the Root Directory, its contents are sent in response to a **GET APPLICATION ID** command with **P1=&H00**, **P2=&H02**.

5.3.3 Elliptic Curve Domain Parameters

If a file with the name "**ECDomainParams**" exists in the Root Directory, the Elliptic Curve Domain Parameters for the **EC167** or **EC211** System Library are loaded from it automatically whenever the card is reset. The file may also contain pre-computed data for speeding up Elliptic Curve operations. Suitable data files are provided in the **\BasicCardPro\Lib\Curves** directory. For example:

```
Dir "\" ' Root directory
  File "ECDomainParams" Lock=Read:Always
    #Include \BasicCardPro\Lib\Curves\EC167-4.64
End Dir
```

This loads the 167-bit Elliptic Curve number 4, with 64 pre-computed points.

5.4 Application Loader Definition Section

An Application will typically require various Components, such as data files and keys, to be created before it can work properly. Creating these Components, and downloading the Application file, will often require a complicated sequence of cryptographic operations, such as **EXTERNAL AUTHENTICATE** commands. This process can be automated by defining it in the source file of the Application itself, in an Application Loader Definition Section. The statements in this Section are saved in the Image file, for interpretation by the Application Loader.

An Application Loader Definition Section is actually an enhanced version of the File Definition Section described in **4.11 File Definition Sections**. (Before reading this Section, you may want to review File Definition Sections.) It consists of a Directory Definition, that can contain File Definitions, nested Directory Definitions, Component Definitions, and Loader Commands.

5.4.1 Common Component Attributes

All Components have the following three attributes in common:

Ref=*ref* — Specifies a reference number between 1 and 65535 by which the Component may be referred to later in the Loader Definition Section. This number must be unique.

Lock=*ACR* — Specifies the ACR of the Component. *ACR* is either (i) the pathname of a previously defined ACR; or (ii) the Reference number of a previously defined ACR; or (iii) an ACR Specification. In case (iii), the Application Loader will create an Anonymous ACR.

If a Component has no ACR, anybody can read, write, or delete it. This is usually a bad idea, so every Component definition is required to contain a **Lock** attribute. However, you can specifically request an unprotected Component, with **Lock=Open**.

Create=*option* — where *option* is one of the following:

- **Always** The Component is always created. If the Component already exists in the card, the Application Loader signals an error and fails.
- **Once** If the Component doesn't already exist in the card, it is created. Otherwise the attributes of the existing Component are checked against the attributes specified in the Component definition; if they don't match, the Application Loader signals an error and fails. No such check is performed on the Component's data.
- **Update** If the Component doesn't already exist in the card, it is created. If the Component already exists, its attributes and data are updated to match the attributes specified in the Component definition.

Never The Component is never created. If the Component does not already exist in the card, the Application Loader signals an error and fails. If any attributes are specified in the Component definition, they are checked against the attributes of the existing Component; if they don't match, the Application Loader signals an error and fails.

If no **Create** attribute is present in a Component Definition, the default is **Create=Update** for directories, and **Create=Always** for other Component types (but this default can be overridden by **Option Create**=*option*).

These attributes will be referred to as *common-attribute* in the following paragraphs.

5.4.2 Directory Definition

Dir *name$* [*common-attribute common-attribute*...]
[*common-attribute common-attribute*... | *component-definition* | *loader-command*]
End Dir [**Lock**=*ACR*]

component-definition is one of:
Directory Definition
Data File Definition
Application File Definition
ACR Definition
Privilege Definition
Flag Definition
Key Definition

See **5.4.9 Loader Commands** for information on *loader-command*.

The reason that "**End Dir Lock**=*ACR*" may be useful is that it lets you assign a Lock to a Directory that depends on a Key or an ACR that belongs to the Directory itself. For instance,

```
Dir "MyApp"
  Key "MyKey" Lock=Never Usage=kuExtAuth Algorithm=AlgAes128
    "(16-byte secret)"
End Dir Lock = Read:Always; Write:ExtAuth("MyKey")
```

5.4.3 Data File Definition

File *name$* [*attribute attribute*...]
[*attribute attribute*... | *data* | **Input** *inputfile*]
[*attribute attribute*... | *data* | **Input** *inputfile*]
...

attribute *common-attribute* | **Len**=*blocklen*
As a special case, **Len=0** sets *blocklen* to the initial length of the file.

data Data to be stored in the file. See **4.11.2 File Definition** for details.

Input *inputfile* Name of file to be included byte-for-byte in the BasicCard file.

5.4.4 Application File Definition

This is a special case of a Data File Definition. It defines a file which is to contain the compiled code and data of the Application.

Application *name$* [*attribute attribute*...]
[*attribute attribute*...]
[*attribute attribute*...]

attribute *common-attribute* | **Len**=*blocklen*

No data statement is allowed. An Application File must be allocated in a single contiguous block, which the compiler ensures by setting *blocklen* to the length of the file, as if by **Len=0**; so although **Len**=*blocklen* is allowed here, it should usually be absent.

5.4.5 ACR Definition

ACR *name$* [*common-attribute common-attribute...*]
[*common-attribute common-attribute... | condition*]
[*common-attribute common-attribute... | condition*]
...

condition	One of the following:	*When satisfied*
	Always	Always
	Never	Never
	ACR **And** *ACR* **And** ... **And** *ACR*	If all *ACR*'s in the list are satisfied
	ACR **Or** *ACR* **Or** ... **Or** *ACR*	If at least one *ACR* in the list is satisfied
	qualified-list	See below
	Not *ACR*	If *ACR* is not satisfied
	(*ACR*)	If *ACR* is satisfied
	Write Once	If the Component data field is empty
	Verify (*Key*)	If the **VERIFY** command has been called with *Key*
	ExtAuth (*Key*)	If the **EXTERNAL AUTHENTICATE** command has been called with *Key*
	SMEnc (*Key*)	If the **START ENCRYPTION** command has been called with *Key* for an Encryption algorithm (**EAX, AES, DES**)
	SMMac (*Key*)	If the **START ENCRYPTION** command has been called with *Key* for an Authentication algorithm (**OMAC**)
	Privilege (*Privilege*)	If the current Application file (or the Terminal program for external access) has been granted the given *Privilege*
	Flag (*Flag*)	If the given *Flag* is set
	Signed (*Key*)	If the current Application file was signed using *Key*, in an **AUTHENTICATE FILE** command or during Secure Transport
	Application (*File*)	If *File* is the current Application
	SecTrans (*Key*)	If Secure Transport with *Key* is active

qualified-list has the form

access-type-list **:** *ACR* **;** *access-type-list* **:** *ACR* **;** ... [*access-type-list* **:**] *ACR*

where *access-type-list* is a list of access types (**Read**, **Write**, **Execute**, **Delete**, **Grant**) separated by commas. If the last *ACR* in the list is not preceded by an *access-type-list*, it applies to all access types not previously mentioned. If every *ACR* is preceded by an *access-type-list*, then access types not occurring in the list are forbidden.

The corresponding list in **5.8.2 ACRs** gives the binary data format of these ACR types.

The *condition* (i.e. the meaning of the ACR) must occur on a single line, except that multiple *access-type-list* specifications may be split into separate lines. For example:

```
ACR "MyACR" Lock=Never
    Read, Execute: Always
    Write: Verify ("MyPassword")
    ExternalAuthenticate ("MyKey")
```

Here, **ExternalAuthenticate ("MyKey")** becomes the access condition for the unspecified access types (**Delete** and **Grant**).

5.4.6 Privilege Definition

A Privilege has no special attributes, and no data:

Privilege *name$* [*common-attribute common-attribute*...]
[*common-attribute common-attribute*...]

5.4.7 Flag Definition

Flag *name$* [=*value*] [*attribute attribute*...]
[*attribute attribute*...]

value	The initial value of the Flag (the Flag will be set if *value* is non-zero).
attribute	*common-attribute* | **SetAttr**=*bitmask*

The *bitmask* values are defined in **5.8.4 Flags**.

5.4.8 Key Definition

Key *name$* [(*error-counter*[, *reset-value*])] [*attribute attribute*...]
[*attribute attribute*... | *data*]
[*attribute attribute*... | *data*]
...

error-counter The initial value of the Key's Error Counter.

reset-value The reset value of the Key's Error Counter. If absent, it is set equal to *error-counter*.

attribute *common-attribute* | **Usage**=*usage-list* | **Algorithm**=*algorithm-list*

data The value of the Key. This is a **Binary Data Field**, which can take the following forms:

- a **String** constant
- **LCIndexedKey** (*LookupTime*, *Index*)

  The Key takes its value from a **Declare Key** *Index* statement (see **3.17.3 Key Declaration**). *LookupTime* is one of the values **ltCompileTime** or **ltLoadTime** defined in COMPONNT.DEF. If **ltCompileTime**, the Key is evaluated by the compiler from a **Declare Key** statement in the source code; if **ltLoadTime**, the Key is evaluated by the Application Loader from a **Declare Key** statement read in an **LCReadKeyFile** command (see **5.4.9 Loader Commands**).
- **LCSerialNumber** (*LookupTime*)

  The Key takes the value of the 8-byte Serial Number of the card. *LookupTime* is one of the values **ltCompileTime** or **ltLoadTime** defined in COMPONNT.DEF. If **ltCompileTime**, the compiler uses the Serial Number defined in the command-line parameter **–Nxxxxxxxxxxxxxxxx**, where each **x** is a hexadecimal digit. If **ltLoadTime**, the Application Loader asks the card for its Serial Number via the **GET APPLICATION ID** command.

  Notes

  1. This feature is expected to be more useful as the *Seed* parameter to **LCBuildKey** than as a way of assigning a card's Serial Number to a Key. See **5.5 Secure Transport** for an example.
  2. A simulated BasicCard has the Serial Number **0123456789ABCDEF**. The **ZCMDCARD** BasicCard debugger uses this value when compiling a MultiApplication BasicCard program. To specify a different value, the **ZCMBASIC** command-line compiler must be used.
- **LCBuildKey** (*Key*, *Len*, *Seed*)

  This function generates *Len* bytes of data from *Key* and *Seed*, using the **SHA-1** Secure Hash Algorithm. The *Seed* parameter is itself a Binary Data Field, which may take any of the forms defined in this paragraph. For example, if *Key* is a Master Key known only to the card issuer, and *Seed* is the card's Serial Number,

then this function can be used to generate card-specific keys, for Secure Transport and other uses. See **5.5 Secure Transport** for an example of this.

- **LCKey** (*Key*)

  This function returns the value of *Key*.

- **LCPublicKey** (*PrivateKey*, *Algorithm*)

  The Key takes the value of the Public Key corresponding to the given *PrivateKey*. The *PrivateKey* parameter is a Binary Data Field, which the compiler must be able to evaluate (i.e. *LookupTime*=**ltLoadTime** is not allowed). *Algorithm* must be **AlgEC167** or **AlgEC211**; the resulting Public Key will be 21 (resp. 27) bytes long. *PrivateKey* can be any length, although it should usually consist of 21 (resp. 27) random bytes.

  The *PrivateKey* parameter is not stored in the Image file.

Multiple *data* statements are allowed, as long as they can all be evaluated at compile time; the values are concatenated.

usage-list is a list of Key Usage values, separated by commas. The values specify the uses to which the key may be put. In general, for maximum security, it is advisable to avoid using a given key for more than one purpose. The following Key Usage values are defined in COMPONNT.DEF:

Const kuVerify	**= 1**	Password Verification
Const kuExtAuth	**= 2**	External Authentication
Const kuSMEnc	**= 3**	Secure Messaging with Encryption algorithm
Const kuSMMac	**= 4**	Secure Messaging with Authentication algorithm
Const kuSign	**= 5**	Digital Signature and File Authentication
Const kuIntAuth	**= 6**	Internal Authentication
Const kuSecTrans	**= 7**	Secure Transport of Files and Keys

algorithm-list is a list of Algorithm IDs, separated by commas. The IDs specify the cryptographic algorithms that the key may be used with. The following Algorithm IDs, defined in AlgID.DEF, are accepted:

Const AlgSingleDesCrc = &H23
Const AlgTripleDesEDE2Crc = &H24
Const AlgTripleDesEDE3Crc = &H25

Const AlgAes128 = &H31
Const AlgAes192 = &H32
Const AlgAes256 = &H33

Const AlgEaxAes128 = &H41
Const AlgEaxAes192 = &H42
Const AlgEaxAes256 = &H43

Const AlgOmacAes128 = &H81
Const AlgOmacAes192 = &H82
Const AlgOmacAes256 = &H83

Const AlgEC167 = &HC1
Const AlgEC211 = &HC2

5.4.9 Loader Commands

Loader Commands are directives to the Application Loader. To use Loader Commands:

#Include LOADCOMM.DEF

The ZC-Basic compiler embeds the Loader Commands in the Image file. The Application Loader reads them from the Image file and executes them, in the order that they occur in the Application Loader Definition Section. They will typically be interleaved with Component Definitions. In the list of Loader Commands given below, the parameters take the following form:

File A filename or File Reference number

Key, *Privilege* Either a constant string containing the pathname of a previously defined Component, or a constant integer which is the Reference number of a previously defined Component. (Reference numbers are assigned with the **Ref**=*ref* attribute.)

Algorithm A cryptographic algorithm ID. A list of algorithm IDs can be found in the previous section**.**

LCReadKeyFile (*filename$*)

Read the Key file into the **Key()** array. The Key file must be present on the host computer when the Application Loader runs. This is useful in conjunction with the *index* parameter in a Key Definition – see **5.4.8 Key Definition**.

LCEC167SetCurve (*DomainParams* **As String*64**)

DomainParams is a string constant that contains a copy of an **EC167DomainParams** structure. File EC167CRV.STR in the Lib\Curves directory contains string constants **EC167Curve1String** through **EC167Curve5String** for the five pre-defined Elliptic Curves. This procedure must be called before using 167-bit Elliptic Curve operations in the Application Loader Section.

LCEC211SetCurve (*DomainParams* **As String*82**)

DomainParams is a string constant that contains a copy of an **EC211DomainParams** structure. File EC211CRV.STR in the Lib\Curves directory contains string constants **EC211Curve1String** through **EC211Curve5String** for the five pre-defined Elliptic Curves. This procedure must be called before using 211-bit Elliptic Curve operations in the Application Loader Section.

LCStartSecureTransport (*Key*, *Algorithm*)

Start Secure Transport of Files and Keys, using the given Key and Algorithm. All Files and Keys will be stored in the Image File in encrypted form, for decryption by the BasicCard. This deactivates the current Application in the card, and disables Application selection until **LCEndSecureTransport**() is called. See **5.5 Secure Transport** and **8.7.34 The SECURE TRANSPORT Command** for more information.

Valid algorithms: **AlgEaxAes128**, **AlgEaxAes192**, **AlgEaxAes256**.

LCEndSecureTransport()

End Secure Transport of Files and Keys.

LCStartEncryption (*Key*, *Algorithm*)

Call the **START ENCRYPTION** command (see **8.7.11**) with the given Key and Algorithm.

All algorithms from **AlgSingleDesCrc** (**&H23**) to **AlgOmacAes256** (**&H83**) are valid.

LCEndEncryption()

Call the **END ENCRYPTION** command (see **8.7.12**).

LCExternalAuthenticate (*Key*, *Algorithm*)

Call the **EXTERNAL AUTHENTICATE** command (see **8.7.17**) with the given Key and Algorithm.

Valid algorithms: **AlgSingleDesCrc**, **AlgTripleDesEDE2Crc**, **AlgTripleDesEDE3Crc**, **AlgAes128**, **AlgAes192**, **AlgAes256**.

LCInternalAuthenticate (*Key*, *Algorithm*)

Call the **INTERNAL AUTHENTICATE** command (see **8.7.18**) with the given Key and Algorithm.

Valid algorithms: **AlgSingleDesCrc**, **AlgTripleDesEDE2Crc**, **AlgTripleDesEDE3Crc**, **AlgAes128**, **AlgAes192**, **AlgAes256**.

LCVerify (*Key*)

Call the **VERIFY** command (see **8.7.19**) with the given Key.

LCGrantPrivilege (*Privilege*, *File*)

Call the **GRANT PRIVILEGE** command (see **8.7.30**) with the given Privilege and File.

LCAuthenticateFile (*Key*, *Algorithm*, [*PrivateKey*,] *File*)

Call the **AUTHENTICATE FILE** command with the given parameters. The signature is computed at compile time, so the Key and the contents of the File must be available to the compiler. The *PrivateKey* parameter is required if *Algorithm* is **AlgEC167** or **AlgEC211**. See **5.7 File Authentication** and **8.7.31The AUTHENTICATE FILE Command** for more information.

Valid algorithms: **AlgOmacAes128**, **AlgOmacAes192**, **AlgOmacAes256**, **AlgEC167**, **AlgEC211**.

LCCheckSerialNumber ()

Check that the card's Serial Number matches that specified in the compiler's **–N** parameter. If not, the Application Loader issues an appropriate error message and fails. The Application Loader uses the **GET APPLICATION ID** command (see **8.7.10**) to read the card's serial number.

5.5 Secure Transport

The MultiApplication BasicCard allows an Application to be loaded at any time. To control the conditions under which this happens, you can set access conditions on the directories of the card, using ACR's. And to ensure the secrecy of the Files and Keys that are loaded, you can use the Secure Transport mechanism. This encrypts the data fields of all Files and Keys in the Image file, using a Key known only to the card and to the issuer. The Application Loader does not need to know this Key, so the encrypted data remains secret.

5.5.1 An Example

The Secure Transport Key will typically be loaded into the card by the card issuer, at card initialisation time. This is a secure environment, so the data need not be encrypted. The following example creates a Secure Transport Key in the card that depends on the card's Serial Number. First, generate a Master Key file using the KEYGEN utility (see **6.9.4 The Key Generator KEYGEN.EXE**). For example:

```
KEYGEN –K100(16) MK.DAT
```

Next, use the Master Key to build a Secure Transport Key for each card:

```
#Include COMPONNT.DEF
#Include LOADCOMM.DEF

#Include MK.DAT

Dir "\" Create=Update

  Key "Master Key" Create=Never
    LCIndexedKey (ltCompileTime, 100)

  Key "Secure Transport Key" Lock=Never
    Usage=kuSecTrans Algorithm=AlgEaxAes128
    LCBuildKey ("Master Key", 16, LCSerialNumber (ltLoadTime))

End Dir Lock Read:Always; Write:SecTrans("Secure Transport Key")
```

Key "**Master Key**" is needed by the Application Loader, and so it must be stored (unencrypted) in the Image file. As this Image file is only used at card initialisation time, this does not compromise the Key's security. Key "**Secure Transport Key**" is calculated by the Application Loader, using the Serial Number that it reads from the card; only this Key is loaded into the card.

(Instead of including **MK.DAT** at compile time, it could have been read at load time, as follows:

```
Call LCReadKeyFile ("MK.DAT")
Key "Master Key" Create=Never
  LCIndexedKey (ltLoadTime, 100)
```

In a secure environment, there is nothing to choose between these two methods.)

Create=Update is required in the Directory Definition, because we change the ACR attribute of the root directory to **Read:Always; Write:SecTrans("Secure Transport Key")**. This ensures that only Applications compiled with Secure Transport enabled can be loaded into the card.

Now the card contains a Secure Transport Key, and can be issued to customers. To load an Application into the card at a later time (and in a different place):

```
#Include COMPONNT.DEF
#Include LOADCOMM.DEF

#Include MK.DAT

Dir "\"

  Key "Master Key" Create=Never
    LCIndexedKey (ltCompileTime, 100)

  Key "Secure Transport Key" Ref=1 Create=Never
    LCBuildKey ("Master Key", 16,_
      LCSerialNumber (ltCompileTime))

  Call LCStartSecureTransport (1, AlgEaxAes128)

    Rem  Load the Application here...

  Call LCEndSecureTransport()

End Dir
```

This must be compiled with the card's Serial Number specified in the command line, with the parameter **–Nxxxxxxxxxxxxxxxx**. (The card's Serial Number is an 8-byte string, returned by the command **GET APPLICATION ID** with **P2=3** – see **8.7.10 The GET APPLICATION ID Command**.) Neither of the Keys is stored in the Image file. The Application's Files and Keys are stored in encrypted form, using a Key known only to the card issuer and the BasicCard, so the Image file can safely be sent to the customer, for example as an e-mail attachment.

5.5.2 Automatic File Authentication

The encryption algorithm used, **EAX**, also authenticates the data it encrypts. So the Secure Transport mechanism can be used to authenticate Files "for free". To do this, simply set

Usage = kuSecTrans, kuSign

when the Secure Transport Key is created. Then all downloaded Files will automatically be flagged as Signed by the Secure Transport Key. This means that the Access Control Rule

Signed ("Secure Transport Key")

will be satisfied whenever the signed Application is running.

5.6 Secure Messaging

Secure Messaging is the encryption or authentication of commands and responses. This is handled in the BasicCard family by the **START ENCRYPTION** and **END ENCRYPTION** commands. The MultiApplication BasicCard is no exception, but the command parameters are slightly different, due to the different way that Keys are represented. In a Terminal program or a single-application BasicCard, a Key is indexed by a key number from 0 to 255, and Secure Messaging is activated by

Call StartEncryption (P1=*key*, **P2=***algorithm*, **Rnd)**

if the encryption algorithm requires four bytes of initialisation data, or

Call ProEncryption (P1=*key*, **P2=***algorithm*, **Rnd, Rnd)**

if eight bytes are required (for Triple DES and AES-based algorithms). The Terminal program interpreter has access to the key, and automatically activates Secure Messaging when it sees the **START ENCRYPTION** command.

In the MultiApplication BasicCard, the following steps are required:

- find the CID of the Key from its name, using **FindComponent**;
- tell the Terminal program interpreter the value of the Key with the given CID, using **AddIndexedKey**;
- call the **START ENCRYPTION** command.

The following procedure, defined in COMMANDS.DEF, performs the necessary steps:

```
Sub SMEncryptionByName (KeyName$, KeyVal$, Algorithm@)
```

If you know the CID, you can save time by calling the following procedure:

```
Sub SMEncryptionByCID (KeyCID%, KeyVal$, Algorithm@)
```

The source code for these procedures is available in COMMANDS.DEF.

5.7 File Authentication

This section illustrates File Authentication using **OMAC** Message Authentication and **EC211** Elliptic Curve cryptography. It shows how to configure a card so that only authenticated files can be loaded as Applications, and how to authenticate an Application so that it can be loaded in such a card. The source files described here are available in the `BasicCardPro\Examples\AuthFile` directory.

OMAC authentication is faster than Elliptic Curve authentication, but Elliptic Curve authentication is more secure, as it doesn't require the Authentication Key to be stored in the BasicCard.

See **5.5.2 Automatic File Authentication** for another method of File Authentication (which, like **OMAC**, requires the Authentication Key to be stored in the BasicCard).

5.7.1 File Authentication Using OMAC

Suppose we decide to use the algorithm **AlgOmacAes128** (**OMAC** with **AES-128**) to authenticate files. For this we need a 16-byte Authentication Key, which we can generate with the KEYGEN utility:

KeyGen –K1(16) OmacKey

This creates a file **OmacKey.bas** containing a 16-byte Key. The following source code in **OmacInit.bas** configures the BasicCard so that only files authenticated with this Key can be loaded:

```
Option Explicit
#Include COMPONNT.DEF
#Include OmacKey.bas

Dir "\"

  Key "Authentication Key" Lock=Never
    Usage=kuSign Algorithm=AlgOmacAes128
    LCIndexedKey (ltCompileTime, 1) ' Key(1) from OmacKey.bas

  ACR "Executable" Lock=Read:Always ' Special name "Executable"
    Signed ("Authentication Key")

End Dir
```

We can compile this and load it into a simulated BasicCard file **OmacCard.img** with the following commands:

ZCMBasic –CM –OI OmacInit
ZCMSim –C\BasicCardPro\MultiApp\ZC65_A.mcf –AOmacInit –D –WCOmacCard

Now we can create and authenticate a simple Application in **OmacApp.bas**:

```
Option Explicit
#Include COMPONNT.DEF
#Include LOADCOMM.DEF
#Include OmacKey.bas
```

```
Dir "\"

  Key "Authentication Key" Ref=100 Create=Never
    LCIndexedKey (ltCompileTime, 1)

  Application "MyApp" ' No Lock until file is authenticated
  Call LCAuthenticateFile (100, AlgOmacAes128, "MyApp")
  Application "MyApp" Create=Update Lock=Execute:Always

End Dir

Command &HA0 &H00 TestMyApp (S$)
  S$ = "TestMyApp"
End Command
```

The Application Loader doesn't need to know the value of "**Authentication Key**", so it is not stored in the Image file. (The compiler issues a warning whenever a Key that is used for File Authentication is also stored in the Image file.) Now we compile this Application and load it into **OmacCard.img**:

ZCMBasic –CM –OI OmacApp
ZCMSim –COmacCard –AOmacApp –D –WC

To check that everything has worked, the following Terminal program **AppTest.bas** selects Application "**MyApp**" and calls its command:

```
Option Explicit
#Include COMMERR.DEF

Declare Command &HA0 &H00 TestMyApp (S$)

ResetCard : Call CheckSW1SW2()
Call SelectApplication ("MyApp") : Call CheckSW1SW2()

Private S$
Call TestMyApp (S$) : Call CheckSW1SW2()
Print S$ ' This shoud print "TestMyApp"
```

To compile and run this program:

ZCMBasic –OI AppTest
ZCMSim –COmacCard AppTest

This should print:

TestMyApp

5.7.2 File Authentication Using Elliptic Curve Cryptography

The MultiApplication BasicCard can authenticate Files with Elliptic Curve algorithms **EC167** and **EC211**. It uses data hashing algorithm **SHA-1** with **EC167**, and **SHA-256** with **EC211**.

This section illustrates File Authentication using the Elliptic Curve algorithm **EC211**. ZeitControl provides five Elliptic Curves for use with this algorithm; we use Curve 3 for this project. First we use the KEYGEN utility to generate a 27-byte Key, for use as our Private Key:

KeyGen –K1(27) EC211Key

This creates a file **EC211Key.bas** containing a 27-byte Key. The following source code in **EC211Init.bas** configures the BasicCard so that only files authenticated with this Key can be loaded. The file "**ECDomainParams**" must be created in the BasicCard; this loads Curve 3 automatically whenever the card is reset:

```
Option Explicit
#Include COMPONNT.DEF
#Include LOADCOMM.DEF

#Include Curves\EC211Crv.Str
#Include EC211Key.Bas ' EC211 Private Key
```

```
Dir "\"

  File "ECDomainParams" Lock=Read:Always
    Rem  Use Curve 3, with 128 pre-computed points:
    #Include Curves\EC211-3.128

  Rem  Let the compiler know the ECDomainParameters:
  Call LCEC211SetCurve (EC211Curve3String)

  Rem  The BasicCard needs the Public Key corresponding to
  Rem  the Private Key (Key(1)) in ECKey.bas:
  Key "ECPublicKey" Lock=Read:Always
    Usage=kuSign Algorithm=AlgEC211
    LCPublicKey (LCIndexedKey (ltCompileTime, 1), AlgEC211)

  ACR "Executable" Lock=Read:Always ' Special name "Executable"
    Signed ("ECPublicKey")

End Dir
```

Only the Public Key is stored in the BasicCard; the Private Key is not required.

We can compile this and load it into a simulated BasicCard file **EC211Card.img** with the following commands:

ZCMBasic –CM –OI EC211Init
ZCMSim –C\BasicCardPro\MultiApp\ZC65_A.mcf –AEC211Init –D –WCEC211Card

Now we can create and authenticate a simple Application in **EC211App.bas**:

```
Option Explicit
#Include COMPONNT.DEF
#Include LOADCOMM.DEF

#Include Curves\EC211Crv.Str
#Include EC211Key.Bas ' EC211 Private Key

Dir "\"

  Call LCEC211SetCurve (EC211Curve3String)

  Key "ECPublicKey" Create=Never

  Application "MyApp" ' No Lock until file is authenticated
  Call LCAuthenticateFile ("ECPublicKey", AlgEC211,_
    LCIndexedKey (ltCompileTime, 1), "MyApp")
  Application "MyApp" Create=Update Lock=Execute:Always

End Dir

Command &HA0 &H00 TestMyApp (S$)
  S$ = "TestMyApp"
End Command
```

No Keys are stored in the Image file; the Private Key is only required by the compiler, and the Public Key is assumed to have already been created in the BasicCard. Now we compile this Application and load it into **EC211Card.img**:

ZCMBasic –CM –OI EC211App
ZCMSim –CEC211Card –AEC211App –D –WC

To check that everything has worked, use the **AppTest** program described in the previous section:

ZCMSim –CEC211Card AppTest

As before, this should print:

TestMyApp

The directory `BasicCardPro\Examples\AuthFile` also contains files **EC167Key.bas**, **EC167Init.bas**, and **EC167App.bas**, to illustrate File Authentication using the **EC167** algorithm.

5.8 Component Details

To use the procedures in the **COMPONENT** System Library (described in **7.4 The COMPONENT Library**), you need to know the internal structure of each Component type. This section describes these structures. Every Component type has attributes, and some Component types have data as well. The format of a Component's attributes depends not only on the Component type, but on whether the attributes are being created, written, or read. All the structures described below are declared as user-defined types in COMPONNT.DEF.

In the **COMPONENT** System Library, attributes are read and written as **String** parameters. The following example shows how to pass a user-defined type in a **String** parameter:

```
#Include COMPONNT.DEF

Function AcrType (CID%) As Byte

  Rem  User-defined type for reading the attributes of an ACR:
  Private Attr As AcrReadAttributes

  Rem  Declare a fixed-length string at the same address:
  Private Attr$ As String*Len(Attr) At Attr

  Rem  Read the attributes into Attr$
  Attr$ = ReadComponentAttr (CID%)

  Rem  Now the attributes can be accessed as structure members:
  AcrType = Attr.AcrType@

End Function
```

5.8.1 Files

In the MultiApplication BasicCard, a File is just a Component of type **ctFile**. It can be accessed as a File, via the standard ZC-Basic file commands, or as a Component, via the **COMPONENT** System Library procedures.

File Attribute Format

The Attribute format depends on whether the Component is a Directory or a Data file.

For **CreateComponent**:

Offset	*Length*	*Directory*	*Data file*	
0	**2**	`ACRCID%`	`ACRCID%`	CID of Component's ACR
2	**1**	`Attributes@`	`Attributes@`	&H80 for Directory; 0 for Data file
3	**2**		`BlockLen%`	Length of allocation block

For **WriteComponentAttr**:

Offset	*Length*	*Directory*	*Data file*	
0	**2**	`ACRCID%`	`ACRCID%`	CID of Component's ACR

For **ReadComponentAttr**:

Offset	*Length*	*Directory*	*Data file*	
0	**2**	`ACRCID%`	`ACRCID%`	CID of Component's ACR
2	**1**	`Attributes@`	`Attributes@`	&H80 for Directory; 0 for Data file
3	**2**		`BlockLen%`	Length of allocation block
5	**2**		`FileLen%`	Length of file

Six corresponding user-defined types can be found in COMPONNT.DEF:

```
DirectoryCreateAttributes      DataFileCreateAttributes
DirectoryWriteAttributes       DataFileWriteAttributes
DirectoryReadAttributes        DataFileReadAttributes
```

File Data Format

File data can not be read or written using procedures from the Component System Library. The standard File I/O commands must be used instead.

5.8.2 ACRs

An Access Control Rule, or ACR, defines the access conditions for a Component. An ACR may have a name, or it may be anonymous.

Anonymous ACRs allow complex ACRs to be built in a single statement; the compiler and the Application Loader construct the necessary sub-components automatically. For example, the statement

File “ABC” Lock = Read: Always; Write: Write Once; Delete: Verify (“MyPassword”)

in a Component Definition Section causes the following five Anonymous ACRs to be created:

Always
Write Once
Verify (“MyPassword”)
Read: Always; Write: Write Once; Delete: Verify (“MyPassword”)

When an Anonymous ACR is created, the BasicCard looks for a match among its existing Anonymous ACRs. If a match is found, the existing ACR is used. This arrangement relies on the fact that an Anonymous ACR can never be overwritten or deleted. An Anonymous ACR must have an **ACRCID%** equal to zero.

ACR Attribute Format

For **CreateComponent** and **ReadComponentAttr**:

Offset	*Length*		
0	**2**	**`ACRCID%`**	CID of Component’s ACR
2	**1**	**`AcrType@`**	As defined in *ACR Data Format* below

For **WriteComponentAttr**:

Offset	*Length*		
0	**2**	**`ACRCID%`**	CID of Component’s ACR

Three corresponding user-defined types can be found in COMPONNT.DEF:

`AcrCreateAttributes`
`AcrReadAttributes`
`AcrWriteAttributes`

ACR Data Format

The format of ACR data depends on the ACR type, which is one of the following:

Type	*Name*	*Data*	*When satisfied*
&H01	**acrAlways**	None	Always
&H02	**acrNever**	None	Never
&H03	**acrAnd**	*ACR, ACR,...*	If all *ACR*’s in the list are satisfied
&H04	**acrOr**	*ACR, ACR,...*	If at least one *ACR* in the list is satisfied
&H05	**acrQualified**	(*AT,ACR*), (*AT,ACR*),...	If the *ACR* corresponding to the current Access Type *AT* is satisfied
&H06	**acrNot**	*ACR*	If *ACR* is not satisfied
&H07	**acrIndirect**	*ACR*	If *ACR* is satisfied
&H10	**acrWriteOnce**	None	If the Component data field is empty
&H20	**acrVerify**	*Key*	If the **VERIFY** command has been called with *Key*
&H30	**acrExtAuth**	*Key*	If the **EXTERNAL AUTHENTICATE** command has been called with *Key*
&H40	**acrSMEnc**	*Key*	If the **START ENCRYPTION** command has been called with *Key* for an Encryption algorithm (**EAX, AES, DES**)
&H50	**acrSMMac**	*Key*	If the **START ENCRYPTION** command has been called with *Key* for an Authentication algorithm (**OMAC**)

&H60	**acrPrivilege**	*Privilege*	If the current Application file (or the Terminal program for external access) has been granted the given *Privilege*
&H70	**acrFlag**	*Flag*	If the given *Flag* is set
&H80	**acrSigned**	*Key*	If the current Application file was signed using *Key*, in an **AUTHENTICATE FILE** command or during Secure Transport
&H90	**acrApp**	*File*	If *File* is the current Application
&HA0	**acrSecTrans**	*Key*	If Secure Transport with *Key* is active

ACR, *Key*, *Privilege*, and *Flag* parameters are two-byte CID's. *AT* is a one-byte Access Type from the following list (the constants are defined in COMPONNT.DEF):

&H01	**atRead**
&H02	**atWrite**
&H04	**atExecute**
&H08	**atDelete**
&H10	**atGrant**

The corresponding list in **5.4.5 ACR Definition** gives the definition syntax of these ACR types, for use in the Application Loader Definition Section.

5.8.3 Privileges

A Privilege is essentially just a name. It has no data, and its only attribute is its **ACRCID%**. The corresponding user-defined type `PrivilegeAttributes` can be found in COMPONNT.DEF.

5.8.4 Flags

A Flag can be either On or Off, and its value can be tested as an access condition in an ACR.

Flag Attribute Format

By default, a flag is cleared whenever the card is reset. The following attribute bits are defined in COMPONNT.DEF:

&H02	**faPermanent**	The flag retains its value when the card is reset or powered down.
&H04	**faClearOnNewApp**	The flag is cleared whenever an Application is selected.
&H08	**faClearOnCommand**	The flag is cleared whenever the card receives a command.

A Flag's attributes are the same for all library procedures:

Offset	*Length*		
0	**2**	`ACRCID%`	CID of Flag's ACR
2	**1**	`Attributes@`	The Flag's attribute bits

The corresponding user-defined type `FlagAttributes` can be found in COMPONNT.DEF.

Flag Data Format

The value of the Flag is stored in bit 0 of the **Attributes@** byte, but it can also be read or written as data, as follows:

- **CreateComponent** — The *data$* parameter must be empty; the initial value of the Flag is taken from the **Attributes@** byte.
- **WriteComponentAttr** — The new value of the Flag is taken from the **Attributes@** byte.
- **ReadComponentAttr** — The value of the Flag is not returned.
- **WriteComponentData** — The *data$* parameter contains a single byte. The Flag is set if this byte is non-zero.
- **ReadComponentData** — A string of length 1 is returned, equal to **Chr$**(0) or **Chr$**(1).

5.8.5 Keys

A Key has three configurable attributes in addition to its **ACRCID%**: a Key Usage Mask, an Algorithm Mask, and an Error Counter.

Key Usage Mask

In general, a cryptographic Key should only be used for a single purpose. In the MultiApplication BasicCard, each Key has a Key Usage Mask that specifies what the key can be used for. The Key Usage values **kuVerify** etc., defined in COMPONNT.DEF, have corresponding bitmasks, as follows:

Constant	*Value*	*Mask*	*Usage*
kuVerify	**1**	**&H0001**	**VERIFY** command
kuExtAuth	**2**	**&H0002**	**EXTERNAL AUTHENTICATE** command
kuSMEnc	**3**	**&H0004**	**START ENCRYPTION** with Encryption algorithm
kuSMMac	**4**	**&H0008**	**START ENCRYPTION** with Authentication algorithm
kuSign	**5**	**&H0010**	**AUTHENTICATE FILE**
kuIntAuth	**6**	**&H0020**	**INTERNAL AUTHENTICATE** command
kuSecTrans	**7**	**&H0040**	**SECURE TRANSPORT** command

Algorithm Mask

As well as the Key Usage mask, a Key has an Algorithm Mask that specifies the cryptographic algorithms that the key may be used for. The Algorithm IDs defined in AlgID.DEF have corresponding bitmasks, as follows:

Algorithm ID	*Value*	*Mask*	*Algorithm*
AlgSingleDesCrc	**&H23**	**&H0001**	Single **DES** with 8-byte key
AlgTripleDesEDE2Crc	**&H24**	**&H0002**	Triple **DES-EDE2** with 16-byte key
AlgTripleDesEDE3Crc	**&H25**	**&H2000**	Triple **DES-EDE3** with 24-byte key
AlgAes128	**&H31**	**&H0004**	**AES** with 16-byte key
AlgAes192	**&H32**	**&H0008**	**AES** with 24-byte key
AlgAes256	**&H33**	**&H0010**	**AES** with 32-byte key
AlgEaxAes128	**&H41**	**&H0020**	**EAX** using **AES** with 16-byte key
AlgEaxAes192	**&H42**	**&H0040**	**EAX** using **AES** with 24-byte key
AlgEaxAes256	**&H43**	**&H0080**	**EAX** using **AES** with 32-byte key
AlgOmacAes128	**&H81**	**&H0100**	**OMAC** using **AES** with 16-byte key
AlgOmacAes192	**&H82**	**&H0200**	**OMAC** using **AES** with 24-byte key
AlgOmacAes256	**&H83**	**&H0400**	**OMAC** using **AES** with 32-byte key
AlgEC167	**&HC1**	**&H0800**	**EC-167** Elliptic Curve Cryptography
AlgEC211	**&HC2**	**&H1000**	**EC-211** Elliptic Curve Cryptography

Error Counter

To prevent attempts to guess the value of a Key by repetition, a Key should normally be configured with an Error Counter. This is a counter that is decremented by one each time the Key is unsuccessfully used in a cryptographic algorithm. If the counter reaches zero, the Key is disabled until it is reinstated via a **WriteComponentAttr** command. Whenever the Key is successfully used, its Error Counter is reset to the configured value; so the initial value of the Error Counter is the number of *consecutive* unsuccessful uses that are allowed before the Key is disabled.

If this Error Counter mechanism is not required, set **ECResetValue@** to zero, and the Key will never be disabled.

Key Attribute Format

The format of the *attr$* parameter is the same for all library procedures:

Offset	*Length*		
0	**2**	`ACRCID%`	CID of Key's ACR
2	**2**	`UsageMask%`	The Key Usage Mask
4	**2**	`AlgorithmMask%`	The Algorithm Mask
6	**1**	`ErrorCounter@`	The current value of the Error Counter
7	**1**	`ECResetValue@`	The Error Counter value after successful use

The corresponding user-defined type `KeyAttributes` can be found in COMPONNT.DEF.

6. Support Software

This document describes Version 5.08 of the ZeitControl MultiDebugger software support package. All the software described in this chapter is available free of charge from our web site at www.BasicCard.com.

6.1 Hardware Requirements

No special hardware is required to develop programs in ZC-Basic – the support software can simulate the BasicCard inside your PC, so you can compile and test software on any system running Windows® 98 or later.

Once the software is written and tested, you will need a PC/SC-compatible card reader, and one or more BasicCards. ZeitControl offers a selection of card readers – see our web site for details. A development kit containing CyberMouse reader, BasicCards, and printed documentation is available from ZeitControl – contact us at Sales@ZeitControl.de.

6.2 Installation

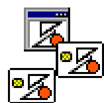
Please obtain the latest version of our development software before installing it. The latest version is available free of charge from our web site at www.BasicCard.com. Installation instructions can be found there.

To install the BasicCard software from the CD, run the program `BasicPro\Setup.exe`. The software is installed in the directory `C:\BasicCardPro` unless you specify a different destination.

6.3 File Types

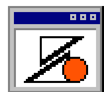
To use the development software effectively, it helps to have a clear idea of the roles played by the different types of files used by the system. We can arrange the files in a three-level hierarchy: *Project Files*, *Program Files*, and *Source Files*. There is a corresponding software hierarchy: development environment **ZCPDE**; debuggers **ZCMDTERM/ZCMDCARD**; and compiler **ZCMBASIC**:

Level 1: Project Files

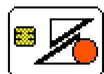


***.ZCP** Project Files
ZCPDE.EXE ZeitControl Professional Development Environment

Level 2: Program Files

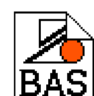


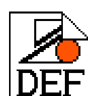
***.ZCT** Terminal Program Files
ZCMDTERM.EXE ZeitControl Terminal Program Debugger



***.ZCC** BasicCard Program Files
ZCMDCARD.EXE ZeitControl BasicCard Program Debugger

Level 3: Source Files





***.BAS** ZC-Basic Source Files
***.DEF** ZC-Basic Definition Files
ZCMBASIC.EXE ZeitControl ZC-Basic Compiler

This hierarchy is not strictly enforced – you can run the debuggers outside the development environment if you just want to test a simple program; or you can compile a program from the Win32 console command line if you don't need to debug it.

***.ZCP** *Project Files*

A Project File simply lists all the Program Files that belong to a single project. What constitutes a project is up to you; the simplest projects contain one Terminal Program File and one BasicCard Program File, but bigger projects may contain two or three Terminal Program Files and a dozen or so BasicCard Program Files.

***.ZCT** *Terminal Program Files*

A Terminal Program File contains:

- compiler options for a Terminal Program, including Source File, Include Paths, and Pre-Defined Constants;
- run-time options, such as initial COM Port and Terminal Program command-line parameters;
- the positions of the various windows.

***.ZCC** *BasicCard Program Files*

A BasicCard Program File can be thought of as a Virtual BasicCard. It contains:

- compiler options for a BasicCard Program, including Source File (or multiple Source Files for a MultiApplication BasicCard), Card Type, Include Paths, and Pre-Defined Constants;
- the EEPROM contents of the Virtual BasicCard;
- the COM Port of the Virtual Card Reader that the program occupies;
- the positions of the various windows.

You can have more than one BasicCard Program File for a given source program, each with its own Virtual EEPROM. And you can run more than one **ZCMDCARD** BasicCard Debugger at a time, as long as no two debuggers occupy the same Virtual Card Reader COM Port.

***.BAS** *and* ***.DEF** *ZC-Basic Source Files*

In our example programs, we make the distinction between .BAS files, which contain code, and .DEF files, which contain only definitions and declarations. This distinction is purely conventional; the compiler doesn't treat the two file types differently.

ZC-Basic Source Files are described in **Chapter 3: The ZC-Basic Language**.

In addition, the **ZCMBASIC** Compiler produces the following two file types as output (among others – see **6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE** for details):

***.IMG** *Image Files*

An Image File contains a compiled Terminal Program or BasicCard Program, with no symbolic debug information. Its contents are described in **11.1 ZeitControl Image File Format**. Two command-line programs accept Image Files as input (and Debug Files too, if the **.DBG** file extension is explicitly given):

- the **ZCMSIM** P-Code Interpreter, which requires a Terminal Program Image File, and optionally one or more BasicCard Program Image Files;
- the **BCLOAD** Download Program, which downloads a BasicCard Image File to a BasicCard.

See **6.9.2 The P-Code Interpreter ZCMSIM.EXE** and **6.9.3 The Card Loader BCLOAD.EXE** for details.

***.DBG** *Debug Files*

A Debug File contains all the information in an Image File, plus symbolic debug information for the debuggers **ZCMDTERM** and **ZCMDCARD**. Its contents are described in **11.2 ZeitControl Debug File Format**.

6.4 Physical and Virtual Card Readers

Whenever you access a BasicCard or a Card Reader from a ZC-Basic Terminal Program, ZeitControl's P-Code Interpreter uses the current value of the **ComPort** variable to determines where to look for the Card Reader. The meaning of the **ComPort** variable depends on the program that contains the P-Code Interpreter: this can be an executable file, the **ZCMSIM** P-Code Interpreter, or the **ZCMDTERM** Terminal Program Debugger.

6.4.1 ComPort in an Executable File

A ZC-Basic program compiled into an executable file accepts the following values for the **ComPort** variable:

1 <= **ComPort <=** 4: Physical Card Reader on serial port COM1-COM4
100 **<= ComPort** <= 199: PC/SC Card Reader – see **3.21.4 PC/SC Functions**
201 **<= ComPort** <= 204: Virtual Card Reader running in the **ZCMDCARD** debugger

6.4.2 ComPort in the ZCMSIM P-Code Interpreter

The **ZCMSIM** P-Code Interpreter accepts the same values for the **ComPort** variable as an executable file, as listed in the previous section. In addition, **ComPort** may be set to any of the **–P** parameters specified on the command line, in which case the corresponding simulated BasicCard is accessed – see **6.9.2 The P-Code Interpreter ZCMSIM.EXE**.

6.4.3 ComPort in the ZCMDTERM Terminal Program Debugger

The **ZCMDTERM** Terminal Program Debugger accepts the following values for the **ComPort** variable:

1 <= **ComPort <=** 4: Physical or Virtual Card Reader
100 **<= ComPort** <= 199: PC/SC Card Reader – see **3.21.4 PC/SC Functions**
201 **<= ComPort** <= 204: Virtual Card Reader running in the **ZCMDCARD** debugger

If 1 <= **ComPort** <= 4, then **ZCMDTERM** has to decide whether to access a Physical or a Virtual Card Reader. It does this on the basis of the settings in the **Options|Terminal Programs...|Card Readers** dialog box. In this dialog box, each of COM1 through COM4 can be set to **Real**, **Auto**, or **Virtual**:

Real Physical Card Reader is accessed
Auto Virtual Card Reader if available, otherwise Physical Card Reader
Virtual Virtual Card Reader running in the **ZCMDCARD** debugger

To enable communication between the Terminal Program and a BasicCard program running in the **ZCMDCARD** BasicCard Program debugger, the **ZCMDCARD** debugger must know which COM Port to attach to. You can specify this in one of two ways:

- in **ZCMDCARD**, via the **Card|Insert in Virtual Reader...** dialog box;
- in **ZCMDCARD** or **ZCPDE**, via the **Options|BasicCard Program...|COM Ports** dialog box.

The first of these is temporary; the second is permanent for the given BasicCard Program File.

6.5 Windows®-Based Software

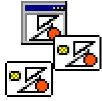
The Windows®-based software consists of the following programs:

- **ZCPDE**, the ZeitControl Professional Development Environment. This program manages projects, creating and maintaining ZeitControl Project files, with **.ZCP** extension. It also contains a built-in text editor.

- **ZCMDTERM**, a source-level symbolic debugger for Terminal programs. It can communicate with one or more **ZCMDCARD** debuggers, and one or more physical card readers. It uses ZeitControl Terminal Program files, with **.ZCT** extension, to store the information that it needs to compile and run Terminal Programs.

- **ZCMDCARD**, a source-level symbolic debugger for BasicCard programs. It waits for commands from the Terminal debugger **ZCMDTERM**, executes the commands under the control of the user, and sends its responses back to the Terminal debugger. It can also download BasicCard programs to a real BasicCard. It uses ZeitControl BasicCard Program files, with **.ZCC** extension, to store the information that it needs to compile and run BasicCard Programs.

6.6 The ZCPDE Professional Development Environment



The **ZCPDE** ZeitControl Professional Development Environment program manages projects, creating and maintaining ZeitControl Project files, with **.ZCP** extension. It also contains a built-in text editor.

6.6.1 ZCPDE File Menu

The **File** menu is for editing text files, and contains no project management functions. It contains the following items:

New	Create a new text file
Open...	Open an existing text file
Open Source File ▸	Open one of the project's source files
Reopen ▸	Open a recently opened text file
Save	Save the current text file
Save As...	Save the current text file under a new name
Save All	Save all modified files
Close	Close the current text file
Close All	Close all current text files
Print...	Print the current text file
Printer Setup...	Set printer options
Exit	Exit the **ZCPDE** program

6.6.2 ZCPDE Edit Menu

The **Edit** menu is for editing text files, and contains no project management functions. It contains the following items:

Undo	Undo the most recent edit operation
Redo	Redo an operation that was cancelled with **Undo**
Cut	Delete text and place it in the clipboard
Copy	Copy text to the clipboard
Paste	Copy text from the clipboard
Delete	Delete text without placing it in the clipboard
Select All	Select the whole text file
Find...	Search for text
Find Next	Find the next occurrence of the most recent search text
Replace...	Search and replace

6.6.3 ZCPDE Project Menu

The **Project** menu contains the project management functions:

New	Create a new project	
Open...	Open an existing project	
Reopen ▸	Open a recently opened project	
Save As...	Save the current project under a different name	
Options	Set the Project Options:	
	Terminal Programs	The project's Terminal Progam Files
	BasicCard Programs	The project's BasicCard Progam Files
	Start Configuration	The programs run by the **Start** item
Start Terminal ▸	Start a Terminal Program in the **ZCMDTERM** debugger	
Start BasicCard ▸	Start a BasicCard Program in the **ZCMDCARD** debugger	
Start	Start all programs in the current project's Start Configuration	
Compile Terminal ▸	Compile a Terminal Program from the current project	
Compile BasicCard ▸	Compile a BasicCard Program from the current project	
Compile Again	Re-compile the most recently compiled program	
Compile All	Compile all the programs in the current project	

6.6.4 ZCPDE Options Menu

The **Options** menu sets the global options for the **ZCPDE** program. It contains a single item, which brings up a multi-page dialog box:

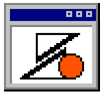
Environment	*Editor*	Set tab width and font
	Compiler	Set Include Path, in Windows® Registry variable **"Software\ZeitControl\BasicCardPro\ZCINC"**
	CardReader	Set default **ComPort**, in Windows® Registry variable **"Software\ZeitControl\BasicCardPro\ZCPORT"**

6.6.5 ZCPDE Help Menu

The **Help** menu contains the following items:

BasicCard Manual	Open this manual on-line
Open Example ▸	Open one of the BasicCard example projects
About...	Display software version number and product information

6.7 The ZCMDTERM Terminal Program Debugger



The **ZCMDTERM** ZeitControl Terminal Program Debugger is a source-level symbolic debugger for Terminal programs. It can communicate with one or more **ZCMDCARD** debuggers, and one or more physical card readers. It uses ZeitControl Terminal Program files, with **.ZCT** extension, to store the information that it needs to compile and run Terminal Programs.

6.7.1 ZCMDTERM File Menu

The **File** menu contains the following items:

New	Create a new Terminal Program File
Open...	Open an existing Terminal Program File
Save	Save the current Terminal Program File
Save As...	Save the current Terminal Program File under a new name
Edit...	Edit a text file in the **ZCPDE** Professional Development Environment
Edit Source ▸	Edit a source file from the current Terminal Program
Compile...	Short cut to the **Options|Terminal Program...|Compiler** dialog box
Exit	Exit the **ZCMDTERM** program

6.7.2 ZCMDTERM View Menu

The **View** menu contains the following items:

Source File ▸	Display a selected source file in the debugger window
Procedure ▸	Display a selected ZC-Basic procedure in the debugger window
Execution Point	Display the code at the current PC
P-Code	Display P-Code instructions and registers in the debugger window
Watches	Open the **Watches** window for monitoring program data
Call Stack	View all active procedures and their local data in the **Call Stack** window
I/O	Open the **I/O** window for monitoring I/O between Terminal and BasicCard

6.7.3 ZCMDTERM Run Menu

The **Run** menu contains the following items:

Run	Start execution from the current PC
Step Over	Execute one instruction, stepping over procedure calls
Step Into	Execute one instruction, stepping into procedure calls
Step Return	Execute until the end of the current procedure
Step to Card	Run until an instruction in a BasicCard program is reached
Step to Cursor	Run to the current cursor position
Restart	Restart the Terminal Program
Pause	Interrupt execution
Evaluate...	Evaluate an expression

Most of these items are also available as short-cut buttons in the debugger window, unless the **Options|Hide Buttons** menu item was selected.

6.7.4 ZCMDTERM Options Menu

The **Options** menu contains the following items:

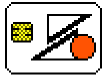
Terminal Program...	Set the Terminal Program options:	
	Compiler	Source file, include paths, etc.
	Run-time	COM port, log file, command-line parameters
	Card Readers	See **6.4.3 ComPort in the ZCMDTERM Terminal Program Debugger**
COM Port...	Short cut to **Terminal Program...|Run-time** dialog box	
Show/Hide Buttons	Show or hide the **Run** menu short-cut buttons	

6.7.5 ZCMDTERM Help Menu

The **Help** menu contains the following items:

BasicCard Manual	Open this manual on-line
About...	Display software version number and product information

6.8 The ZCMDCARD BasicCard Program Debugger



The **ZCMDCARD** ZeitControl BasicCard Program Debugger is a source-level symbolic debugger for BasicCard programs. It waits for commands from the Terminal debugger **ZCMDTERM**, executes the commands under the control of the user, and sends its responses back to the Terminal debugger. It can also download BasicCard programs to a real BasicCard. It uses ZeitControl BasicCard Program files, with **.ZCC** extension, to store the information that it needs to compile and run BasicCard Programs.

6.8.1 ZCMDCARD File Menu

The **File** menu contains the following items:

New	Create a new BasicCard Program File
Open...	Open an existing BasicCard Program File
Save	Save the current BasicCard Program File
Save As...	Save the current BasicCard Program File under a new name
Edit...	Edit a text file in the **ZCPDE** Professional Development Environment
Edit Source ▸	Edit a source file from the current BasicCard Program
Compile...	Short cut to the **Options|BasicCard Program...|Compiler** dialog box
Exit	Exit the **ZCMDCARD** program

6.8.2 ZCMDCARD Application Menu

The **Application** menu is visible if the MultiApplication BasicCard has been selected in the **Options|BasicCard Program...** dialog box. It contains the following items:

Add...	Add an Application to the Application List
Load All	Load all Applications in the Application List into the virtual BasicCard

In addition, it contains a menu item for each Application in the Application List, with the following sub-menu:

View	View the Application's source code
Compile...	Compile the Application
Load...	Load the Application into the virtual BasicCard
Remove...	Remove the Application from the Application List

6.8.3 ZCMDCARD View Menu

The **View** menu contains the following items:

Source File ▸	Display a selected source file in the debugger window
Procedure ▸	Display a selected ZC-Basic procedure in the debugger window
Execution Point	Display the code at the current PC
P-Code	Display P-Code instructions and registers in the debugger window
Watches	Open the **Watches** window for monitoring program data
Call Stack	View all active procedures and their local data in the **Call Stack** window
I/O	Open the **I/O** window for monitoring I/O between Terminal and BasicCard
File System	View files and directories in the BasicCard
Files & Components	View files and components in a MultiApplication BasicCard

6.8.4 ZCMDCARD Run Menu

The **Run** menu contains the following items:

Run	Start execution from the current PC
Step Over	Execute one instruction, stepping over procedure calls
Step Into	Execute one instruction, stepping into procedure calls
Step Return	Execute until the end of the current procedure
Step to Terminal	Run until an instruction in the Terminal program is reached
Step to Cursor	Run to the current cursor position
Pause	Interrupt execution
Evaluate...	Evaluate an expression

Most of these items are also available as short-cut buttons in the debugger window, unless the **Options|Hide Buttons** menu item was selected.

6.8.5 ZCMDCARD Card Menu

The **Card** menu contains the following items:

Insert in Virtual Reader ▸	Attach **ZCMDCARD** to a Virtual Card Reader COM Port
Remove from Virtual Reader	Release the Virtual Card Reader COM Port
Download to Real Card...	Download the BasicCard program to a real BasicCard

6.8.6 ZCMDCARD Options Menu

The **Options** menu contains the following items:

BasicCard Program...	Set the BasicCard Program options:	
	Compiler	Source file, card type, include paths, etc.
	COM Ports	Virtual and Physical Card Reader COM Ports
Show/Hide Buttons	Show or hide the **Run** menu short-cut buttons	

6.8.7 ZCMDCARD Help Menu

The **Help** menu contains the following items:

BasicCard Manual	Open this manual on-line
About...	Display software version number and product information

6.9 Command-Line Software

The following programs are run from a Win32 command-line console (or "DOS box"):

- **ZCMBASIC**, a compiler for the ZC-Basic programming language.
- **ZCMSIM**, a P-Code interpreter that runs compiled ZC-Basic programs. **ZCMSIM** runs a Terminal program, and can run BasicCard programs simultaneously in simulated BasicCards, or communicate via a card reader with genuine BasicCards.
- **BCLOAD**, for downloading P-Code to the BasicCard.
- **KEYGEN**, a program that generates random keys and primitive polynomials for use in encryption.
- **BCKEYS**, for downloading keys to the Compact and Enhanced BasicCards.

Each of these programs takes a filename as its main parameter. Other command-line parameters begin with '–' (minus sign) followed by one or more option letters, sometimes followed by data. No spaces are allowed between the minus sign and the option letters, or between the option letters and the data. Option letters may be upper or lower case.

ZCMBASIC, **ZCMSIM**, and **BCLOAD** support parameter input files: if any command-line parameter has the form '*@filename*', subsequent parameters are read from the given file, one line at a time. Empty lines, and lines whose first non-space character is a single quote, are ignored. To specify a parameter that begins with the '@' character, simply repeat the '@' character; for example, "@@X" is passed to the program as "@X", and is not treated as a parameter file. This feature is also active for executable files created by the **ZCMBASIC** compiler.

Notes:

- Three of these programs – **ZCMSIM**, **BCLOAD**, and **BCKEYS –** communicate with a card reader, via a serial port or the PC/SC driver. The default value of the COM port is taken from the environment variable **ZCPORT**; or the Windows® Registry variable "**HKEY_CURRENT_USER\Software\ZeitControl\BasicCardPro\ZCINC"** if this environment variable does not exist; or 1 if neither of these variables exists. (To specify PC/SC reader number *n*, set the COM port to 100+*n*.)
- If a filename parameter contains spaces, it must be enclosed in quotation marks on the command line. (For example: `ZCMBASIC -OI "Hello World"` compiles the file "`Hello World.BAS`" and creates the file "`Hello World.IMG`".)

6.9.1 The ZC-Basic Compiler ZCMBASIC.EXE

The compiler **ZCMBASIC.EXE** takes ZC-Basic source code as input, and produces P-Code as output. It compiles the entire program in one pass; there is no linking stage. To run the compiler:

ZCMBASIC [*param* [*param* **. . .**]] *input-file* [*param* [*param* **. . .**]]

input-file The ZC-Basic source file. If no file extension is supplied, *input-file***.bas** is assumed.

param One of the following:

–C*type* Compiles code for the given virtual machine type:

–CT or **–C0**	Terminal (the default).
–CC1 or **–C1.1**	Compact BasicCard version **ZC1.1**
–CE*n* or **–C3.***n*	Series 3 Enhanced BasicCard version **ZC3.*n***
–CF*filename*	Professional BasicCard with Configuration File *filename*. If no file extension is supplied, *filename***.zcf** is assumed.
–CM	MultiApplication BasicCard

See Sections **1.6**–**1.9** for information about the different BasicCard types.

–D*symbol*[=*val*] Defines *symbol* as if the source program contained the statement **Const** *symbol*=*val*. The *val* parameter must be an integer or a string; arithmetic expressions are not allowed. If *val* is absent, it defaults to 1.

–E[*exe-file*] Creates an executable file that will run in a DOS box under Microsoft Windows®. If no file extension is supplied, *exe-file***.exe** is created. If *exe-file* is absent, *input-file***.exe** is created.

–H*heap-size* Specifies the Heap size of an Application for the MultiApplication BasicCard. See **5.2.4 Memory Allocation** for more information.

–I*path* Adds *path* to the list of directories to search for **#Include** files (see **3.3.1 Source File Inclusion**). A closing backslash in *path* is optional. Multiple paths may be supplied, separated by semicolons.

–N*serial-number* Specifies the 8-byte Serial Number of a MultiApplication card, for use by the Component Section parser in the compiler. *serialnumber* must consist of 16 hexadecimal digits.

–OI[*image-file*] Generates an image file. If no file extension is supplied, *image-file***.img** is created. If *image-file* is absent, *input-file***.img** is created.

The image file is described in **11.1 ZeitControl Image File Format**.

–OD[*debug-file*] Generates a debug information file. If no file extension is supplied, *debug-file***.dbg** is created. If *debug-file* is absent, *input-file***.dbg** is created.

The debug file is described in **11.2 ZeitControl Debug File Format**.

–OA[*app-file*] Generates an Application file. If no file extension is supplied, *app-file***.app** is created. If *app-file* is absent, *input-file***.app** is created. The output file is a byte-for-byte copy of the Application file in the BasicCard. (Normally you won't need to create Application files, as the Application Loader finds all the information it needs in the image file.)

–OL[*list-file*] Generates a list file. If no file extension is supplied, *list-file***.lst** is created. If *list-file* is absent, *input-file***.lst** is created.

The list file is described in **11.4 List File Format**.

–OM[*map-file*] Generates a map file. If no file extension is supplied, *map-file***.map** is created. If *map-file* is absent, *input-file***.map** is created.

The map file is described in **11.5 Map File Format**.

–OE[*error-file*] Writes all error messages to a file. If *error-file* already exists, it is deleted before compilation begins. If no file extension is supplied, *error-file***.err** is created. If *error-file* is absent, *input-file***.err** is created.

–S*stack-size* Sets the size of the P-Code stack. Normally the compiler can work out for itself how big the stack has to be. But if the program contains recursive procedure calls or recursive **GoSub** calls, the compiler must guess the stack size, because it can't know how deep the recursion will go. You can override this guess with **–S***stack-size* (or with the **#Stack** pre-processor directive – see **3.3.9 Stack Size**).

–S*state* Switches the card into the specified state after the P-Code is downloaded. See also **3.3.7 Card State**. Only the first letter of *state* is significant:

First letter of *state*:	**'L'**	**'P'**	**'T'**	**'R'**
New card state:	**LOAD**	**PERS**	**TEST**	**RUN**

6.9.2 The P-Code Interpreter ZCMSIM.EXE

The program **ZCMSIM.EXE** loads and runs a compiled ZC-Basic Terminal program from a ZeitControl Image File (or Debug File). It can also simultaneously run one or more BasicCard programs in simulated BasicCards, or it can communicate with real BasicCards via physical card readers. And for the MultiApplication BasicCard, it has a built-in Application Loader. To run the **ZCMSIM** program:

ZCMSIM [*param* [*param* **. . .**]] *image-file* [*P1$* [*P2$* **. . .**]]

Parameters *before* the image-file name are processed by the **ZCMSIM** program, as described below. Parameters *after* the image-file name (*P1$*, *P2$*,...) are passed to the Terminal program via the pre-defined **String** array **Param$(1 To nParams)** – see **3.21.10 Pre-Defined Variables**.

image-file The image file output by the compiler. If no file extension is supplied, *image-file***.img** is assumed. (So if this is a Debug File, the **.dbg** extension must be present.)

Note: The *image-file* parameter must be present, unless **ZCMSIM** is functioning as an Application Loader for the MultiApplication BasicCard.

param One of the following:

–C*card-file* The image file of a BasicCard program. If this parameter is present, **ZCMSIM** simulates a BasicCard in the PC. If no file extension is supplied, *card-file***.img** is assumed. See also Note 2 below.

–A*card-file* The image file of a MultiApplication BasicCard Application. The Application Loader will be invoked to load the Application into the (real or simulated) MultiApplication BasicCard. If no file extension is supplied, *card-file***.img** is assumed.

–L[*log-file*] Generates a log file, containing the commands sent to the card and their responses. If no file extension is supplied, *log-file***.log** is created. If *log-file* is absent, *image-file***.log** is created.

–P*com-port* The number of the COM port that the card reader is attached to. (This can also be set from within the Terminal program itself, via the **ComPort** pre-defined variable.) This parameter may appear more than once – see Note 1 below.

–W Write the EEPROM data back to the image file(s) when the Terminal program exits. The Terminal program EEPROM data is written back to *image-file*. If the **–C** parameter is present on the command line, the EEPROM data in the simulated BasicCard program is written back to *card-file* when the Terminal program exits.

–WT[*new-file*] Write the Terminal program EEPROM data back to *new-file* when the Terminal program exits. If no file extension is supplied, *new-file***.img** is created. If *new-file* is absent, the EEPROM data is written back to *image-file*.

–WC[*new-file*] Write the EEPROM data in the simulated BasicCard program back to *new-file* when the Terminal program exits. If no file extension is supplied, *new-file***.img** is created. If *new-file* is absent, the EEPROM data is written back to *card-file*.

–D Display the Application Loader commands on the screen as they are executed. (For use in conjunction with the –**A** parameter.)

P1$*, *P2$,... These parameters are separated by spaces or tabs. To pass a space or tab in a parameter, enclose it in quotation marks; to pass a quotation mark in a parameter, precede it with a backslash. (Backslashes not followed by quotation marks are passed as is.)

Notes:

1. If multiple **–P** parameters are present:

   - **–C** and **–WC** apply to the card on the most recently specified COM port;
   - the **ComPort** variable is set from the last **–P** parameter.

   For instance, to communicate with a simulated BasicCard program on COM1 and a real BasicCard on COM2:

   ZCMSIM –P1 –C*card-file* **–P2** *image-file*

2. If *card-file* is a ZeitControl Configuration File (with .ZCF or .MCF extension), an empty card of the appropriate type is simulated. This is for the MultiApplication BasicCard – the BasicCard type is not available from the image file of an Application (which is independent of the specific BasicCard OS), so this information must be supplied separately, via the –**C** parameter. For example, to test Applications **App1** and **App2** with Terminal program **Term**:

   ZCMSIM –C\BasicCardPro\MultiApp\ZC65_A.MCF –AApp1 –AApp2 –D Term

   In this case only, the *image-file* parameter may be absent; **ZCMSIM** then functions as a stand-alone Application Loader. If the *card-file* parameter is also absent, **ZCMSIM** will attempt to load the Applications into a real MultiApplication BasicCard. For instance:

   ZCMSIM –P2 –AApp1 –AApp2 –D

6.9.3 The Card Loader BCLOAD.EXE

The program **BCLOAD.EXE** downloads P-Code and data to a single-application BasicCard.

The ZC-Basic compiler produces a ZeitControl Image File as output, containing P-Code and data in binary form. To run the **BCLOAD** program:

BCLOAD [*param* [*param* **. . .**]] *image-file* [*param* [*param* **. . .**]]

image-file The image file output by the compiler. If no file extension is supplied, *image-file***.img** is assumed. (A debug file is also allowed here; in this case. the **.dbg** extension must be supplied.)

param One of the following:

–D Displays the commands on the screen as they are executed.

–L[*log-file*] Generates a log file, containing the commands sent to the card and their responses. If no file extension is supplied, *log-file***.log** is created. If *log-file* is absent, *image-file***.log** is created.

–E[*error-file*] Writes all error messages to a file. If *error-file* already exists, it is deleted before the download begins. (So if *error-file* exists after the program exits, it means that an error occurred.) If no file extension is supplied, *error-file***.err** is created. If *error-file* is absent, *image-file***.err** is created.

–P*com-port* The number of the COM port that the card reader is attached to.

–S*state* Switches the card into the specified state after the download. Only the first letter of *state* is significant:

First letter of *state*:	**‘L’**	**‘P’**	**‘T’**	**‘R’**
New card state:	**LOAD**	**PERS**	**TEST**	**RUN**

Notes:

1. The ZC-Basic source code for this program is supplied on the distributon disk, in the `BasicCardPro\Source\BCLoad` directory. **BCLOAD.EXE** was compiled with the COMPILE.BAT command file in the same directory.

2. To download an Application to the MultiApplication BasicCard, use the built-in Application Loader in **ZCMSIM** or **ZCMDCARD**.

6.9.4 The Key Generator KEYGEN.EXE

The program **KEYGEN.EXE** generates cryptographic keys and primitive polynomials for the encryption and decryption of commands and responses. It creates a ZC-basic source file containing **Declare Key** and/or **Declare Polynomial** statements. This file can be **#Included** in the source code of the Terminal and BasicCard programs, or it can be downloaded separately to a Compact or Enhanced BasicCard using the **BCKEYS** Key Loader program. The program prompts the user to press keys on the keyboard at random; the cryptographic keys and polynomials are generated from this user input, after hashing with the **MD5** algorithm (see R.L. Rivest, "The MD5 Message Digest Algorithm", RSA Data Security, Inc., April 1992). To run the **KEYGEN** program:

KEYGEN [*param* [*param* **. . .**]] *key-file* [*param* [*param* **. . .**]]

key-file The name of the key file to create or update. If no file extension is supplied, *key-file***.bas** is assumed.

param One of the following:

–K*key*[**(***len*[**,** *count*]**)**] *key* is a key number between 0 and 255; *len* is a key length between 1 and 255; and *count* is the initial value of the error counter for the key, between 0 and 15 (see **3.17.3 Key Declaration**). If *len* is absent, it defaults to 8; if *count* is absent, the error counter for the key is disabled. You can create multiple keys by specifying the **–K** parameter more than once.

–P Generates two random primitive polynomials for use by the **SG-LFSR** encryption algorithms.

–Q Generates random numbers quickly, without requiring keyboard input from the user.

Note: This feature is provided for convenience of use during the development of an application. Keys and polynomials generated with the **–Q** parameter should not be used in a released application, as this might compromise the security of the encryption algorithms.

–U *key-file* is updated, rather than being created from scratch – existing keys and polynomials in *key-file* are preserved, unless overridden by **–K** or **–P**.

Note: The generation of cryptographic keys is a delicate business. The security of the encryption algorithms used by the BasicCard relies on the secrecy of the keys and polynomials generated by the **KEYGEN** program, which in turn relies on the quality of the random number generator. To foster confidence in the security of our product, we provide the C++ source code of the **KEYGEN** program in the directory `BasicCardPro\Source\Keygen`.

6.9.5 The Key Loader BCKEYS.EXE

The program **BCKEYS.EXE** downloads cryptographic keys and/or polynomials to a Compact or Enhanced BasicCard. The following conditions apply to the downloading of keys and polynomials:

- The BasicCard must be in state **LOAD** (or switchable to state **LOAD**);
- The BasicCard must already have been loaded with P-Code and data by the **BCLOAD** program;
- All keys that you want to download must have been declared in the ZC-Basic source code, with **Declare Key** statements.

The program takes a key file as input. This is a ZC-Basic source file that contains only **Declare Key** and/or **Declare Polynomials** statements. The **KEYGEN** program can generate key files for you – see **6.9.4 The Key Generator KEYGEN.EXE**.

To run the **BCKEYS** program:

BCKEYS [*param* [*param* **. . .**]] *key-file* [*param* [*param* **. . .**]]

key-file The key file, as described above. If no file extension is supplied, *key-file***.bas** is assumed.

param One of the following:

–K[*key*] *key* is a key number between 0 and 255. You can download multiple keys by specifying this parameter more than once. If *key* is absent, all the keys in *key-file* are downloaded.

–P Downloads the polynomials to the BasicCard.

If neither **–K** nor **–P** appears on the command line, then all the keys and polynomials in *key-file* are downloaded.

–L[*log-file*] Generates a log file, containing the commands sent to the card and their responses. If no file extension is supplied, *log-file***.log** is created. If *log-file* is absent, *key-file***.log** is created.

–D Displays the commands on the screen as they are executed.

–P*com-port* The number of the COM port that the card reader is attached to.

–S*state* Switches the card into the specified state after the download. Only the first letter of *state* is significant:

First letter of *state*:	**'L'**	**'T'**	**'R'**
New card state:	**LOAD**	**TEST**	**RUN**

Note: State **PERS** is not available in Compact or Enhanced BasicCards, so it is not allowed here.

7. System Libraries

In Terminal programs and Enhanced, Professional, and MultiApplciation BasicCard programs, the functionality of the ZC-Basic language can be extended using ZeitControl System Libraries.

In Terminal programs, and Professional and MultiApplication BasicCards, the System Libraries are built into the Operating System; in the Enhanced BasicCard, System Libraries are implemented as Plug-In Libraries that are loaded into EEPROM only if they are needed. A ZeitControl Plug-In Library File *library*.**lib** is provided for each Enhanced BasicCard Plug-In Library. In all cases, to use a library:

#Include *library*.**def**

This loads the library if necessary, and declares its procedures and data.

The following System Libraries are currently available:

Name	*Description*	*Terminal*	*Enhanced BasicCard*	*Professional BasicCard*	*Multi-Application BasicCard*
RSA	RSA Public-Key Cryptography	✓		*	
AES	Advanced Encryption Standard	✓	✓	*	✓
EC–211	211-bit Elliptic Curve Cryptography	✓		*	✓
EC–167	167-bit Elliptic Curve Cryptography	✓		*	✓
EC–161	161-bit Elliptic Curve Cryptography	✓	✓		
COMPONENT	Security Component handling	✓			✓
EAX	Encryption with Authentication	✓		*	✓
OMAC	Message Authentication	✓		*	✓
SHA	Secure Hash Algorithms	✓	✓	✓	✓
IDEA	International Data Encryption Algorithm	✓	✓	✓	
MATH	Mathematical functions	✓			
MISC	Miscellaneous procedures	✓	✓	✓	✓

* These System Libraries are available in some, but not all, Professional BasicCards. See the Professional BasicCard datasheet for the latest information.

These libraries are supplied with the distribution kit, in the `BasicCardPro\Lib` directory. The program **LIBVER**, in the same directory, displays the name and version number of an Enhanced BasicCard Plug-In Library file.

In the descriptions of the individual libraries, error codes may be defined. These error codes are signalled via the **LibError** variable. The **ZCMBASIC** compiler automatically declares this variable if any libraries are included that can return an error code. **LibError** contains the most recent error code signalled by a library procedure. A library procedure never sets **LibError** back to zero; if you want to continue after detecting a library error, you should set **LibError** to zero yourself.

A library error code is a 2-byte value of the form &H4XXX, with the high nibble equal to 4. Therefore, unless you are using the **T=0** protocol (and at the cost of strict ISO compatibility), you can return **LibError** in the **SW1SW2** status word if a library error occurs in a BasicCard program. For example:

```
Sub CheckLibError()
  If LibError = 0 Then Exit Sub
  SW1SW2 = LibError
  LibError = 0 ' Reset LibError for the next command
  Exit
End Sub
```

7.1 RSA: The Rivest-Shamir-Adleman Library

The **RSA** library implements Rivest-Shamir-Adleman public-key cryptography. It is based on the document **PKCS #1 v2.0: RSA Cryptography Standard** from RSA Data Security, Inc. The following operations are supported:

- on-card private/public key pair generation, with public key length up to 1024 bits;
- encryption and decryption;
- digital signature generation and verification.

7.1.1 Overview

In the **RSA** Plug-In Library, a private key consists of three numbers (p, q, e), where p and q are prime numbers and e is a number relatively prime to p-1 and q-1. The corresponding public key consists of the two numbers (n, e), where n is the product of p and q.

The private exponent d is the inverse of e modulo (p-1)(q-1). Mathematically, this means that for any number m, m^{ed} is equal to m modulo n. If Alice wants to send a message m to Bob that only Bob can decrypt, Alice computes $c = m^e$ modulo n using Bob's public key (n_B, e_B). Bob can then recover m modulo n (and therefore m, if m is less than n), as follows:

- using p and q, compute the private exponent d;
- compute $m = c^d$ modulo n.

Similarly, if Alice wants to sign a message m, she computes the private exponent d using her own private key (p_A, q_A, e_A), and then computes the signature $s = m^d$ modulo n. Anyone who has Alice's public key (n_A, e_A) can verify that $s^e = m$ modulo n; and therefore that whoever created the signature s had knowledge of Alice's private key (and was therefore presumably Alice herself).

The security of the **RSA** system rests on the difficulty of recovering p and q if only their product n is known: the *factorisation problem*. If I know n and e, but I don't know p and q, then I can't calculate the private exponent d. The difficulty of the factorisation problem depends on the size of n. Current state-of-the-art factoring methods can factor a 512-bit public key in a matter of months; 768-bit public keys are expected to resist factorisation for a few more years; and 1024-bit keys are expected to be secure for the foreseeable future.

The **RSA** Plug-In Library represents large integers as ZC-Basic strings; the first byte in the string (with subscript 1) is the most significant byte.

To load the **RSA** library:

#Include RSA.DEF

The file RSA.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

The following procedures are provided:

Function RsaPseudoPrime (*x$*, *nRounds***)**
Sub RsaGenerateKey (*nBits*, *eBits*, *p$*, *q$*, *e$***)**
Function RsaPublicKey (*p$*, *q$***) As String**
Sub RsaEncrypt (*Mess$*, *n$*, *e$***)**
Sub RsaDecrypt (*Mess$*, *p$*, *q$*, *e$***)**
Sub RsaPKCS1Sign (*Hash$*, *p$*, *q$*, *e$*, *Sig$***)**
Function RsaPKCS1Verify (*Hash$*, *n$*, *e$*, *Sig$***)**
Sub RsaPKCS1Encrypt (*Mess$*, *n$*, *e$***)**
Function RsaPKCS1Decrypt (*Mess$*, *p$*, *q$*, *e$***)**
Sub RsaOAEPEncrypt (*Mess$*, *EP$*, *n$*, *e$***)**
Function RsaOAEPDecrypt (*Mess$*, *EP$*, *p$*, *q$*, *e$***)**

These procedures are described in the following sections.

7.1.2 Key Generation

To generate a private key:

Call RsaGenerateKey (*nBits*, *eBits*, *p$*, *q$*, *e$***)**

nBits Length of public key *n*. Set *nBits* = 1024 for maximum security. In a BasicCard program, *nBits* must be a multiple of 16, with 496 <= *nBits* <= 1024. In a Terminal program, *nBits* can be any number between 16 and 4064.

eBits Length of public exponent *e*. In a BasicCard program, *eBits* must be a multiple of 8, with 8 <= *eBits* <= 32. In a Terminal program, *eBits* can be any number between 8 and 2032. If *nBits* is 1024, we recommend *eBits* = 32.

p$*, *q$, *e$* The private key (*p*, *q*, *e*).

RsaGenerateKey uses the Rabin-Miller primality test, as described in **IEEE P1363: Standard Specifications for Public Key Cryptography**. The number of Rabin-Miller rounds depends on *nBits*; it is chosen so that the probability of a given factor being composite is less than 1 in 2^{100}.

The following error codes are returned in the **LibError** variable:

RsaKeyTooShort In a BasicCard program: *nBits* < 496.
In a Terminal program: *nBits* < 16.

RsaKeyTooLong In a BasicCard program: *nBits* > 1024.
In a Terminal program: *nBits* > 4064.

RsaBadProcParams In a BasicCard program: *nBits* is not a multiple of 16, or *eBits* is not a multiple of 8, or *eBits* < 8, or *eBits* > 32.
In a Terminal program: *eBits* < 8, or *eBits* > 2032.

To calculate the public key modulus *n* from *p* and *q*:

n$ = **RsaPublicKey** (*p$*, *q$*)

The following error code is returned in the **LibError** variable:

RsaKeyTooLong In a BasicCard program: *p$* or *q$* longer than 512 bits.
In a Terminal program: *n$* longer than 2032 bits.

If you want to generate your own random numbers *p$* and *q$*, you can test them for primality with:

IsPrime = **RsaPseudoPrime** (*x$*, *nRounds*)

x$ Number to test for primality.
nRounds Number of rounds of Rabin-Miller primality test to run.
IsPrime **True** if *x$* survives *nRounds* rounds of the Rabin-Miller primality test.

7.1.3 Cryptographic Primitives

Four cryptographic primitives are defined in **PKCS #1 v2.0: RSA Cryptography Standard**:

RSAEP ((*n*, *e*), *m*) **RSA** Encryption Primitive: $c = m^e$ modulo *n*
RSADP ((*n*, *d*), *c*) **RSA** Decryption Primitive: $m = c^d$ modulo *n*
RSASP1 ((*n*, *d*), *c*) **RSA** Signature Primitive 1: $s = m^d$ modulo *n*
RSAVP1 ((*n*, *e*), *s*) **RSA** Verification Primitive 1: $m = s^e$ modulo *n*

RSAEP and **RSAVP1** are functionally identical, as are **RSADP** and **RSASP1**. The **RSA** Plug-In Library provides two procedures. In a BasicCard, the exponent *e$* must be odd, and less than *n$*:

*Cryptographic primitives **RSAEP** and **RSAVP1***

Call RsaEncrypt (*Mess$*, *n$*, *e$*)

This procedure computes *Mess$* $^{e\$}$ modulo *n$*, returning the result in *Mess$*.

In a BasicCard program, the following error codes are returned in the **LibError** variable:

RsaKeyTooShort *n$* is shorter than 248 bits
RsaKeyTooLong *n$* is longer than 1024 bits
RsaBadProcParams *Mess$* is longer than 1024 bits

*Cryptographic primitives **RSADP** and **RSASP1***

Call RsaDecrypt (*Mess$*, *p$*, *q$*, *e$*)

This procedure first computes *d$* = inverse of *e$* modulo (*p$*-1)(*q$*-1). Then it computes *Mess$* $^{d\$}$ modulo *p$ q$*, returning the result in *Mess$*.

In a BasicCard program, the following error codes are returned in the **LibError** variable:

RsaKeyTooShort	*p$* or *q$* is shorter than 248 bits
RsaKeyTooLong	*p$* or *q$* is longer than 512 bits
RsaBadProcParams	*Mess$* is longer than 1024 bits

7.1.4 Signature Scheme With Appendix

As described in **PKCS #1 v2.0: RSA Cryptography Standard**, a *signature scheme with appendix* consists of a *signature generation operation* and a *signature verification operation*. One signature scheme with appendix is defined: **RSASSA-PKCS1-v1_5**.

The **RSA** Plug-In Library uses **SHA-1** as the hash function for the signature scheme.

To generate a signature using the **RSASSA-PKCS1-V1_5-SIGN** signature generation operation:

Call RsaPKCS1Sign (*Hash$*, *p$*, *q$*, *e$*, *Sig$***)**

Hash$	The 20-byte **SHA-1** hash of the data to be signed.
p$, q$, e$	The private key (*p*, *q*, *e*).
Sig$	The signature calculated by **RsaPKCS1Sign**. It has the same size as *n$* (where *n* = *pq* is the public-key modulus).

The following error codes are returned in the **LibError** variable:

RsaKeyTooShort	*n$* is shorter than 376 bits
RsaBadProcParams	*Hash$* is not 20 bytes long

To verify a signature using the **RSASSA-PKCS1-V1_5-VERIFY** signature verification operation:

SignatureValid = **RsaPKCS1Verify (***Hash$*, *n$*, *e$*, *Sig$***)**

Hash$	The 20-byte **SHA-1** hash of the data that was signed.
n$, e$	The private key (*n*, *e*).
Sig$	The signature to be verified.
SignatureValid	**True** if the signature is valid.

The following error codes are returned in the **LibError** variable:

RsaKeyTooShort	*n$* is shorter than 376 bits
RsaBadProcParams	*Hash$* is not 20 bytes long

7.1.5 Encryption Schemes

As described in **PKCS #1 v2.0: RSA Cryptography Standard**, an *encryption scheme* consists of an *encryption operation* and a *decryption operation*. Two encryption schemes are defined: **RSAES-PKCS1-v1_5** and **RSAES-OAEP**. The second of these is cryptographically more robust, but is bigger and slower; it is currently only available in Terminal programs.

The **RSA** Plug-In Library uses **SHA-1** as the hash function for the encryption schemes.

*The **RSAES- PKCS1-v1_5** Encryption Scheme*

To encrypt a message using the **RSAES-PKCS1-V1_5-ENCRYPT** encryption operation:

Call RsaPKCS1Encrypt (*Mess$*, *n$*, *e$***)**

Mess$	The message to be encrypted. It must be at least 11 bytes shorter than *n$*. The encrypted message is returned in *Mess$*.
n$, e$	The public key (*n*, *e*).

The following error code is returned in the **LibError** variable:

RsaBadProcParams	*Mess$* is not at least 11 bytes shorter than *n$*.

To decrypt a message using the **RSAES-PKCS1-V1_5-DECRYPT** decryption operation:

MessageValid = **RsaPKCS1Decrypt** (*Mess$*, *p$*, *q$*, *e$*)

Mess$	The message to be decrypted. It must be the same length as *n$* (where *n* = *pq* is the public-key modulus). The decrypted message is returned in *Mess$*.
p$*, *q$, *e$*	The private key (*p*, *q*, *e*).
MessageValid	**True** if *Mess$* was successfully decrypted.

The following error code is returned in the **LibError** variable:

RsaBadProcParams *Mess$* is not the same size as *n$*.

*The **RSAES-OAEP** Encryption Scheme*

The **RSAES-OAEP** scheme accepts *encoding parameters* as input. The same encoding parameters must be specified for encryption and decryption. The encoding parameters can be any arbitrary string, and need not be secret; if in doubt, use the empty string “”.

To encrypt a message using the **RSAES-OAEP-ENCRYPT** operation (Terminal programs only):

Call RsaOAEPEncrypt (*Mess$*, *EP$*, *n$*, *e$***)**

Mess$	The message to be encrypted. It must be at least 42 bytes shorter than *n$*. The encrypted message is returned in *Mess$*.
EP$	The encoding parameters. Any string is accepted.
n$*, *e$	The public key (*n*, *e*).

The following error code is returned in the **LibError** variable:

RsaBadProcParams *Mess$* is not at least 42 bytes shorter than *n$*.

To decrypt a message using the **RSAES-OAEP-DECRYPT** operation (Terminal programs only):

MessageValid = **RsaOAEPDecrypt (***Mess$*, *EP$*, *p$*, *q$*, *e$***)**

Mess$	The message to be decrypted. It must be the same length as *n$* (where *n* = *pq* is the public-key modulus). The decrypted message is returned in *Mess$*.
EP$	The encoding parameters. They must match the *EP$* parameter to the **RsaOAEPEncrypt** procedure.
p$*, *q$, *e$*	The private key (*p*, *q*, *e*).
MessageValid	**True** if *Mess$* was successfully decrypted.

The following error code is returned in the **LibError** variable:

RsaBadProcParams *Mess$* is not the same size as *n$*.

7.2 AES: The Advanced Encryption Standard Library

This library implements the Advanced Encryption Standard defined in Federal Information Processing Standard FIPS 197. This standard is available on the Internet, at http://csrc.nist.gov/encryption/aes/. **AES** uses the Rijndael algorithm as its cryptographic primitive. The Standard specifies three permitted key lengths: 128 bits, 192 bits, and 256 bits. All three key lengths are available to Terminal programs. At the time of writing, Professional BasicCard **ZC5.5** and MultiApplication BaicCard **ZC6.5** support all three key lengths; other versions of the BasicCard are restricted to 128-bit keys.

To load this library:

#Include AES.DEF

The file AES.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

The **AES** library consists of a single procedure:

Function AES (*Type%***,** *Key$***,** *Block$***) As String**

This function encrypts or decrypts the 16-byte *Block$* with the given *Key$*, acording to the *Type%* parameter:

Type%

128	Encryption with 128-bit key. **Len** (*Key$*) must be >= 16.
192	Encryption with 192-bit key. **Len** (*Key$*) must be >= 24.
256	Encryption with 256-bit key. **Len** (*Key$*) must be >= 32.
-128	Decryption with 128-bit key. **Len** (*Key$*) must be >= 16.
-192	Decryption with 192-bit key. **Len** (*Key$*) must be >= 24.
-256	Decryption with 256-bit key. **Len** (*Key$*) must be >= 32.

The return value of the function is the encrypted or decrypted *Block$*. If *Block$* is shorter than 16 bytes, it is padded with zeroes before encryption/decryption; if it is longer than 16 bytes, it is truncated before encryption/decryption. In any case, the contents of the original *Block$* are unchanged.

The following error codes are returned in the **LibError** variable:

AesBadType	*Type%* is not ±128, ±192, or ±256.
AesUnsupportedType	*Type%* is ±192 or ±256, but the key length is not supported.
AesKeyTooShort	*Key$* is shorter than 16/24/32 bytes.

7.3 The Elliptic Curve Libraries

Elliptic Curve Cryptography is a branch of Public Key Cryptography that is especially suitable for Smart Card implementation, for (at least) two reasons:

- the generation of private/public key pairs is simple enough to be implemented in a Smart Card;
- it requires much smaller key sizes than other well-known methods for the same level of security.

Three Elliptic Curve libraries are available for ZC-Basic programs:

- Library **EC–211** over the field GF(2^{211}), with 211-bit keys. This is the most secure of the three Elliptic Curve libraries, currently considered equivalent to 2048-bit **RSA**. It is available for Professional BasicCard **ZC5.5 REV H**, MultiApplication BasicCard **ZC6.5 REV D**, and all higher revisions.
- Library **EC–167** over the field GF(2^{167}), with 167-bit keys. This is currently considered equivalent to 1024-bit **RSA**. It is available for all Series 5 Professional BasicCards and Series 6 MultiApplication BasicCards.
- Library **EC–161** over the field GF(2^{168}), with 161-bit keys. See below for a discussion on the security of this library compared to the **EC–167** library. It is available for all Enhanced BasicCards.

All three libraries are available to Terminal programs.

The important difference between libraries **EC–167** and **EC–161** is not the key length (167 vs. 161), but the field exponent (167 vs. 168). In a Smart Card implementation of Elliptic Curve Cryptography, arithmetic over the underlying field must be made as fast as possible. Certain field exponents allow ingenious short cuts, speeding up the arithmetic significantly. One such exponent is 168, as used by **EC–161**. Our implementation achieves a speed-up factor of five or six; without this speed-up, Elliptic Curve Cryptography in the Enhanced BasicCard would be too slow for practical use.

However, the latest consensus among experts is that the field exponent should be a prime number, such as 211 or 167; certain composite exponents have been shown to be cryptographically weak, and the feeling is that all composite exponents (for example, 168) should therefore be avoided. So current expert opinion would not recommend library **EC–161** for applications requiring maximum security.

Each library supports the following Elliptic Curve operations:

- private/public key pair generation;
- session key generation;
- digital signature generation;
- digital signature verification (not available in the Enhanced BasicCard).

Our implementation follows the standard **IEEE P1363: Standard Specifications for Public Key Cryptography**. Section **7.3.9 Conformance Specification** specifies the methods used in the Elliptic Curve libraries, using the terminology of **IEEE P1363**.

A simple Elliptic Curve application can be found in the directory `BasicCardPro\Examples\EC`.

7.3.1 Loading an Elliptic Curve Library

To load an Elliptic Curve library:

#Include EC–*XXX*.DEF

(we use *XXX*, here and later, to denote any of 211, 167, or 161). These files are supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

7.3.2 Setting the Elliptic Curve Parameters

An Elliptic Curve is defined by its EC Domain Parameters; suitable Elliptic Curves are supplied in the directory `BasicCardPro\Lib\Curves`. Choose one of these for your application. We supply five Elliptic Curves for libraries **EC–211** and **EC–167**, and three Elliptic Curves for library **EC–161**. The *Curve Definition Files* EC211-1.16 through EC211-5.128, EC167-1.16 through EC167-5.128, and EC161-1.16 through EC161-5.64 contain curve definitions in ZC-Basic, for inclusion in a source program. File EC-*XXX*.BIN contains the binary data for all the curves for a given library, for run-time loading in a Terminal program.

Specifying an Elliptic Curve in a Enhanced or Professional BasicCard program

To specify the EC Domain Parameters to be used in an Enhanced or Professional BasicCard program:

#Include Curves\EC*XXX–C*.*N*

where *C* is a curve number from 1 to 5 (from 1 to 3 for library **EC–161**), and *N* is a power of 2 between 16 and 128 (between 16 and 64 for library **EC–161**). In an Enhanced or Professional BasicCard program, the curve must be chosen at compile time; it can't be re-loaded at run-time. This Curve Definition File loads *N* pre-computed Elliptic Curve points into EEPROM to speed up Elliptic Curve operations. The more pre-computed points, the faster the card, but the less free EEPROM space. If EEPROM space is at a premium, use 16 pre-computed points; if speed is the most important factor, use 64 or 128 pre-computed points.

Specifying an Elliptic Curve in a MultiApplication BasicCard program

To specify the EC Domain Parameters to be used in a MultiApplication BasicCard program:

Call EC*XXX*SetCurve (*filename$***)**

where *filename$* is the name of a file in the BasicCard that contains the same data as one of the **Curves\EC*XXX–C*.*N*** curve definition files. The data in this file must occupy a single contiguous data block in EEPROM. See the preceding paragraph for the meaning of *C* and *N*.

For example:

```
Dir "\ECApp" ' Start File Definition Section
  File "CurveParams" Len=0 ' Len=0 makes single contiguous block
    Lock=Read:Always  ' Read-only access for everybody
    #Include "Curves\EC211-2.64" ' Import file data
End Dir Lock=Read:Always ' End File Definition Section

Call EC211SetCurve ("\ECApp\CurveParams")
If LibError <> 0 Then ' Report error
...
```

Alternatively, if the special file "**ECDomainParams**" exists in the Root Directory, it is automatically loaded whenever the card is reset – see **5.3.3 Elliptic Curve Domain Parameters**.

Specifying an Elliptic Curve in a Terminal program

In the Terminal program, an Elliptic Curve must be explicitly loaded using **EC*XXX*SetCurve**. There are three ways of doing this:

- If you know in advance which curve to use, you can include its definition file. For example:

```
#Include EC211-3.16
Call EC211SetCurve (EC211Params)
```

  But note that only one such definition file is allowed in a program.

- If the card has a suitable command, you can load the curve from the card. For example:

```
Private Curve As EC167DomainParams
Call GetCurve (Curve) : Call CheckSW1SW2()
Call EC167SetCurve (Curve)
```

  See `BasicCardPro\Examples\EC` for an example of this.

- You can read the curve from binary files EC-*XXX*.BIN. For example:

```
Private Curve As EC161DomainParams
Open "EC-161.BIN" For Random As #1 Len=Len(EC161DomainParams)
Get #1, 2, Curve ' Read Elliptic Curve #2
Close #1
Call CheckFileError()
Call EC161SetCurve (Curve)
```

If the EC domain parameters are invalid, procedure **EC*XXX*SetCurve** returns error code **EC*XXX*BadCurveParams** in variable **LibError**.

In a Terminal program or a MultiApplication BasicCard program, you must call **EC*XXX*SetCurve** before you call any other procedures from the **EC–*XXX*** library. If not, error code **EC*XXX*CurveNotInitialised** will be returned in variable **LibError**.

7.3.3 Key Generation

To generate a public/private key pair:

Case 1: Terminal and single-application BasicCard programs

Call EC*XXX*GenerateKeyPair()

Case 2: MultiApplication BasicCard program

Call EC*XXX*GenerateKeyPair (*PrivateKey$*, *PublicKey$*)

This procedure generates a random private key and its associated public key, storing them in **Eeprom** strings **EC*XXX*PrivateKey** and **EC*XXX*PublicKey** (Case 1) or in the procedure parameters *PrivateKey$* and *PublicKey$* (Case 2). The **EC–211** library generates 27-byte private and public keys; the **EC–167** library generates 21-byte private and public keys; and the **EC–161** library generates a 21-byte private key and a 22-byte public key.

7.3.4 Computing a Public Key from a Private Key

Case 1: Terminal and single-application BasicCard programs

Call EC*XXX*SetPrivateKey (*PrivateKey$*)

This procedure copies *PrivateKey$* (reduced modulo *r*) to the **Eeprom** string **EC*XXX*PrivateKey**, and computes the associated **Eeprom** string **EC*XXX*PublicKey**. (*r* is explained in **7.3.8 Binary Representation Formats**: *EC Domain Parameters*.) Key lengths are as described in the previous paragraph, **7.3.3 Key Generation**.

Case 2: MultiApplication BasicCard program

PublicKey$* = **EC*XXX*MakePublicKey (*PrivateKey$)**

This function computes the public key from a specific private key.

If *PrivateKey$* is zero modulo *r*, error code **EC*XXX*BadProcParams** is returned in variable **LibError**.

7.3.5 Generating a Digital Signature

A private key is used to generate digital signatures. To sign data consisting of a **String** expression:

Case 1: Terminal and single-application BasicCard programs

*Signature$* = **EC***XXX***HashAndSign (***Data$***)**

Case 2: MultiApplication BasicCard program

*Signature$* = **EC***XXX***HashAndSign (***PrivateKey$***,** *Data$***)**

The **EC–211** library returns a 54-byte signature; libraries **EC–167** and **EC–161** return a 42-byte signature.

To sign a longer body of data, first compute the hash function for the data (see **7.7.1 Hashing Functions**), and then:

Case 1: Terminal and single-application BasicCard programs

*Signature$* = **EC***XXX***Sign (***Hash$***)**

Case 2: MultiApplication BasicCard program

*Signature$* = **EC***XXX***Sign (***PrivateKey$***,** *Hash$***)**

In Case 1, if no private key has been set, these procedures return error code **EC***XXX***KeyNotInitialised** in variable **LibError**.

7.3.6 Verifying a Digital Signature

To verify a digital signature, you need the signer's public key. To verify the signature of a message consisting of a **String** expression:

Status = **EC***XXX***HashAndVerify (***Signature$***,** *Message$***,** *PublicKey$***)**

Signature$	The signature to be verified: 54 bytes (**EC–211**) or 42 bytes (**EC–167** and **EC–161**)
Message$	The message that was signed
PublicKey$	The signer's public key: 27 bytes (**EC–211**), 21 bytes (**EC–167**), 22 bytes (**EC–161**)

This function returns **True** or **False** according to whether the signature is valid or not.

To verify a longer message, first compute the hash function for the message (see **7.7.1 Hashing Functions**), and then verify its signature with the function:

Status = **EC***XXX***Verify (***Signature$***,** *Hash$***,** *PublicKey$***)**

If *Signature$* or *PublicKey$* are not the correct length, error code **EC***XXX***BadProcParams** is returned in variable **LibError**.

7.3.7 Session Key Generation

If two parties know each other's public keys, they can use them to agree on a secret value, 27 bytes long for the **EC–211** library and 21 bytes long for the **EC–167** and **EC–161** libraries. This value is called the *shared secret* for the two parties; to compute it, you need to know the private key of one party and the public key of the other party. To compute the shared secret:

Case 1: Terminal and single-application BasicCard programs

*SharedSecret$* = **EC***XXX***SharedSecret (***PublicKey$***)**

Case 2: MultiApplication BasicCard program

*SharedSecret$* = **EC***XXX***SharedSecret (***PrivateKey$***,** *PublicKey$***)**

PrivateKey$	The known private key (in Case 1, this must be in **EC***XXX***PrivateKey**)
PublicKey$	The other party's public key
SharedSecret$	The shared secret

If *PublicKey$* is not the correct length, or it is not a point on the curve, error **EC***XXX***BadProcParams** is returned in variable **LibError**.

This shared secret can then be used to generate session keys for encrypting messages between the two parties; unlike the shared secret, a session key can be different on different occasions. **EC–211** uses the

SHA–256 algorithm to generate 32-byte session keys; **EC–167** and **EC–161** use the **SHA–1** algorithm to generate 20-byte session keys.

To generate a session key, the parties must agree on a *Key Derivation Parameter*, which can be any sequence of bytes, and need not be kept secret. For maximum security, it should be different each time a session key is generated. For example, it might be a standard header followed by the date and time. To generate the session key:

*SessionKey$* = **EC***XXX***SessionKey (***KDP$***,** *SharedSecret$***)**

KDP$	Key Derivation Parameter, a string of any length
SharedSecret$	The shared secret value, returned by **EC***XXX***SharedSecret**
SessionKey$	The 32-byte or 20-byte session key

Note: Generating a shared secret is a complicated calculation, which can take several seconds in some BasicCards. But once a shared secret has been generated for a given public key, session key generation is mush faster, especially if **Len(***KDP$***)** + **Len(***SharedSecret$***)** <= 55. (Typically, a smart card application will only need to generate session keys for a single public key, for which the shared secret is computed just once in the card's lifetime.)

7.3.8 Binary Representation Formats

This section specifies the binary representations of the data objects that are used in the Elliptic Curve libraries: integers, field elements, elliptic curves, points on the curve, and signatures.

Integers

Integers in this implementation have a length of either 1 byte, 21 bytes, or 27 bytes. The first (or leftmost) byte is the most significant – in a 27-byte integer, it contains bits 215-208; in a 21-byte integer, it contains bits 167-160. The last (or rightmost) byte contains bits 7-0.

Field Elements

The library **EC–211** implements operations on Elliptic Curves over the field **GF**(2^{211}). An element of **GF**(2^{211}) is represented by 211 bits stored in 27 bytes. A Polynomial Basis field representation is used; the Field Polynomial is

$$p(t) = t^{211} + t^{11} + t^{10} + t^{8} + 1$$

The first (leftmost) byte contains the coefficients of t^{210} and t^{209}.

The library **EC–167** implements operations on Elliptic Curves over the field **GF**(2^{167}). An element of **GF**(2^{167}) is represented by 167 bits stored in 21 bytes. A Polynomial Basis field representation is used; the Field Polynomial is

$$p(t) = t^{167} + t^{6} + 1$$

The first (leftmost) byte contains the coefficients of t^{166} through t^{160}.

The library **EC–161** implements operations on Elliptic Curves over the field **GF**(2^{168}). An element of **GF**(2^{168}) is represented by 168 bits stored in 21 bytes. The field representation is non-standard (i.e. it does not use a Polynomial Basis or a Normal Basis); for this reason we provide source code, in C and ZC-Basic, for converting between ZeitControl's **EC–161** representation and a standard Polynomial Basis representation. This Polynomial Basis representation uses irreducible field polynomial

$$p(t) = t^{168} + t^{15} + t^{3} + t^{2} + 1$$

The source code is in directory `BasicCardPro\Source\FldConv`.

EC Domain Parameters

An Elliptic Curve *E* over **GF**(2^m) is defined by an equation of the form

$$y^2 + xy = x^3 + ax^2 + b$$

where *a* and *b* are elements of **GF**(2^m) with $b \neq 0$. The curve *E* consists of all points (x, y) with $x, y \in$ **GF**(2^m) that satisfy this equation, together with a *Point at Infinity*, denoted O. The order *#E* of the curve is the number of points in *E*. For cryptographic purposes, this order must have a large prime divisor, i.e. $\#E = kr$ for some (large) prime *r*. As well as *a*, *b*, *r*, and *k*, a point $G \in E$ must be specified, of order *r*

(that is, r is the smallest positive integer such that $rG = O$.) Field elements a and $b \in$ **GF**(2^m), integers r and k, and point $G \in E$ constitute the *EC domain parameters*.

The library **EC–211** accepts any set of EC domain parameters (a, b, r, k, G) satisfying the following:

- a is zero in all bit positions except for bits 7-0 ;
- r is exactly 211 bits long, i.e. $2^{210} < r < 2^{211}$;
- k is equal to 2.

The user-defined type **EC211DomainParams**, defined in file `BasicCardPro\Lib\EC-211.DEF`, contains curve parameters a (1 byte), b (27 bytes), r (27 bytes), and G (27 bytes), for a total of 82 bytes.

The library **EC–167** accepts any set of EC domain parameters (a, b, r, k, G) satisfying the following:

- a is zero in all bit positions except for bits 7-0 ;
- r is exactly 167 bits long, i.e. $2^{166} < r < 2^{167}$;
- k is equal to 2.

The user-defined type **EC167DomainParams**, defined in file `BasicCardPro\Lib\EC-167.DEF`, contains curve parameters a (1 byte), b (21 bytes), r (21 bytes), and G (21 bytes), for a total of 64 bytes.

The library **EC–161** accepts any set of EC domain parameters (a, b, r, k, G) that satisfies the following conditions:

- a is zero in all bit positions except for bits 78-72 ;
- r is exactly 161 bits long, i.e. $2^{160} < r < 2^{161}$;
- k is a single byte, equal to 2 modulo 4.

The user-defined type **EC161DomainParams**, defined in file `BasicCardPro\Lib\EC-161.DEF`, contains curve parameters a (1 byte), b (21 bytes), r (21 bytes), k (1 byte), and G (22 bytes), for a total of 66 bytes.

Points on the Curve

Points on the curve play two roles in Elliptic Curve cryptography:

- EC domain parameter G is a point on the curve;
- every public key is a point on the curve. (For a private key s, the corresponding public key is sG.)

If P is on the curve and $x_P \neq 0$, then $y^2 + x_P y = x_P^3 + a x_P^2 + b$ has two solutions, y_0 and y_1. Moreover, the two expressions y_0 / x_P and y_1 / x_P differ only in bit 0 (in the Polynomial Basis representation); so if we know x_P and bit 0 of y_P / x_P , we can recover point P in full. This bit is called the *compressed y-coordinate* of the point P, denoted $\tilde{y}_P$.

A point P on a curve over **GF**(2^{211}) is represented by 27 bytes, with $\tilde{y}_P$ in bit 215, and x_P in bits 210-0.

A point P on a curve over **GF**(2^{167}) is represented by 21 bytes, with $\tilde{y}_P$ in bit 167, and x_P in bits 166-0.

A point P on a curve over **GF**(2^{168}) is represented by 22 bytes, with x_P in the leftmost 21 bytes (i.e. in bits 175-8), and $\tilde{y}_P$ in bit 0.

Signatures

A signature consists of two integers (c, d). Each of these integers is 27 bytes long in library **EC–211**, and 21 bytes long in libraries **EC–167** and **EC–161**, for a total signature length of 54 or 42 bytes. See **IEEE P1363** for the definitions of c and d.

7.3.9 Conformance Specification

This implementation follows the standard **IEEE P1363: Standard Specifications for Public Key Cryptography**. In the terminology of this standard, the following schemes, primitives, and additional techniques are implemented:

Scheme	*Description*	*Terminal*	*BasicCard*
ECKAS-DH1	Elliptic Curve Key Agreement Scheme, Diffie-Hellman version, where each party contributes one key pair. This scheme uses primitive **ECSVDP-DH**, with additional technique **KDF1.**	✓	✓
ECSSA	Elliptic Curve Signature Scheme with Appendix. This scheme uses primitives **ECSP-NR** (in the Terminal and the BasicCard) and **ECSV-NR** (in the Terminal only), and additional technique **EMSA1**.	✓	✓

Primitive	*Description*	*Terminal*	*BasicCard*
ECSVDP-DH	Elliptic Curve Secret Value Derivation Primitive, Diffie-Hellman version.	✓	✓
ECSP-NR	Elliptic Curve Signature Primitive, Nyberg-Rueppel version.	✓	✓
ECVP-NR	Elliptic Curve Verification Primitive, Nyberg-Rueppel version.	✓	**Not Enhanced BasicCard**

Additional Technique	*Description*	*Terminal*	*BasicCard*
KDF1	Key Derivation Function. The hash function is **SHA–256: Secure Hash Standard** for library **EC–211**, and **SHA–1: Secure Hash Algorithm Revision 1** for libraries **EC–167** and **EC–161**.	✓	✓
EMSA1	Encoding Method for Signatures with Appendix. The hash function is **SHA–256: Secure Hash Standard** for library **EC–211**, and **SHA–1: Secure Hash Algorithm Revision 1** for libraries **EC–167** and **EC–161**.	✓	✓

7.4 The COMPONENT Library

This library is available in the MultiApplication BasicCard, and in the Terminal Program. See **Chapter 5: The MultiApplication BasicCard** for information on Components. Procedures in the **COMPONENT** library report errors via the **LibError** variable; a list of error codes (beginning **ce...**) can be found in COMPONNT.DEF. In Terminal programs, errors are also reported via **SW1SW2**. The corresponding error codes can be found in COMMANDS.DEF.

To use the **COMPONENT** library:

#Include COMPONNT.DEF

The following procedures for handling Security Components are provided:

Sub SelectApplication (*filename$*)

> Select the Application contained in the given file. **Execute** access to the file is required. See **8.7.21 The SELECT APPLICATION Command** for further information.

Sub CreateComponent (*type@*, *name$*, *attr$*, *data$*)

> Create a Component. **Write** access is required to the parent directory. *name$* can be empty, if an anonymous ACR is being created. The formats of *attr$* and *data$* depend on the type of the Component; they are described in **5.8 Component Details**. See **8.7.22 The CREATE COMPONENT Command** for further information.

Sub DeleteComponent (*CID%*)

> Delete a Component. **Delete** access to the Component is required. See **8.7.23 The DELETE COMPONENT Command** for further information.

Sub WriteComponentAttr (*CID%*, *attr$***)**

Write a Component's Attributes. Both **Write** and **Delete** access to the Component are required. The format of *attr$* depends on the type of the Component; it is described in **5.8 Component Details**. See **8.7.24 The WRITE COMPONENT ATTR Command** for further information.

Function ReadComponentAttr (*CID%***) As String**

Read a Component's attributes. **Read** access to the Component's parent directory is required (but not **Read** access to the Component itself). The format of the returned string depends on the type of the Component; it is described in **5.8 Component Details**. See **8.7.25 The READ COMPONENT ATTR Command** for further information.

Sub WriteComponentData (*CID%*, *data$***)**

Write a Component's Data. **Write** access to the Component is required. See **8.7.26 The WRITE COMPONENT DATA Command** for further information.

Function ReadComponentData (*CID%***) As String**

Read a Component's data. **Read** access to the Component is required. See **8.7.27 The READ COMPONENT DATA Command** for further information.

Function FindComponent (*type@*, *name$***) As Integer**

Find a Component of a given type, and return its CID. Just like a filename, *name$* can be a full pathname (beginning with a backslash character) or a relative pathname (relative to the current directory). **Read** access is required to all directories in the path (but not to the Component itself). See **5.1 Components** for details. If the Component does not exist, **LibError** is set to **ceComponentNotFound**.

See **8.7.28 The FIND COMPONENT Command** for further information.

Function ComponentName (*CID%***) As String**

Return the full pathname of the Component with the given CID. **Read** access is required to all directories in the path (but not to the Component itself). See **8.7.29 The COMPONENT NAME Command** for further information.

Sub GrantPrivilege (*CID%*, *filename$***)**

Grant the Privilege with the given CID to the specified file. Requires **Grant** access to the Privilege, and **Write** access to the file. The Privilege is added to the file's Rights List. The file will typically be an Application, although this is not required.

If *filename$* is an empty string, the Privilege is granted to the Terminal program, and lasts until the card is reset. The Terminal program may possess up to three Privileges at once.

See **8.7.30 The GRANT PRIVILEGE Command** for further information.

Function AuthenticateFile (*KeyCID%*, *Algorithm@*, *Filename$*, *Signature$***) As Integer**

Authenticate a file with the given Key, using OMAC or EC-167 Elliptic Curve Cryptography. The Key is added to the file's Rights List. See **8.7.31 The AUTHENTICATE FILE Command** for further information.

Function ReadRightsList (*Filename$*, *RightsList%()***) As Integer**

Read the Rights List of the given file into an array. The Rights List contains the CID's of the Privileges granted to the file, and the Keys with which the file has been authenticated. See **8.7.32 The READ RIGHTS LIST Command** for further information.

Sub LoadSequence (*Phase@***)**

Start or finish a Loader Sequence transaction. *Phase@* is equal to **LoadSequenceStart**, **LoadSequenceEnd**, or **LoadSequenceAbort** (defined in COMPONNT.DEF). If *Phase@* is equal to **LoadSequenceAbort**, and no **LoadSequenceEnd** has intervened, then all Components created since **LoadSequenceStart** are deleted. See **8.7.33 The LOAD SEQUENCE Command** for further information.

Sub SecureTransport (*KeyCID%*, *Algorithm@* , *Nonce$*)

If *KeyCID%* is non-zero, start Secure Transport; if *KeyCID%* is zero, end Secure Transport. This procedure is available in the Terminal program only. See **8.7.34 The SECURE TRANSPORT Command** for further information.

7.5 The EAX Library

EAX is an algorithm for Authenticated Encryption. See **9.6 The EAX Algorithm** for a brief description of the algorithm; a full description is available from NIST's web site, at http://csrc.nist.gov/CryptoToolkit/modes/proposedmodes/. The **EAX** library is currently available for the Terminal program, Professional BasicCard **ZC5.5**, and MultiApplication BasicCard **ZC6.5**. To use the **EAX** library:

#Include EAX.DEF

The **EAX** algorithm takes the following parameters as input:

- A block cipher algorithm. This implementation uses **AES** with key length 128, 192, or 256 bits.
- A cryptographic key for use by the block cipher algorithm.
- A Nonce. This is to ensure that subsequent invocations of **EAX** give different results, even if they encrypt the same data. The Nonce can be any string, which need not be secret, but should be different for each invocation.
- A Header. This contains data that is only authenticated, not encrypted.
- A Message. This contains the data to be encrypted and authenticated.

The algorithm encrypts the message, and computes a 16-byte Tag that authenticates the Header and the Message.

The following procedures are provided:

Function EAXInit (*Type%*, *Key$*) **As String**

This function returns an 87-byte string containing the internal state of the **EAX** algorithm. This string must be provided as the first parameter to all the other procedures in the library. The *Type%* parameter is the length of the key, in bits; it must be 128, 192, or 256. This function need only be called once for a given key.

Sub EAXProvideNonce (*EaxState* **As String**, *Key$*, *N$*)

String *N$* contains the Nonce. This can be any string, which need not be secret, but should be different for each invocation. Call this subroutine once for each invocation of the **EAX** algorithm. It must be called before any of the following procedures.

Sub EAXProvideHeader (*EaxState* **As String**, *Key$*, *H$*)

This subroutine can be called any number of times, to specify successive parts of the Header. Calls to **EAXProvideHeader** may be interleaved with calls to **EAXComputeCiphertext** or **EAXComputePlaintext**.

Sub EAXComputeCiphertext (*EaxState* **As String**, *Key$, M$*)

This subroutine can be called any number of times, to specify successive parts of the Message to be encrypted. The string *M$* is encrypted in place. Calls to **EAXComputeCiphertext** may be interleaved with calls to **EAXProvideHeader**.

Sub EAXComputePlaintext (*EaxState* **As String**, *Key$*, *M$*)

This subroutine can be called any number of times, to specify successive parts of the encrypted Message. The string *M$* is decrypted in place. Calls to **EAXComputePlaintext** may be interleaved with calls to **EAXProvideHeader**.

Function EAXComputeTag (*EaxState* **As String**, *Key$*) **As String**

Call this function at the end to compute the Tag. A 16-byte string is returned.

7.6 The OMAC Library

OMAC is an algorithm for Message Authentication. See **9.8 The OMAC Algorithm** for a brief description of the algorithm; a full description is available from NIST's web site, at http://csrc.nist.gov/CryptoToolkit/modes/proposedmodes/. The **OMAC** library is currently available for the Terminal program, Professional BasicCard **ZC5.5**, and MultiApplication BasicCard **ZC6.5**. To use the **OMAC** library:

#Include OMAC.DEF

The **OMAC** algorithm takes the following parameters as input:

- A block cipher algorithm. This implementation uses **AES** with key length 128, 192, or 256 bits.
- A cryptographic key for use by the block cipher algorithm.
- A Message. This contains the data to be authenticated.

The algorithm computes a 16-byte Tag that authenticates the Message.

The simplest way to calculate the Tag is to use the following function:

Function OMAC (*Type%*, *Key$*, *Mess$***) As String**

> The *Type%* parameter is the length of the key, in bits; it must be 128, 192, or 256. This function computes the Tag for message *Mess$* and returns it as a 16-byte string.

If your message is too long to fit into a string, or if you have multiple messages to authenticate and you want to process them as fast as possible, you can use the incremental procedures:

Function OMACInit (*Type%*, *Key$***) As String**

> This function returns a 34-byte string containing the internal state of the **OMAC** algorithm. This string must be provided as the first parameter to the following library procedures. The *Type%* parameter is the length of the key, in bits; it must be 128, 192, or 256. This function need only be called once for a given key.

Sub OMACStart (*OmacState* **As String)**

> Call this subroutine once for every message, before processing the message data.

Sub OMACAppend (*OmacState* **As String**, *Key$*, *Mess$***)**

> Call this subroutine to add *Mess$* to the message being authenticated. This subroutine can be called any number of times, to authenticate a message of any length.

Function OMACEnd (*OmacState* **As String**, *Key$***) As String**

> This function computes the Tag of the message, returning it as a 16-byte string.

7.7 SHA: The Secure Hash Algorithm Library

This library implements the Secure Hash Algorithms **SHA–1** and **SHA–256** as defined in the Federal Information Processing Standards document FIPS 180–2. The algorithms take an arbitrary message as input, and output a 20-byte hash (**SHA–1**) or 32-byte hash (**SHA–256**) of that message. It is supposed to be computationally infeasible to invert these algorithms. More specifically:

- given a 20- or 32-byte hash, it is computationally infeasible to construct a message with that hash;
- it is computationally infeasible to construct two different messages with identical hashes.

The **SHA** library was implemented as an adjunct to the **RSA** and Elliptic Curve libraries. In the first place, it provides approved hashing algorithms for use in Elliptic Curve digital signature generation; and in the second place, it provides a source of cryptographically strong pseudo-random numbers, for the generation of keys and signatures.

However, it can also be used as a stand-alone library. To load this library:

#Include SHA.DEF

The file SHA.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

The **SHA–256** algorithm is new in Version 5.22 of the development software; earlier versions provided **SHA–1** only. **SHA–256** procedures are currently available in Terminal programs, Professional BasicCard **ZC5.5 REV H**, and MultiApplication BasicCard **ZC6.5 REV D**. **SHA–256** procedure names begin with **Sha256**; **SHA–1** procedure names begin with **Sha**.

7.7.1 Hashing Functions

If a message is contained in a **String**, you can compute its hash with a single function call:

Function ShaHash (*S$***) As String**
Function Sha256Hash (*S$***) As String**

To hash longer messages, you must use the following procedures:

Professional and MultiApplication BasicCards:

Sub ShaStart (*HashBuff$***)**
Sub ShaAppend (*HashBuff$, S$***)**
Function ShaEnd (*HashBuff$***) As String**

Sub Sha256Start (*HashBuff$***)**
Sub Sha256Append (*HashBuff$, S$***)**
Function Sha256End (*HashBuff$***) As String**

Other Environments:

Sub ShaStart()
Sub ShaAppend (*S$***)**
Function ShaEnd() As String

Sub Sha256Start()
Sub Sha256Append (*S$***)**
Function Sha256End() As String

Call **ShaStart()** (resp. **Sha256Start()**) to initialise the hashing process, then **ShaAppend (***S$***)** (resp. **Sha256Append (***S$***)**) for successive blocks of data, and finally **ShaEnd()** (resp. **Sha256End()**) to get the 20-byte (resp. 32-byte) hash value. In the Professional and MultiApplication BasicCards, the *HashBuff$* argument is used to store the internal state of the hash algorithm; other environments have static buffers for this purpose.

7.7.2 Pseudo-Random Number Generation

The Professional and MultiApplication BasicCards have hardware random number generators; other environments must generate pseudo-random numbers in software. The Secure Hash Algorithm is one source of cryptographically strong pseudo-random numbers. To do this properly, it must be fed with some initial source of random data, for instance user key-strokes (see example program **ECTERM** in directory `BasicCardPro\Examples\EC`).

Sub ShaRandomSeed (*Seed$***)**

This function mixes the given seed into the 'randomness pool'.

Function ShaRandomHash() As String

This function returns a random string, 32 bytes long in a Terminal program, 20 bytes long in an Enhanced BasicCard program. Each byte in the string is a random number between 0 and 255 inclusive.

Each time that you call **ShaRandomSeed (***Seed$***)** , the seed is mixed into the 'randomness pool'. The effect is cumulative, so the more data you mix in, the better. The ZC-Basic interpreter mixes in some data of its own each time this procedure is called:

- The Terminal program mixes in the date and time, and the elapsed CPU time for the process.
- The Enhanced BasicCard mixes in its unique serial number. So any two cards will generate different sequences, even if they are fed with the same seeds.

The Enhanced BasicCard has no other internal source of randomness, so you must send it random data from the Terminal program if cryptographically strong random numbers are required, for instance when generating key pairs for use by the **EC–161** Elliptic Curve Cryptography library.

7.8 IDEA: International Data Encryption Algorithm

The **IDEA** library implements the International Data Encryption Algorithm, a block cipher with a 128-bit key size. This algorithm is cryptographically as strong as Triple DES, but is more than three times as fast. To load this library:

#Include IDEA.DEF

The file IDEA.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

Note: The International Data Encryption Algorithm may be used free of charge for non-commercial purposes. For commercial use, permission must be obtained from the patent holders:

Ascom Systec Ltd. Gewerbepark CH-5506 Maegenwil Switzerland	Internet: http://www.ascom.com/infosec e-mail: IDEA@ascom.ch

7.8.1 IDEA Functions

The library privides two functions:

Function IdeaEncrypt (*Key$*, *Data$*) As String
Function IdeaDecrypt (*Key$*, *Data$*) As String

Key$ The 16-byte cryptographic key.
Data$ The 8-byte data block to be encrypted or decrypted.

Both functions return an 8-byte string.

If **Len(*Key$*) < 16** or **Len(*Data$*) < 8**, variable **LibError** is set to **IdeaBadProcParams** (&H4301).

The **IDEA** algorithm can be used in various modes of operation: Electronic Codebook (**ECB**) mode, Cipher Feedback (**CFB**) mode, etc. These modes have been implemented in ZC-Basic in the file IDEATEST.BAS, in the directory `BasicCardPro\Examples\IDEA`.

7.9 MATH: Mathematical Functions

The **MATH** library provides standard mathematical functions such as **Exp** and **Sin**. It may only be used in Terminal programs. To load this library:

#Include MATH.DEF

The file MATH.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory.

7.9.1 Error Codes

The **MATH** library procedures can signal the following error codes in **LibError**:

MathDomain	A parameter was outside the valid range, e.g. **Log (–1.0)**
MathSingularity	The function has a singularity at the given point, e.g. **Tan (MathPi / 2)**
MathOverflow	The maximum **Single** value of 3.402823E+38 was exceeded
MathUnderflow	The minimum **Single** value of 1.401298E–45 was truncated to zero
MathLossOfPrecision	Total loss of precision renders the result meaningless, e.g. **Sin (1E30)**

These constants are defined in MATH.DEF.

7.9.2 Integer Rounding

Function Floor (*X!*) As Single	The largest integer <= *X!*, as a **Single** value
Function Ceil (*X!*) As Single	The smallest integer >= *X!*, as a **Single** value

7.9.3 Exponentiation

Function Pow (*X!*, *Y!*) **As Single**	*X!* to the power *Y!*
Function Exp (*X!*) **As Single**	***e*** to the power *X!* (***e*** is the base of natural logarithms)
Function LogE (*X!*) **As Single**	The natural logarithm of *X!* (i.e. the logarithm to base ***e***)
Function Log10 (*X!*) **As Single**	The logarithm of *X!* to base 10

7.9.4 Trigonometric Functions

Function Hypot (*X!*, *Y!*) **As Single**	**Sqrt** (*X!* * *X!* + *Y!* * *Y!*) (with no intermediate overflow)
Function Sin (*X!*) **As Single**	Sine function
Function Cos (*X!*) **As Single**	Cosine function
Function Tan (*X!*) **As Single**	Tangent function **Tan** (*X!*) = **Sin** (*X!*) **/ Cos** (*X!*)
Function ASin (*X!*) **As Single**	Inverse Sine function (**–π/2** <= **ASin** (*X!*) <= **π/2**)
Function ACos (*X!*) **As Single**	Inverse Cosine function (**0** <= **ACos** (*X!*) <= **π**)
Function ATan (*X!*) **As Single**	Inverse Tangent function (**–π/2** < **ATan** (*X!*) < **π/2**)
Function ATan2 (*Y!*, *X!*) **As Single**	Inverse Tangent at (*X!*, *Y!*) (**–π** < **ATan2** (*Y!*, *X!*) <= **π**)

7.9.5 Hyperbolic Functions

Function SinH (*X!*) **As Single**	Hyperbolic Sine: **(Exp** (*X!*) **– Exp** (*–X!*)**) / 2**
Function CosH (*X!*) **As Single**	Hyperbolic Cosine: **(Exp** (*X!*) + **Exp** (*–X!*)**) / 2**
Function TanH (*X!*) **As Single**	Hyperbolic Tangent: **SinH** (*X!*) **/ CosH** (*X!*)

7.9.6 Mathematical Constants

The following constants are defined in MATH.DEF:

Const MathE = 2.718281828	The base ***e*** of natural logarithms
Const MathPi = 3.141592654	**π**

7.10 MISC: Miscellaneous Procedures

The **MISC** library provides miscellaneous utility procedures. To load this library:

#Include MISC.DEF

The file MISC.DEF is supplied with the distribution kit, in the `BasicCardPro\Lib` directory. It contains the following procedures, all of which are defined in more detail below:

For Terminal programs:

Timing Functions	**Sub GetDateTime (***DT* **As DateTime)**
	Function TimeInterval (*StartTime* **As DateTime,** *EndTime* **As DateTime) As Long**
	Function UnixTime() As Long
Suspending the Program	**Sub Sleep (***Milliseconds* **As Long)**
Executing a Command Line	**Sub Execute (***CommandString$***)**
CRC Calculations	**Function CRC16 (***S$***) As Integer**
	Sub UpdateCRC16 (*CRC***,** *S$***)**
	Function CRC32 (*S$***) As Long**
	Sub UpdateCRC32 (*CRC* **As Long,** *S$***)**
Random String	**Sub RandomString (***S$***,** *Len***)**
Making a Noise	**Sub Beep (***Frequency***,** *Duration* **As Long)**

For Enhanced BasicCards **ZC3.3**, **ZC3.4**, **ZC3.5**, **ZC3.6**:

Fast EEPROM Writes	**Sub FastEepromWrites ()**

For Professional and MultiApplication BasicCards:

Random String	**Sub RandomString (***S$***,** *Len***)**
Communications	**Function LePresent()**
	Sub SuspendSW1SW2Processing()
Hardware Data	**Function CardSerialNumber() As String**
Free Memory	**Sub GetFreeMemory (***Mem* **As FreeMemoryData)**
Power Management	**Function SetProcessorSpeed (***Divider@***)**

7.10.1 Timing Functions

Three timing procedures are provided, for use in Terminal programs only.

Two of these procedures take parameters of type **DateTime**, defined in MISC.DEF:

```
Type DateTime
    Year, Month, Day
    Hour, Minute, Second
    Millisecond
End Type
```

Sub GetDateTime (*DT* **As DateTime)**

Returns the current system date and time in *DT*.

Note: DT is filled in from the system clock. Under MS-DOS and Windows®, the system clock has a resolution of about 55 milliseconds, which is rounded to a multiple of 10. So values returned by **GetDateTime** will jump in increments of 50 or 60 milliseconds.

Function TimeInterval (*StartTime* **As DateTime,** *EndTime* **As DateTime) As Long**

Returns the time interval between *StartTime* and *EndTime*, in milliseconds. This interval will be a multiple of the system clock resolution; see note to **GetDateTime**.

For examples of the use of these procedures, see programs ECINIT.BAS and ECTEST.BAS in directory `BasicCardPro\Examples\EC`.

The third timing procedure returns the number of seconds elapsed since 1st January 1970:

Function UnixTime() As Long

7.10.2 Suspending the Program

In a Terminal program, the following subroutine suspends execution for the specified number of milliseconds:

Sub Sleep (*Milliseconds* **As Long)**

This frees the CPU for other processes to use.

7.10.3 Executing a Command Line

An operating system command can be executed from a Terminal program using the **Execute** subroutine:

Sub Execute (*CommandString$***)**

The following error codes are returned in the **LibError** variable:

MiscCommandTooLong	Under MS-DOS, the command string was longer than 128 bytes
MiscFileNotFound	The command string specified a non-existent executable file
MiscNotExecutable	The command string specified a non-executable file
MiscOutOfMemory	Insufficient memory to execute the command
MiscUnexpectedError	The operating system returned an unexpected error code

These constants are defined in MISC.DEF.

Note that it is not possible to retrieve an error code generated by the command itself.

7.10.4 CRC Calculations

Function CRC16 (*S$*) As Integer — Returns the 16-bit CRC of the string *S$*
Sub UpdateCRC16 (*CRC*, *S$*) — Allows cumulative calculation of 16-bit CRC's
Function CRC32 (*S$*) As Long — Returns the 32-bit CRC of the string *S$*
Sub UpdateCRC32 (*CRC* As Long, *S$*) — Allows cumulative calculation of 32-bit CRC's

To calculate the CRC of a single **String** value, call **CRC16** or **CRC32**. To calculate CRC's for larger amounts of data, first initialise *CRC* to zero, then call **UpdateCRC16** or **UpdateCRC32** with successive values of *S$*.

Here are 'C' functions to calculate the 16-bit and 32-bit CRC's:

```
unsigned short CRC16 (unsigned char *p, unsigned int len)
  {
  unsigned short crc = 0 ;
  while (len--)
    {
    unsigned char NextByte = *p++ ;
    int i ;
    for (i = 0 ; i < 8 ; i++, NextByte >>= 1)
      {
      if ((crc ^ NextByte) & 1)
        {
        crc >>= 1 ;
        crc ^= 0xCA00 ;
        }
      else crc >>= 1 ;
      }
    }
  return crc ;
  }

unsigned long CRC32 (unsigned char *p, unsigned int len)
  {
  unsigned long crc = 0 ;
  while (len--)
    {
    unsigned char NextByte = *p++ ;
    int i ;
    for (i = 0 ; i < 8 ; i++, NextByte >>= 1)
      {
      if ((crc ^ NextByte) & 1)
        {
        crc >>= 1 ;
        crc ^= 0xA3000000 ;
        }
      else crc >>= 1 ;
      }
    }
  return crc ;
  }
```

7.10.5 Making a Noise

The Terminal program can generate an audible beep with the **Beep** subroutine:

Sub Beep (*Frequency*, *Duration* As Long)

The duration is in milliseconds.

Note: The *Frequency* and *Duration* parameters are only effective under Windows® NT, Windows® 2000, and later systems; they are ignored under Windows® 98 (although they must be present).

7.10.6 Fast EEPROM Writes

The EEPROM in the Enhanced BasicCard has an erase/write cycle time of 6 milliseconds – it takes this long to guarantee that each bit has been completeley discharged and/or recharged. The BasicCard has no internal clock, so it must count instruction cycles to estimate the elapsed time. However, it has no way of knowing the clock frequency, so it must assume the worst case – it must assume that the clock is running at its maximum allowed speed. This maximum speed is specified in standard ISO/IEC 7816-3 as 5 MHz.

If the card reader is generating a slower clock frequency, then EEPROM writes will take longer than they need to. For instance, most readers (including ZeitControl's Chip-X® and CyberMouse® card reader) generate a clock frequency of 3.57 MHz; so instead of 6 milliseconds, an EEPROM write takes 8.4 milliseconds. If speed is important to you, and if you know that the clock frequency is only 3.57 MHz (or less), you can call the following procedure:

Sub FastEepromWrites()

The BasicCard operating system will then speed up its EEPROM writes, so that they take 6 milliseconds at the assumed slower clock speed. This procedure is available for Enhanced BasicCards **ZC3.3**, **ZC3.4**, **ZC3.5**, and **ZC3.6**.

Warning: If in fact the card reader is running at faster than 3.57 MHz, calling this procedure may result in subsequent loss of EEPROM data through charge leakage.

7.10.7 Random String

In the Terminal program and in all current Professional BasicCards, a **String** variable can be filled with random data:

Sub RandomString (*S$***,** *Len***)**

On return, *S$* contains *Len* bytes of random data.

7.10.8 SW1-SW2 Processing

Normally, if **SW1-SW2 <> &H9000**, and **SW1 <> &H61**, then **ODATA** is not sent – see **8.5 Commands and Responses**. You can override this behaviour in some BasicCards with the following procedure call:

Sub SuspendSW1SW2Processing()

The card will then send the **ODATA** field in the response, regardless of the value of **SW1-SW2**. This procedure only affects the current command. See **3.3.4 The #Pragma Directive** for an alternative method.

At the time of writing, this procedure is available in Professional BasicCards **ZC4.5A** (from Revision D), **ZC4.5D** (from Revision D), and **ZC5.5** (all revisions), and in MultiApplication BasicCard **ZC6.5**.

7.10.9 Card Serial Number

In Professional and MultiApplication BasicCards, the card's unique Serial Number is available as an 8-byte string:

Function CardSerialNumber() As String

This is the same number that is returned by the **GET APPLICATION ID** command when **P2 = 3** – see **8.7.10 The GET APPLICATION ID Command**.

7.10.10 Free Memory

In the MultiApplication BasicCard, you can find out the state of the various memory allocation heaps:

Sub GetFreeMemory (*Mem* **As FreeMemoryData)**

For each heap, the total free memory and the size of the largest free block are returned in a **HeapData** structure:

```
Type HeapData
  TotalFreeMemory%
  LargestFreeBlock%
End Type

Type FreeMemoryData
  RamHeapData As HeapData
  AppFileHeapData As HeapData
  EepromHeapData As HeapData
End Type
```

See **5.2.4 Memory Allocation** for more information on heaps in the MultiApplication BasicCard.

7.10.11 Power Management

The new high-performance chips used in the latest Professional and MultiApplication BasicCards run more than twice as fast as previous versions. However, they require more power, which may be a disadvantage for certain applications. So you can slow the processor down to reduce power consumption:

Function SetProcessorSpeed (*Divider@***) As Byte**

The higher the value of *Divider@* , the slower the processor speed. The function returns the previous value of *Divider@*.

Divider@ is rounded down to the nearest value that is supported by the processor. The set of supported values depends on the hardware. Current BasicCards provide the following options:

ZC5.4 REV H 1 <= *Divider@* <= 16
ZC5.5 REV H *Divider@* = 1, 2, 4, or 8
ZC6.5 REV D *Divider@* = 1, 2, 4, or 8

Whatever the range of supported values, **SetProcessorSpeed (1)** sets the maximum processor speed, and **SetProcessorSpeed (255)** sets the minimum processor speed. **SetProcessorSpeed (0)** does nothing, but returns the current value.

Part II

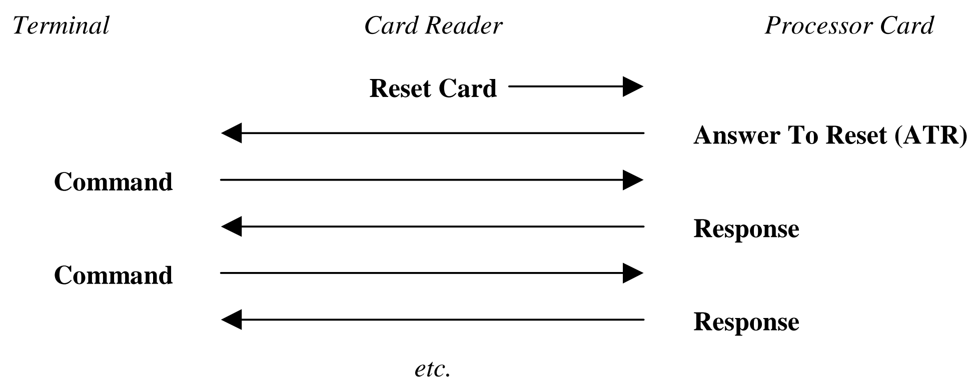
Technical Reference

8. Communications

Note: Throughout this chapter, **bold** numbers are hexadecimal.

8.1 Overview

As outlined in **1.1 Processor Cards**, communication between a Terminal and a Processor Card proceeds, via a Card Reader, as a series of Commands (initiated by the Terminal) and Responses (sent by the Processor Card). The series starts with the Card Reader sending a **Reset Card** signal to the Processor Card:



Two documents describe this process in detail:

1. **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*

This document describes the communication between the Card Reader and the Processor Card, from the bit level through the byte level to the block level. We will be concerned with three aspects:

- the structure of the **ATR**;
- the **T=0** character transmission protocol;
- the **T=1** block transmission protocol.

2. **ISO/IEC 7816-4**: *Interindustry commands for interchange*

This document describes Commands and Responses. We will be concerned with three aspects:

- the contents of Commands and Responses;
- the method by which the **T=0** protocol transmits Commands and Responses;
- the method by which the **T=1** protocol transmits Commands and Responses.

We provide a summary of these documents in the following sections. Most readers can skip these sections; they are provided mainly for users who need to program the BasicCard to be compatible with existing systems.

In these documents, a Command or Response is referred to as an **APDU** (application protocol data unit). The structure of Command and Response **APDU**'s is described in **8.5 Commands and Responses**.

8.2 Answer To Reset

With the Answer To Reset (**ATR**), the Processor Card identifies itself and indicates which protocols it supports. Most of the data in the **ATR** is not relevant to a BasicCard programmer. The following information is important:

- whether the card supports the **T=0** and/or the **T=1** protocols;
- the maximum communication speed that the card allows;
- the Historical Characters.

The Compact and Enhanced BasicCards support only the **T=1** protocol, at 9600 baud. They send the following **ATR** (the byte names are from ISO/IEC):

TS	T0	TB1	TC1	TD1	TD2	TA3	TB3	T1-TK
3B	**EF**	**00**	**FF**	**81**	**31**	**50** or **20**	**45** or **75**	'BasicCard ZC*vvv*'

Briefly, what this means is:

TS = 3B Direct convention (high = **1**, low = **0**; least significant bit arrives first)
T0 = EF **E** → **TB1**, **TC1**, **TD1** follow; **F** → 15 historical characters
TB1 = 00 No EEPROM programming voltage required
TC1 = FF Waiting time between two characters = 11 **ETU**
TD1 = 81 **TD2** follows (**T=1** indication)
TD2 = 31 **TA3**, **TB3** follow (**T=1** indication)
TA3 = 50 or **20** **IFSC** (Information Field Size) = &H50 in Compact card, &H20 in Enhanced card
TB3 = 45 or **75** **CWT** (character waiting time) = (11 + 32) **ETU** (= 3.33 ms between characters)
In ZC1.1, ZC3.3, and ZC3.5 cards (**TB3 = 45**):
BWT (block waiting time) = (11 + 16*960) **ETU** (= 1.6 seconds between blocks)
In later cards (**TB3 = 75**):
BWT (block waiting time) = (11 + 128*960) **ETU** (= 12.8 seconds between blocks)
T1-TK The historical characters (*vvv* is the BasicCard firmware version number)

An **ETU** (elementary time unit) is one bit, or 372 clock cycles. The timing figures assume a clock frequency of 3.57 MHz. Historical characters **T1-TK** can be configured in ZC-Basic with the **Declare ATR** statement; the whole of the **ATR** can be specified with **Declare Binary ATR** – see **3.20.1 Customised ATR**.

The Professional BasicCards are more flexible in their capabilities; they support the **T=0** protocol as well as the **T=1** protocol, and they can run at up to 38400 baud. Here is a typical **ATR** (from the Professional BasicCard **"ZC4.5D REV C"**):

TS	T0	TA1	TB1	TC1	TD1	TC2	T1-TK
3B	**FC**	**13**	**00**	**FF**	**40**	**80**	'ZC4.5D REV C'

TS = 3B Direct convention (high = **1**, low = **0**; most significant bit arrives first)
T0 = FC **F** → **TA1**, **TB1**, **TC1**, **TD1** follow; **C** → 12 historical characters
TA1 = 13 **FI = 1**; **DI = 3** → maximum allowed communication speed = 38400 baud
TB1 = 00 No EEPROM programming voltage required
TC1 = FF Waiting time between two characters = 11 **ETU**
TD1 = 40 **TC2** follows (**T=0** indication)
TC2 = 80 **WI** = 128 → **WWT** (work waiting time) = 12.8 seconds

More examples are available in the file **BasicCardPro\Inc\ATRList.Def**, supplied with the distribution kit. This file contains the **ATR** of every currently available BasicCard.

8.3 The T=0 Protocol

The **T=0** protocol is a character-level transmission protocol for integrated circuit cards with contacts, defined in the document **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*. Some Professional BasicCards support the **T=0** protocol, as well as the **T=1** protocol described in the next section. **T=1** is faster, easier to use, and less error-prone; you should only use the **T=0** protocol if you are implementing a pre-existing **T=0** command set, or you need to use card readers that don't support the **T=1** protocol.

The **T=0** protocol is defined as a sequence of messages exchanged between the **IFD** (interface device) and the **ICC** (integrated circuit card). In the present context, the **IFD** is the Terminal program, and the

ICC is the BasicCard. The exchange begins when the **ICC** is powered up and responds with an **ATR** (Answer To Reset). Thereafter the **IFD** sends a **TPDU** (transmission protocol data unit) containing a Command, and the **ICC** replies with a **TPDU** containing the Response. A **TPDU** is a lower-level object than an **APDU**; we will see later how **APDU**'s are constructed from **TPDU**'s.

8.3.1 TPDU Transmission

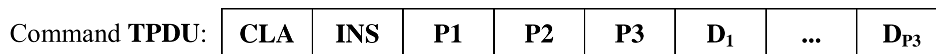
When the **IFD** sends a Command **TPDU** and the **ICC** replies with a response **TPDU**, only one of the two **TPDU**'s may contain data. If the Command **TPDU** contains data, it is an *incoming data transfer*; if the Response **TPDU** contains data, it is an *outgoing data transfer*. The **T=0** protocol does not provide any mechanism for specifying which of the two **TPDU**'s may contain data; and in fact the protocol grinds to a halt if the **IFD** and **ICC** don't agree on the direction of data transfer.

In both cases, the **IFD** first sends a 5-byte command header:

CLA	Class byte – first byte of two-byte **CLA INS** command identifier. This byte may not be **FF**.
INS	Instruction byte – second byte of two-byte **CLA INS** command identifier. **INS** must be even, and the top nibble may not be **6** or **9**.
P1	Parameter 1 of 4-byte **CLA INS P1 P2** command header.
P2	Parameter 2 of 4-byte **CLA INS P1 P2** command header.
P3	Number of data bytes.

From the command header, the **ICC** must be able to determine whether the **IFD** expects an incoming or outgoing data transfer.

Incoming Data Transfer



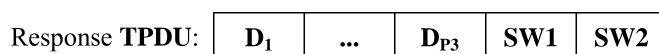
The **ICC** acknowledges the 5-byte command header by echoing the **INS** byte (more variations are described in the **ISO/IEC** document, but the BasicCard does not use them):

The **IFD** then sends **P3** bytes of data:

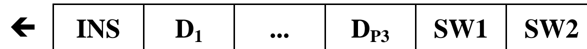
The **ICC** responds with a two-byte status code:

where the top nibble of **SW1** is **6** or **9** (but **SW1=60** is not allowed). Status codes are described in **8.6 Status Bytes SW1 and SW2**.

Outgoing Data Transfer



The **ICC** acknowledges the 5-byte command header by echoing the **INS** byte, and then sends **P3** data bytes, followed by a two-byte status code:



In both cases, the **ICC** may reject the command by responding immediately with **SW1-SW2** instead of echoing **INS**.

If the **WWT** work waiting time is exceeded, the **IFD** will time out. The **ICC** can restart the timer, and so delay the time out, by sending a **NULL** (**60**) byte. In a BasicCard program, this is done with the **WTX** statement:

WTX *n*

The ZC-Basic syntax requires the parameter *n*, although it is ignored if the card is using **T=0** protocol.

8.3.2 APDU Transmission by T=0

This section describes the methods defined by ISO/IEC for implementing **APDU** exchanges under **T=0**. If you are not familiar with the structure of Command and Response **APDU**'s, you should read **8.5 Commands and Responses** before continuing.

There are four cases to consider. We adhere to the notation in **ISO/IEC 7816-4**: *Interindustry commands for interchange*, **Annex A** (normative): **Transportation of APDU messages by T=0**:

Case 1: **Lc=0**, and **Le** not present: no incoming data, and no outgoing data
Case 2: **Lc=0**, and **Le** present: outgoing data only
Case 3: **Lc** non-zero, and **Le** not present: incoming data only
Case 4: **Lc** non-zero, and **Le** present: incoming and outgoing data

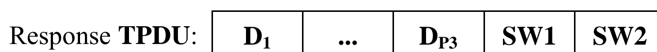
8.3.3 Case 1: No Incoming Data or Outgoing Data

The Command **TPDU** consists of the Command **APDU** with **P3=0** appended:

8.3.4 Case 2: Outgoing Data Only

Case 2S.1 – Le accepted

If the **ICC** accepts the value of **Le** supplied by the **IFD**, the Command and Response **TPDU** are identical to the Command and Response **APDU**:



Case 2S.2 – Le definitely not accepted

If the **ICC** does not accept **Le**, and does not want to suggest an alternative, it replies with **SW1-SW2=6700**:

Command **APDU:**

CLA	INS	P1	P2	Le

Command **TPDU:**

CLA	INS	P1	P2	P3=Le

Response **TPDU**:

67	00

Response **APDU**:

67	00

Case 2S.3 – Le not accepted, La indicated

If the **ICC** does not accept **Le**, and has an alternatve **La** to suggest, it responds with **SW1-SW2** = **6C La**, and the **IFD** can re-issue the command to receive the outgoing data:

Command **APDU:**

CLA	INS	P1	P2	Le

Command **TPDU:**

CLA	INS	P1	P2	P3=Le

Response **TPDU**:

6C	La

Command **TPDU:**

CLA	INS	P1	P2	P3=La

Response **TPDU**:

D_1	...	D_{La}	SW1	SW2

Response **APDU**:

D_1	...	D_{La}	61	La

Case 2S.4 – Command not accepted

Command **APDU:**

CLA	INS	P1	P2	Le

Command **TPDU:**

CLA	INS	P1	P2	P3=Le

Response **TPDU**:

SW1	SW2

Response **APDU**:

SW1	SW2

with **SW1=6***X* except **6C**, or **SW1-SW2=9***XXX* except **9000**.

8.3.5 *Case 3: Incoming Data Only*

The Command and Response **TPDU** are identical to the Command and Response **APDU**:

Command **APDU:**

CLA	INS	P1	P2	Lc	D_1	...	D_{Lc}

Command **TPDU:**

CLA	INS	P1	P2	P3=Lc	D_1	...	D_{P3}

Response **TPDU**:

SW1	SW2

Response **APDU**:

SW1	SW2

8.3.6 *Case 4: Incoming and Outgoing Data*

The Command **TPDU** is identical to the Command **APDU**, but with **Le** removed:

Command **APDU:**

CLA	INS	P1	P2	Lc	D_1	...	D_{Lc}	Le

Command **TPDU:**

CLA	INS	P1	P2	P3=Lc	D_1	...	D_{P3}

Depending on the response, the **IFD** may issue a **GET RESPONSE** Command to request the outgoing data. This command has **INS**=**C0**, **P1=0**, **P2=0**, but the ISO/IEC document leaves the **CLA** byte unspecified. ZeitControl's Terminal software (the **IFC**) uses **CLA=0**; the BasicCard operating system accepts any value for **CLA** that is not a user-defined command.

Case 4S.1 – Command not accepted

Response **TPDU**:

SW1	SW2

Response **APDU**:

SW1	SW2

with **SW1=6***X* except **61**, or **SW1-SW2=9***XXX* except **9000**.

Case 4S.2 – Command accepted

Response **TPDU**:

90	00

The **IFD** issues a **GET RESPONSE** Command:

Command **TPDU:**

CLA=00	INS=C0	P1=00	P2=00	P3=Le

Transmission then proceeds as in *Case 2*.

Case 4S.3 – Command accepted with information added

The **ICC** accepts the command, and indicates that **Lx** bytes of outgoing data are available:

Response **TPDU**:

61	Lx

The **IFD** issues a **GET RESPONSE** Command, with **P3**=**min(Le,Lx)**:

Command **TPDU:**

CLA=00	INS=C0	P1=00	P2=00	P3

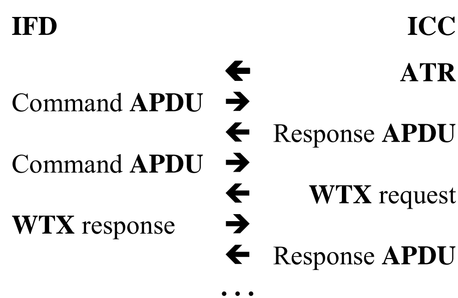
Transmission then proceeds as in *Case 2*.

8.4 The T=1 Protocol

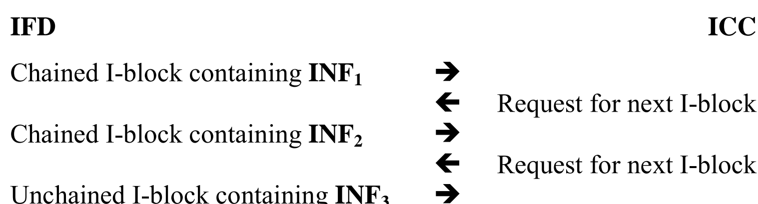
The **T=1** protocol is a block-level transmission protocol for integrated circuit cards with contacts, defined in the document **ISO/IEC 7816-3**: *Electronic signals and transmission protocols*. The BasicCard contains a full implementation of this **T=1** standard, including **NAD** awareness, chaining, retries, **WTX** requests, and **IFS** requests. This section describes those parts of the **T=1** protocol that a programmer of the BasicCard might want to know: (i) the error-free transmission of I-blocks; (ii) the **WTX** request. The mechanisms for chaining, error handling, and **IFS** adjustment are hidden from the programmer, and are not described here. For a detailed definition of the **T=1** protocol, see document **ISO/IEC 7816-3**.

8.4.1 APDU Transmission by T=1

The **T=1** protocol is defined as a sequence of messages exchanged between the **IFD** (interface device) and the **ICC** (integrated circuit card). In the present context, the **IFD** is the Terminal program, and the **ICC** is the BasicCard. The exchange begins when the **ICC** is powered up and responds with an **ATR** (Answer To Reset). Thereafter the **IFD** sends an **APDU** containing a Command, and the **ICC** replies with an **APDU** containing the Response. In between receiving a command and sending its response, the **ICC** may transmit a **WTX** request (waiting time extension), to ask for more time:



Each **APDU** is transmitted in one or more *I-blocks*. An I-block is the fundamental unit of transmission in the **T=1** protocol; successive I-blocks are chained together to produce the Command and Response **APDU**'s. In the following example, **APDU** is the concatenation of $\mathbf{INF_1}$, $\mathbf{INF_2}$, and $\mathbf{INF_3}$:



The maximum allowed length of an I-block depends on the direction of transmission, and on protocol parameters that can vary dynamically; it is typically 32-128 bytes.

8.4.2 Structure of an I-block

An I-block contains the following fields. All fields are one byte, except the **INF**:

NAD Node Address byte. The low nibble contains the Node Address (0-7) of the sender, and the high nibble contains the Node Address (0-7) of the intended recipient. The BasicCard responds to all Node Address values, unless otherwise instructed with the pre-defined **ASSIGN NAD** command. The **NAD** of the response I-block is equal to the **NAD** of the command I-block with the high and low nibbles reversed.

PCB Protocol control byte. Alternates between **00** and **40** (unless chaining is in progress). The BasicCard programmer can ignore this byte.

LEN The length of the **INF** field in bytes.

INF Information field – the information content of the I-block. The **T=1** protocol says nothing about the internal format of the **INF** field.

LRC Longitudinal redundancy check. A simple **Xor** of all the preceding bytes.

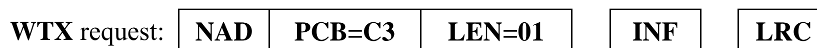
8.4.3 WTX Request

The **BWT** (block waiting time) defined in the **ATR** tells the **IFD** how long to wait for a response before timing out. The BasicCard **ATR** defines a **BWT** of 1.6 seconds (BasicCard versions ZC1.1, ZC3.3, and ZC3.5), or 12.8 seconds (all other BasicCards). If a command is going to take longer than this, it must request more time using a **WTX** (waiting time extension) request. In ZC-Basic, this takes the form

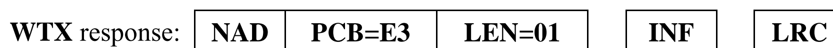
WTX *BWT-units*

BWT-units A **Byte** expression, giving the requested time in multiples of the **BWT**. **WTX** requests are not cumulative; the time allowed is counted from the time of the request, and cancels any previous **WTX** requests.

A **WTX** request contains the following fields:

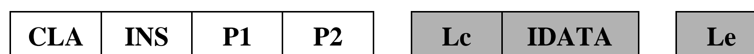


The **INF** field has length 1, and contains the value *BWT-units*. The response to this request contains an identical **INF** field:



8.5 Commands and Responses

This section describes the contents of commands and responses, as defined in the document **ISO/IEC 7816-4**: *Interindustry commands for interchange*. The **APDU** of a command has the following structure (shaded blocks are optional):



CLA Class byte – first byte of two-byte **CLA INS** command identifier. If the **T=0** protocol is used, this byte may not be **FF**.

INS Instruction byte – second byte of two-byte **CLA INS** command identifier. For ISO compatibility, this byte should be even. If the **T=0** protocol is used, the top nibble may not be **6** or **9**.

P1 Parameter 1 of 4-byte **CLA INS P1 P2** command header.

P2 Parameter 2 of 4-byte **CLA INS P1 P2** command header.

Lc Length of **IDATA** field in command.

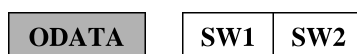
IDATA Data expected by command. In the case of a ZC-Basic command, this field contains the parameters passed by the caller.

Le Expected length of **ODATA** field in response (supplied by caller).

In the BasicCard, **CLA** and **INS** can refer to pre-defined commands (all of which have **CLA=C0**) or ZC-Basic commands (**CLA** and **INS** are specified by the programmer for each command). **P1** and **P2** are retained in the BasicCard for **ISO** compatibility; you can use them if you like, or ignore them. If you want to use them, the parameters passed to you by the caller are available as **Public Byte** variables **P1** and **P2**; and you can specify their values in commands that you call using the *PreSpec* field described in **3.14.3 Calling a Command**:

Call *command-name* (**[P1=***expr***,] [P2=***expr***,]** *arg-list*)

The **APDU** of a response has the following structure (the shaded block is optional):



ODATA Data returned by command. In the case of a ZC-Basic command, this field contains the parameters that were passed by the caller, as modified by the called command.
SW1 First status byte.
SW2 Second status byte.

SW1 and **SW2** are pre-defined **Public** variables of type **Byte**. Before a command is executed, they have the values **&H90** and **&H00**, which is a standard status code meaning "Command successfully completed". If you want to return an error code to the caller, just set **SW1** and **SW2** to the appropriate values before you exit the command.

Notes:

- if **SW1-SW2 <> &H9000**, and **SW1 <> &H61**, then **ODATA** is discarded: any return values are lost. In some Professional BasicCards, you can override this behaviour – see **3.3.4 The #Pragma Directive** and **7.10.8 SW1-SW2 Processing**.
- in a card using the **T=0** protocol, the high nibble of **SW1** must be **6** or **9**.

8.6 Status Bytes SW1 and SW2

8.6.1 BasicCard Operating System

The following status codes are returned by the BasicCard operating system (codes marked with ***** are returned by the MultiApplication BasicCard only):

swCommandOK **9000** Command successfully completed.

sw1LeWarning **61***XX* Command successfully completed, but **Le** was not equal to *XX*.

swRetriesRemaining **63C***X* A command was wrongly encrypted, and the error counter for the active key has been decremented to *X*. If *X* reaches zero, the key is disabled.

sw1PCodeError **64***XX* P-Code error *XX* occurred in the BasicCard. (The P-Code error codes are described in the next section.)

swEepromWriteError **6581** A write to EEPROM failed. (This is a hardware error.)

swBadEepromHeap **6582** The EEPROM heap is in an inconsistent state.

swBadFileChain **6583** The BasicCard File System is in an inconsistent state.

swKeyNotFound **6611** The key specified in a **START ENCRYPTION** command was not configured with a **Declare Key** statement in the BasicCard program.

swPolyNotFound **6612** The **SG-LFSR** algorithm was specified in a **START ENCRYPTION** command, but primitive polynomials were not configured with a **Declare Polynomials** statement in the BasicCard program.

swKeyTooShort **6613** The cryptographic key specified in a **START ENCRYPTION** command was too short for the algorithm. All algorithms require at least 8-byte keys; the **Triple DES** algorithm requires 16-byte keys.

swKeyDisabled **6614** The active key has been disabled, either explicitly with a **Disable Key** statement, or automatically when its error counter reached zero.

swUnknownAlgorithm	**6615**	Parameter **P1** in a **START ENCRYPTION** command does not specify a valid algorithm.
swAlreadyEncrypting	**66C0**	A **START ENCRYPTION** command was received while encryption was already active.
swNotEncrypting	**66C1**	An **END ENCRYPTION** command was received while encryption was not active.
swBadCommandCRC	**66C2**	The active encryption algorithm is **SG_LFSR** with **CRC**, and the CRC in a command was invalid.
swDesCheckError	**66C3**	The active encryption algorithm is **Single DES** or **Triple DES**, and the authentication bytes in a command were invalid.
swCoprocessorError	**66C4**	The Crypto-Coprocessor has reported an internal error.
swAesCheckError	**66C5**	The active encryption algorithm is **AES**, and the authentication bytes in a command were invalid.
***swBadSignature**	**66C6**	An **AUTHENTICATE FILE** command contained an invalid signature.
***swBadAuthenticate**	**66C7**	Invalid **VERIFY** or **EXTERNAL AUTHENTICATE** command.
swLcLeError	**6700**	Either **Lc** has an unexpected value; or **Le** is absent when it should be present, or present when it should be absent.
swCommandTooLong	**6781**	A command will not fit in the command buffer. In the Compact BasicCard, this is the same size as the P-Code stack; in the Enhanced BasicCard, it is 256 bytes. (In state **LOAD**, other limits may apply, but the software support package handles this case.)
swResponseTooLong	**6782**	The response from the card is too long to be sent.
swInvalidState	**6985**	A built-in command was called, but the state of the BasicCard is invalid for the command.
swCardUnconfigured	**6986**	The card has not been configured by ZeitControl.
swNewStateError	**6987**	The state of the BasicCard has been changed with a **SET STATE** command. After a **SET STATE** command, the BasicCard must be reset before it will accept any furhter commands.
***swBadComponentName**	**69C0**	A Component name contained an invalid character.
***swComponentNotFound**	**69C1**	A Component was not found in the BasicCard.
***swAccessDenied**	**69C2**	The required access conditions were not satisfied.
***swComponentAlreadyExists**	**69C3**	A Component with the given name already exists.
***swBadComponentChain**	**69C4**	The card's internal Component chain has become corrupted. Contact ZeitControl for assistance.
***swNameTooLong**	**69C5**	The full path name of the Component is longer than 254 characters.
***swOutOfMemory**	**69C6**	The BasicCard has insufficient free memory to execute the command.
***swInvalidACR**	**69C7**	An ACR has an unrecognised type.
***swBadComponentType**	**69C8**	A Component is not of the required type.
***swKeyUsage**	**69CD**	Current usage not enabled in Key's Usage attribute.
***swKeyAlgorithm**	**69CE**	Current algorithm not enabled in Key's Algorithm attribute.

***swTooManyTempFlags**	**69D0**	The limit of 64 temporary Flags has been reached.
***swExecutableAcrDenied**	**69D1**	The Application file does not satisfy the "**\Executable**" ACR.
***swApplicationNotFound**	**69D2**	Application file not found.
***swACRDepth**	**69D3**	Compound ACR's can be nested to a limit of at most 5 levels.
***swBadComponentAttr**	**69D4**	Attempt to write invalid Component Attributes.
***swBadComponentData**	**69D5**	Attempt to write invalid Component Data.
***swBadAppFile**	**69D6**	The file is not a valid Application file.
***swLoadSequenceActive**	**69D7**	Attempt to activate LoadSequence or delete a Component when LoadSequence is already active.
***swLoadSequenceNotActive**	**69D8**	Attempt to close or abort a non-existent LoadSequence.
***swLoadSequencePhase**	**69D9**	Invalid Phase parameter to LoadSequence command.
***swBadEaxTag**	**69DC**	Invalid **EAX** tag received during Secure Transport.
***swSecureTransportActive**	**69DD**	Attempt to activate Secure Transport when already active.
***swSecureTransportInactive**	**69DE**	Attempt to close non-existent Secure Transport session.
***swComponentReferenced**	**69DF**	Attempt to delete a Component referenced by another Component.
swP1P2Error	**6A00**	**P1** or **P2** is invalid for the command.
swOutsideEeprom	**6A02**	An invalid address was passed in **P1P2** to one of the built-in EEPROM access commands.
swDataNotFound	**6A88**	The built-in command **GET APPLICATION ID** returns this error code if no Application ID was configured in the BasicCard.
sw1LaWarning	**6C***XX*	Command successfully completed, but **La** was not equal to *XX*.
swINSNotFound	**6D00**	The **INS** byte of the command was not recognised (although the **CLA** byte was valid).
swCLANotFound	**6E00**	The **CLA** byte of the command was not recognised.
swInternalError	**6F00**	An unexpected error condition was detected.

8.6.2 BasicCard P-Code Interpreter

If the P-Code interpreter in the BasicCard detects an error, it returns **sw1PCodeError** (**64**) in **SW1**, and the specific P-Code error in **SW2**. The P-Code error is one of the following:

pcStackOverflow	**01**	The P-Code stack has grown beyond its comfigured size.
pcDivideByZero	**02**	A division by zero (or a Mod with zero divisor) occurred.
pcNotImplemented	**03**	An unimplemented P-Code instruction was executed (e.g. a floating-point instruction in the Compact BasicCard).
pcBadRamHeap	**04**	Corruption of RAM has left the heap in an inconsistent state.
pcBadEepromHeap	**05**	Corruption of EEPROM has left the heap in an inconsistent state.
pcReturnWithoutGoSub	**06**	A Return statement was executed with no corresponding GoSub.
pcBadSubscript	**07**	One of the subscripts in an array access was out of bounds.
pcBadBounds	**08**	One of the array subscript bounds in a ReDim statement was out of range.
pcInvalidReal	**09**	A floating-point operand was not a valid IEEE-format number.

pcOverflow	**0A**	The result of an arithmetic operation was too large or small for the destination.
pcNegativeSqrt	**0B**	An attempt was made to take the square root of a negative number.
pcDimensionError	**0C**	An array parameter did not have the expected number of dimensions.
pcBadStringCall	**0D**	An invalid parameter was passed to a string function.
pcOutOfMemory	**0E**	There was not enough free memory left to complete the instruction.
pcArrayNotDynamic	**0F**	The array parameter in a ReDim statement was not Dynamic.
pcArrayTooBig	**10**	The array size requested in a ReDim statement was too large.
pcDeletedArray	**11**	An attempt was made to access an element of a deleted array.
pcPCodeDisabled	**12**	A previous P-Code error has disabled the BasicCard. The card must be reset before it can execute P-Code again.
pcBadSystemCall	**13**	A SYSTEM instruction had an invalid sub-function code.
pcBadKey	**14**	An invalid key number was passed to a cryptographic function.
pcBadLibraryCall	**15**	An invalid Plug-In Library function was called.
pcStackUnderflow	**16**	The P-Code stack has shrunk to a negative size.

8.6.3 Terminal P-Code Interpreter

The P-Code interpreter in the Terminal program can return the following status codes in **SW1-SW2**:

swNoCardReader	**6790**	No card reader detected on the given COM port.
swCardReaderError	**6791**	An invalid reply was received to a card reader command.
swNoCardInReader	**6792**	No card is inserted in the card reader.
swCardPulled	**6793**	The card has been removed from the card reader.
swT1Error	**6794**	An unrecoverable **T=1** protocol error occurred while communicating with the card.
swCardError	**6795**	An invalid response was received to a BasicCard command.
swCardNotReset	**6796**	The card has not been reset. A BasicCard must be reset before the Terminal program can send it any commands.
swKeyNotLoaded	**6797**	The key specified in a **START ENCRYPTION** command is unknown to the Terminal program.
swPolyNotLoaded	**6798**	The **SG-LFSR** algorithm was specified in a **START ENCRYPTION** command, but primitive polynomials have not been configured in the Terminal program.
swBadResponseCRC	**6799**	The active encryption algorithm is **SG_LFSR** with **CRC**, and the CRC in a response was invalid.
swCardTimedOut	**679A**	The card did not respond within the time allowed.
swTermOutOfMemory	**679B**	The Terminal program has insufficient free memory to process the response.
swBadDesResponse	**679C**	The active encryption algorithm is **Single DES** or **Triple DES**, and the authentication bytes in a response were invalid.
swInvalidComPort	**679D**	The COM port is not in the range 1-4.
swNoPcscDriver	**679F**	No PC/SC driver is installed on the PC.
swPcscReaderBusy	**67A0**	The PC/SC reader is busy.

swPcscError	**67A1**	An unexpected PC/SC error occurred.
swComPortBusy	**67A2**	Another process is using the COM port.
swBadATR	**67A3**	The BasicCard returned an invalid **ATR**.
swT0Error	**67A4**	A **T=0** protocol error occurred.
swPTSError	**67A7**	An error occurred during Protocol Type Selection.
swDataOverrun	**67A8**	The Terminal has lost characters sent by the card reader.
swBadAesResponse	**67A9**	The active encryption algorithm is **AES**, and the authentication bytes in a response were invalid.
swReservedINS	**6D80**	An attempt was made to send a forbidden **INS** in **T=0** protocol.
swReservedCLA	**6E80**	An attempt was made to send **CLA=FF** in **T=0** protocol.

8.7 Pre-Defined Commands

8.7.1 States of the BasicCard

The Compact and Enhanced BasicCards have four states:

NEW: The card is in state **NEW** before ZeitControl configures it.

LOAD: The card is in state **LOAD** when the application developer gets it.

TEST: State **TEST** lets the application developer test software in the card.

RUN: The card is in state **RUN** when it is issued to the end user.

The Professional BasicCard has five states:

NEW: The card is in state **NEW** before ZeitControl configures it.

LOAD: The card is in state **LOAD** when the application developer gets it.

PERS: State **PERS** is for initialising the file system: files can be created and accessed by anybody, but ZC-Basic code cannot be run.

TEST: State **TEST** lets the application developer test software in the card.

RUN: The card is in state **RUN** when it is issued to the end user.

The card can be switched between **LOAD**, **PERS**, and **TEST** any number of times, but the **RUN** state is permanent. Once the card is switched to state **RUN**, it can’t be re-programmed.

The MultiApplication BasicCard has the same five states as the Professional BasicCard:

NEW: The card is in state **NEW** before ZeitControl configures it.

LOAD: Reserved to ZeitControl for EEPROM initialisation.

PERS: In state **PERS**, everybody has access to all Components, and the **CLEAR EEPROM** command is enabled.

TEST: State **TEST** is identical to state **RUN**, except that the card can be switched back to state **PERS**.

RUN: The card is in state **RUN** when it is issued to the end user. This state is permanent.

In the MultiApplication BasicCard, state **LOAD** is normally only available to ZeitControl; the card will usually be in state **PERS** when the application developer gets it, and can only be switched between states **PERS**, **TEST**, and **RUN**. Contact our Sales department if you need to write directly to EEPROM in state **LOAD**.

8.7.2 Pre-Defined Commands – a Summary

Single-Application BasicCards

The operating system in a single-application BasicCard contains twelve or thirteen pre-defined commands. All commands have class byte **CLA = C0**. The **INS** byte takes the values **00, 02, 04, . . . , 16, 18**, as follows:

GET STATE	**00**	Get the state and version of the card
EEPROM SIZE	**02**	Get the address and length of EEPROM
CLEAR EEPROM	**04**	Set specified bytes to FF
WRITE EEPROM	**06**	Load data into EEPROM
READ EEPROM	**08**	Read data from EEPROM
EEPROM CRC	**0A**	Calculate CRC over a specified EEPROM address range
SET STATE	**0C**	Set the state of the card
GET APPLICATION ID	**0E**	Get the Application ID string
START ENCRYPTION	**10**	Start automatic encryption of command/response data
END ENCRYPTION	**12**	End automatic encryption
ECHO	**14**	Echo the command data
ASSIGN NAD	**16**	Assign a Node Address to the card (Compact and Enhanced BasicCards only)
FILE IO	**18**	Execute a file system operation

Most of these commands are enabled only when the BasicCard is in an appropriate state. The following table summarises which internal commands are valid in which states:

	NEW	**LOAD**	**PERS**	**TEST**	**RUN**
GET STATE	✓	✓	✓	✓	✓
EEPROM SIZE	✓	✓			
CLEAR EEPROM	✓	✓			
WRITE EEPROM	✓	✓			
READ EEPROM	✓	✓	*	*	*
EEPROM CRC	✓	✓			
SET STATE	✓	✓	✓	✓	
GET APPLICATION ID				✓	✓
START ENCRYPTION				✓	✓
END ENCRYPTION				✓	✓
ECHO	✓	✓	✓	✓	✓
ASSIGN NAD	✓	✓	✓	✓	✓
FILE IO		**	✓	✓	✓

* The **READ EEPROM** command is allowed in states **PERS**, **TEST**, and **RUN** if encryption with key number **0** is enabled (see **8.7.7 The READ EEPROM Command**).

** In the Enhanced BasicCard only, the **FILE IO** command is allowed in state **LOAD**.

In state **NEW**, no checks are performed on addresses of EEPROM reads and writes. (This is to allow ZeitControl to install upgrades to the BasicCard operating system, before delivery to the application developer.)

In state **LOAD**, the EEPROM access commands are restricted to user EEPROM.

In a single-application BasicCard, these commands will typically be called at the following points in the development cycle:

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1. Write and test a ZC-Basic application on the PC
2. **EEPROM SIZE** – check that the card has the expected EEPROM size
3. **CLEAR EEPROM** – set EEPROM to a known state
4. **WRITE EEPROM** – download the application to the card
5. **EEPROM CRC** – check that the EEPROM was correctly written
6. **FILE IO** – create files and directories
7. **SET STATE** to **TEST** and reset the card
8. Run the application in the card
9. **SET STATE** to **LOAD** and reset the card
10. **READ EEPROM** to check any EEPROM changes made by the application

(Most of this is handled automatically by the ZeitControl MultiDebugger development software.) When the application is written and tested, cards can be switched into the **RUN** state for delivery to end users.

Applications in the MultiApplication BasicCard will normally be loaded by the Application Loader, built into the ZCMSIM command-line interpreter and the ZCMDCARD BasicCard debugger.

MultiApplication BasicCard

The operating system in the MultiApplication BasicCard contains the following commands in addition to those listed above:

GET CHALLENGE	**40**	Get a cryptographic Challenge for **EXTERNAL AUTHENTICATE**
EXTERNAL AUTHENTICATE	**42**	Authenticate the Terminal program to the BasicCard
INTERNAL AUTHENTICATE	**44**	Authenticate the BasicCard to the Terminal program
VERIFY	**46**	Verify the user's password or PIN
GET FREE MEMORY	**48**	Get the amount of free memory available in the global heap
SELECT APPLICATION	**A0**	Select an Application
CREATE COMPONENT	**A2**	Create a Component
DELETE COMPONENT	**A4**	Delete a Component
WRITE COMPONENT ATTR	**A6**	Write a Component's attributes
READ COMPONENT ATTR	**A8**	Read a Component's attributes
WRITE COMPONENT DATA	**AA**	Write a Component's data
READ COMPONENT DATA	**AC**	Read a Component's data
FIND COMPONENT	**AE**	Get the CID of a Component from its name
COMPONENT NAME	**B0**	Get the name of a Component from its CID
GRANT PRIVILEGE	**B2**	Grant a Privilege to a File
AUTHENTICATE FILE	**B4**	Authenticate a File with a Signature
READ RIGHTS LIST	**B6**	Read the Privileges and Signatures of a File
LOAD SEQUENCE	**B8**	Start, end, or abort a Load Sequence session
SECURE TRANSPORT	**BA**	Start or end a Secure Transport session

8.7.3 The GET STATE Command

GET STATE – Get the state and version of the card

Command syntax:

CLA	INS	P1	P2	Le
C0	00	00	00	00

Response:

ODATA	SW1	SW2
state (1 byte), *version* (n bytes)	**61**	n+1

This command returns the state and version of the BasicCard.

The *state* byte (Compact and Enhanced BasicCards):

state:	**00**	**01**	**02**	**03**
State of card:	**NEW**	**LOAD**	**TEST**	**RUN**

The *state* byte (Professional and MultiApplication BasicCards):

state:	**00**	**01**	**02**	**03**	**04**
State of card:	**NEW**	**LOAD**	**PERS**	**TEST**	**RUN**

The length of the *version* field depends on the card type, as follows:

Compact BasicCard: n = 0 (i.e. no version field is returned)
Enhanced BasicCard: n = 2: major version number (**03**) followed by minor version number
Other card types: n >= 3: the version info is an ASCII string

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is present, or **Le** is absent
swP1P2Error **P1 <> 00** or **P2 <> 00**

To call **GET STATE** from a Terminal program:

```
#Include COMMANDS.DEF
Call GetState (state@, version$)
```

8.7.4 The EEPROM SIZE Command

EEPROM SIZE – Get the address and length of EEPROM

Command syntax:

CLA	INS	P1	P2	Le
C0	**02**	**00**	**00**	**04**

Response:

ODATA	SW1	SW2
start (2 bytes), *length* (2 bytes)	**90**	**00**

Returns the start address and length of loadable EEPROM.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present, or **Le** is absent
swInvalidState	Card is not in **NEW** or **LOAD** state
swP1P2Error	**P1 <> 00** or **P2 <> 00**

To call **EEPROM SIZE** from a Terminal program:

```
#Include COMMANDS.DEF
Call EepromSize (start%, length%)
```

8.7.5 The CLEAR EEPROM Command

CLEAR EEPROM – Set specified bytes to **FF**

Single-Applications BasicCards

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**04**	*addr*	**02**	*length* (2 bytes)

Response:

SW1	SW2
90	**00**

Sets *length* bytes of EEPROM to **FF**, starting from address *addr*.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** <> **02**, or length of **IDATA** <> **02**
swInvalidState	Card is not in **NEW** or **LOAD** state
swOutsideEeprom	Address range not wholly contained in EEPROM

To call **CLEAR EEPROM** from a Terminal program:

```
#Include COMMANDS.DEF
Call ClearEeprom (P1P2=addr%, length%)
```

MultiApplication BasicCard in state **PERS**

Command syntax:

CLA	INS	P1	P2
C0	**04**	**00**	**00**

Response:

SW1	SW2
90	**00**

Sets all of EEPROM to **FF**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** <> **02**, or length of **IDATA** <> **02**
swInvalidState	Card is not in state **NEW**, **LOAD**, or **PERS**

To call **CLEAR EEPROM** from a Terminal program for the MultiApplication BasicCard:

```
#Include COMMANDS.DEF
Call ClearEeprom (Lc=0, 0)
```

8.7.6 The WRITE EEPROM Command

WRITE EEPROM – Load data into EEPROM

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**06**	*addr*	*len*	*data*

Response:

SW1	SW2
90	**00**

Writes *data* (*len* bytes) to EEPROM starting at address *addr*.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** <> length of **IDATA**
swInvalidState	Card is not in **NEW** or **LOAD** state
swOutsideEeprom	Address range not wholly contained in EEPROM

To call **WRITE EEPROM** from a Terminal program:

```
Declare Command &HC0 &H06 WriteEeprom (data$, Disable Le)
Call WriteEeprom (P1P2=addr%, data$)
```

Note: For security reasons, the **WRITE_EEPROM** command is encrypted, and is not available for general use. Calling this command from a user program is likely to damage the card irreparably. For this reason, it is not included in COMMANDS.DEF. However, it is possible to call this command with data supplied by the compiler in the Image File – see the **BCLOAD.EXE** source code in `BasicCardPro\Source\BCLoad` for an example of how to do this. In such cases, you must declare the **WriteEeprom** command yourself, as shown above.

8.7.7 The READ EEPROM Command

READ EEPROM – Read data from EEPROM

Command syntax:

CLA	INS	P1P2	Le
C0	**08**	*addr*	*len*

Response:

ODATA	SW1	SW2
data (*len* bytes)	**90**	**00**

Reads *len* bytes from EEPROM starting from address *addr*. If you have configured key number **00** in the card, then the **READ EEPROM** command can be called whatever the state of the card, by enabling encryption with key **00**. You should consider this option whenever the card contains data that is not available elsewhere – if the card becomes unusable for any reason, for example because of hardware errors writing to EEPROM, you can recover the data this way.

Command-Specific Error Codes in SW1-SW2:

swLcLeError — **Lc** is present, or **Le** is absent
swInvalidState — Card is not in **NEW** or **LOAD** state, and key **00** is not active
swOutsideEeprom — Address range not wholly contained in EEPROM

To call **READ EEPROM** from a Terminal program:

```
#Include COMMANDS.DEF
Call ReadEeprom (P1P2=addr%, data$, Le=len@)
```

8.7.8 The EEPROM CRC Command

EEPROM CRC – Calculate a CRC over a specified EEPROM address range

Command syntax:

CLA	INS	P1P2	Lc	IDATA	Le
C0	**0A**	*addr*	**02**	*length* (2 bytes)	**02**

Response:

ODATA	SW1	SW2
CRC (2 bytes)	**90**	**00**

Returns the CRC of *length* bytes from address *addr*. All bytes must be in EEPROM. This command can be used to verify the contents of EEPROM after downloading an application to the card.

In the Enhanced BasicCard, this command also serves the function of enabling the BasicCard file system. To access the file system while the card is still in state **LOAD**, an **EEPROM CRC** command must be sent, to let the card know that the relevant data structures have been downloaded; the **BCLOAD** program does this automatically after downloading a ZC-Basic program to the BasicCard.

Warning: Do not call this command in the Enhanced BasicCard before a valid ZC-Basic program has been loaded. The card will attempt to enable a non-existent file system, which can permanently disable the card. (In the Compact and Professional BasicCards, you can call this command at any time.)

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** <> **02** or length of **IDATA** <> **02** or **Le** not present
swInvalidState	Card is not in **NEW** or **LOAD** state
swOutsideEeprom	Address range not wholly contained in EEPROM

To call **EEPROM CRC** from a Terminal program:

```
#Include COMMANDS.DEF
Call EepromCRC (P1P2=addr%, length%)
```

The CRC is returned in the `length%` variable.

Note: If **Le** >= 3, the Professional BasicCard returns a 32-bit CRC. To call the 32-bit **EEPROM CRC** command from a Terminal program:

```
#Include COMMANDS.DEF
CRCHi% = length%
Call EepromCRC32 (P1P2=addr%, CRCHi%, CRCLo%)
```

16-bit and 32-bit CRC calculations are described in **7.10.4 CRC Calculations**.

8.7.9 The SET STATE Command

SET STATE – Set the state of the card

Command syntax:

CLA	INS	P1	P2
C0	**0C**	*state*	**00**

Response:

SW1	SW2
90	**00**

This command changes the state of the card, as folllows:

Compact and Enhanced BasicCards

state:	**01**	**02**	**03**
New card state:	**LOAD**	**TEST**	**RUN**

Professional and MultiApplication BasicCards

state:	**01**	**02**	**03**	**04**
New card state:	**LOAD**	**PERS**	**TEST**	**RUN**

After this command is successfully called, no further commands are allowed until the card is reset.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** present
swInvalidState	Card is in **RUN** state
swCardUnconfigured	The card has not been configured by ZeitControl. If you see this error, contact ZeitControl for a replacement card.
swP1P2Error	**P1 = 00** or **P1 > RUN** or **P2 <> 00**

To call **SET STATE** from a Terminal program:

```
#Include COMMANDS.DEF
Call SetState (P1=state@)
```

Note: This command may also be used to certify EEPROM code in Enhanced BasicCards **ZC3.1**, **ZC3.2**, and **ZC3.31**. Contact ZeitControl if you need to know how this works.

8.7.10 The GET APPLICATION ID Command

GET APPLICATION ID – Get the Application ID string

Single-Application BasicCards

Command syntax:

CLA	INS	P1	P2	Le
C0	**0E**	**00**	**00** or **03**	**00**

Response:

ODATA	SW1	SW2
Data	**61**	*len*

P2 = **00:** *Data* contains the Application ID specified in the ZC-Basic source code statement:

Declare ApplicationID = *Application-ID*

P2 = 03: In later Professional BasicCard versions, *Data* contains the 8-byte hardware Serial Number of the card, as returned by the **MISC** System Library function **CardSerialNumber()**. This functionality is available in the following revisions:

ZC4.5A REV F **ZC4.5D REV F** **ZC5.4 REV G** **ZC5.5 REV G**

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present or **Le** is absent
swInvalidState	Card is not in **TEST** or **RUN** state
swP1P2Error	**P1 <> 00** or **P2 <> 00**
swDataNotFound	Application ID not configured

To call **GET APPLICATION ID** from a Terminal program for a single-application BasicCard:

```
#Include COMMANDS.DEF
Call GetApplicationID (ApplicationID$)
```

MultiApplication BasicCard

Command syntax:

CLA	INS	P1	P2	Le
C0	**0E**	*index*	*type*	**00**

Response:

ODATA	SW1	SW2
Data	**61**	*len*

type	*Data*
0	Application ID of Application specified in *index*
1	Filename of Application specified in *index*
2	Contents of special file "**\CardID**" – see **5.3.2Card ID File**; *index* must be zero
3	8-byte hardware Serial Number of the card; *index* must be zero

For *type* equal to **0** or **1**, if *index* is equal to zero, it refers to the currently selected Application. If *index* is equal to *n* with *n* >= 1, it refers to the nth executable Application file (according to the order in which the files were created).

To call **GET APPLICATION ID** from a Terminal program for the MultiApplication BasicCard:

```
#Include COMMANDS.DEF
Call GetApplicationID (P1=index@, P2=type%, Data$)
```

8.7.11 The START ENCRYPTION Command

START ENCRYPTION – Start automatic encryption of command/response data

This command initiates automatic encryption of command and response data fields. Its format depends on the card type.

Compact and Enhanced BasicCards:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**10**	*algorithm*	*key*	**04**	*Random number* **RA** (4 bytes)	**04**

Response:

ODATA	SW1	SW2
Random number **RB** (4 bytes)	**90**	**00**

Professional BasicCard:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**10**	*algorithm*	*key*	len_R	*Random number* **RA** (len_R bytes)	**00**

Response:

ODATA	SW1	SW2
algorithm (1 byte); *Random number* **RB** (len_R bytes)	**61**	len_R+1

MultiApplication BasicCard:

Command syntax:

CLA	INS	P1P2	Lc	IDATA	Le
C0	**10**	*KeyCID*	len_R+1	*algorithm* (1 byte); *Random number* **RA** (len_R bytes)	**00**

Response:

ODATA	SW1	SW2
algorithm (1 byte); *Random number* **RB** (len_R bytes)	**61**	len_R+1

algorithm is one of the following cryptographic algorithms, defined in the file AlgID.DEF:

algorithm		len_R	*key length*
AlgSgLfsr	**SG-LFSR** (Shrinking Generator – Linear Feedback Shift Register)	**4**	**8**
AlgSgLfsrCrc	**SG-LFSR** with **CRC-16**	**4**	**8**
AlgSingleDes	**Single DES** (Data Encryption Standard, 8-byte key)	**4**	**8**
AlgTripleDes	**Triple DES-EDE2** (Data Encryption Standard, 16-byte key)	**4**	**10** (=16_{10})
AlgSingleDesCrc	**Single DES** with CRC	**4**	**8**
AlgTripleDesEDE2Crc	**Triple DES-EDE2** with CRC	**4**	**10** (=16_{10})
AlgTripleDesEDE3Crc	**Triple DES-EDE3** with CRC	**4**	**18** (=24_{10})
AlgAes128	**AES-128** (Advanced Encryption Standard, 128-bit key)	**8**	**10** (=16_{10})
AlgAes192	**AES-192** (Advanced Encryption Standard, 192-bit key)	**8**	**18** (=24_{10})
AlgAes256	**AES-256** (Advanced Encryption Standard, 256-bit key)	**8**	**20** (=32_{10})
AlgEaxAes128	**EAX** with **AES-128**	**8**	**10** (=16_{10})
AlgEaxAes192	**EAX** with **AES-192**	**8**	**18** (=24_{10})
AlgEaxAes256	**EAX** with **AES-256**	**8**	**20** (=32_{10})
AlgOmacAes128	**OMAC** with **AES-128**	**0**	**10** (=16_{10})
AlgOmacAes192	**OMAC** with **AES-192**	**0**	**18** (=24_{10})
AlgOmacAes256	**OMAC** with **AES-256**	**0**	**20** (=32_{10})

For descriptions of these algorithms, and the role of **RA** and **RB**, see **Chapter 9: Encryption Algorithms**.

In single-application BasicCards, *key* is the key number. It must match one of the key numbers configured in the BasicCard program with the ZC-Basic **Declare Key** statement, of length at least *key length* from the above table. If the **START ENCRYPTION** command is successful, the pre-defined variable **KeyNumber** is set equal to *key*.

In the MultiApplication BasicCard, *KeyCID* is the CID of the Key . If the **START ENCRYPTION** command is successful, the pre-defined variable **SMKeyCID** is set equal to *KeyCID*.

Algorithms supported in the Compact BasicCard

The Compact BasicCard supports algorithms **AlgSgLfsr** and **AlgSgLfsrCrc**.

Algorithms supported in the Enhanced BasicCard

The Enhanced BasicCard supports algorithms **AlgSingleDes** and **AlgTripleDes**.

Algorithms supported in the Professional BasicCard

The different Professional BasicCard versions support various combinations of cryptographic algorithms. See the **Professional BasicCard Datasheet** for up to date information. At the time of writing, the following versions are available:

BasicCard	*Algorithms*
ZC4.5A	**AlgAes128**
ZC4.5D	**AlgSingleDesCrc**, **AlgTripleDesCrc**
ZC5.4	**AlgAes128**, **AlgAes192**, **AlgAes256**, **AlgSingleDesCrc**, **AlgTripleDesEDE2Crc**
ZC5.5	All the algorithms in the above table from **AlgSingleDesCRC** to **AlgOmacAes256**

Algorithms supported in the MultiApplication BasicCard

The MultiApplication BasicCard supports all the algorithms in the above table from **AlgSingleDesCRC** to **AlgOmacAes256**.

Automatic Algorithm Selection

The Enhanced, Professional, and MultiApplication BasicCards support automatic algorithm selection: If *algorithm* is zero, then the card automatically selects the strongest algorithm that is compatible with len_R and the key length. In the Professional and MultiApplication BasicCards, the algorithm thus selected is returned in the first byte of **ODATA**.

The Compact BasicCard returns with **SW1-SW2 = swUnknownAlgorithm** if *algorithm* is zero.

Command-Specific Error Codes in SW1-SW2:

swKeyNotFound	Key number *key* was not configured
swPolyNotFound	Primitive polynomials were not initialised
swKeyTooShort	Key number *key* is too short
swKeyDisabled	Key number *key* is disabled
swUnknownAlgorithm	*algorithm* is unknown, or is not enabled in the card
swAlreadyEncrypting	Encryption is already enabled
swLcLeError	*Compact and Enhanced BasicCards*: **Lc** <> **04**, or **Le** is absent *Professional and MultiApplication BasicCards*: **RA** too short, or **Le** absent
swInvalidState	Card is not in **TEST** or **RUN** state

To call **START ENCRYPTION** from a Terminal program for a Compact or Enhanced BasicCard, or a Professional BasicCard with **DES** support:

```
#Include COMMANDS.DEF
Call StartEncryption ([P1=Algorithm@,] P2=KeyNumber@, Rnd)
```

To call **START ENCRYPTION** from a Terminal program for a Professional BasicCard:

```
#Include COMMANDS.DEF
Call ProEncryption ([P1=Algorithm@,] P2=KeyNumber@, Rnd, Rnd)
```

Note that both forms are accepted by a Professional BasicCard with **DES** support.

To call **START ENCRYPTION** from a Terminal program for a MultiApplication BasicCard, see **5.6 Secure Messaging**.

Alternatively, for all BasicCard types, **COMMANDS.DEF** defines the subroutine **AutoEncryption**, which automatically selects the correct version of the command:

```
#Include COMMANDS.DEF
Call AutoEncryption (KeyNumber@, KeyName$)
```

where *KeyName$* is the name of the Key in the MultiApplication BasicCard (so it can be the empty string if the card is known to be a single-application type).

8.7.12 The END ENCRYPTION Command

END ENCRYPTION – End automatic encryption

Command syntax:

CLA	INS	P1	P2
C0	12	00	00

Response:

SW1	SW2
90	00

This command ends automatic encryption of command and response data fields.

Command-Specific Error Codes in SW1-SW2:

swNotEncrypting	Encryption is not currently enabled
swLcLeError	**Lc** or **Le** present
swInvalidState	Card is not in **TEST** or **RUN** state
swP1P2Error	**P1 <> 00** or **P2 <> 00**

To call **END ENCRYPTION** from a Terminal program:

```
#Include COMMANDS.DEF
Call EndEncryption()
```

8.7.13 The ECHO Command

ECHO – Echo the command data

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	14	*increment*	00	*datalen*	*data*	*resplen*

Response:

ODATA	SW1	SW2
data+increment	90	00

This command simply adds *increment* to each byte in *data*, and returns *resplen* bytes. It is intended for testing communication and encryption (see **9.13 Encryption – a Worked** Example).

Note: The Compact and Enhanced BasicCards ignore *resplen*, always returning *datalen* bytes.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** <> length of **IDATA** or **Le** not present
swP1P2Error **P2 <> 00**

To call **ECHO** from a Terminal program:

```
#Include COMMANDS.DEF
Call Echo (P1=increment@, S$, Le=resplen@)
```

8.7.14 The ASSIGN NAD Command

ASSIGN NAD – Assign a Node Address to the card

Command syntax:

CLA	INS	P1	P2
C0	**16**	*NAD*	**00**

Response:

SW1	SW2
90	**00**

If 1 <= *NAD* <= 7, this command tells the card to respond only to those messages in which the high nibble of the first byte (the **NAD**) is equal to *NAD*. If *NAD* = 0, this command tells the card to respond to all messages. Other values of *NAD* are invalid.

Notes:

- The **ASSIGN NAD** command is not used by ZeitControl's software; all commands sent by the Terminal program have **NAD=00**.
- This command is supported only by Compact BasicCard **ZC1.1** and Enhanced BasicCards **ZC3.3** through **ZC3.9**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** present
swP1P2Error	**P1 > 07** or **P2 <> 00**

To call **ASSIGN NAD** from a Terminal program:

```
#Include COMMANDS.DEF
Call AssignNAD (P1=NAD@)
```

8.7.15 The FILE IO Command

FILE IO – Execute a file system operation (not available in Compact BasicCard)

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**18**	*SysCode*	*filenum*	*CommandLen*	*CommandData*	*ResponseLen*

Response:

ODATA	SW1	SW2
status (1 byte) + *ResponseData*	**90**	**00**

This command is sent whenever the Terminal program attempts to access the file system in the BasicCard. The P-Code interpreter in the PC builds the command automatically, sends it to the BasicCard, and interprets the response. *SysCode* is the same as the *SysCode* parameter to the **SYSTEM** P-Code instruction – see **10.7.4 FILE SYSTEM Functions**. The *status* byte in the **ODATA** field is the **FileError** byte for the operation. The format of the *CommandData* and *ResponseData* fields depends on the value of *SysCode*, and is not described in this document.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** <> length of **IDATA**, or **Le** absent
swP1P2Error *SysCode* is not a valid file system operation

The **FILE IO** command was not designed to be called directly from a Terminal program. The P-Code interpreter calls it automatically when a file system operation is requested – see **Chapter 4: Files and Directories** for a description of the file system commands available in ZC-Basic.

8.7.16 The GET CHALLENGE Command

GET CHALLENGE – Get a cryptographic Challenge for **EXTERNAL AUTHENTICATE**

Command syntax:

CLA	INS	P1	P2	Le
C0	40	00	00	*ChallengeLen*

Response:

ODATA	SW1	SW2
Challenge	90	00

This command returns a random string of bytes as a Challenge for a subsequent **EXTERNAL AUTHENTICATE** command. If the Algorithm that will be used in the **EXTERNAL AUTHENTICATE** command is **AlgSingleDesCrc** or **AlgTripleDesCrc**, then *ChallengeLen* must be at least 8; if the Algorithm is **AlgAes128**, **AlgAes192**, or **AlgAes256**, then *ChallengeLen* must be at least 16. If **Le** is zero, or greater than 16, then 16 bytes are returned; this is valid for all Algorithms.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present or **Le** is absent
swP1P2Error	**P1P2 <> 0**

To call **GET CHALLENGE** from a Terminal program:

```
#Include COMPONNT.DEF
Call GetChallenge (Challenge$, Le=ChallengeLen@)
```

Note: If you need to avoid a name clash with the ISO **GET CHALLENGE** command, just define the constant **NoISONames**, at the start of the Terminal program (with **Const NoISONames = True**) or as a compiler option. You can still call the BasicCard command, using the name **ZCGetChallenge**.

8.7.17 The EXTERNAL AUTHENTICATE Command

EXTERNAL AUTHENTICATE – Authenticate the Terminal program to the BasicCard

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	42	*KeyCID*	*n*+1	*Algorithm* (1 byte); *Response to Challenge*

Response:

SW1	SW2
90	00

The **EXTERNAL AUTHENTICATE** command is used to prove to the BasicCard that the Terminal program has access to a given Key. It does this by encrypting the Challenge returned by the **GET CHALLENGE** command, using the Algorithm's block encryption primitive.

Algorithm One of **AlgSingleDesCrc**, **AlgTripleDesCrc**, **AlgAes128**, **AlgAes192**, **AlgAes256**

n Block length of *Algorithm*: 8 bytes for **AlgSingleDesCrc** or **AlgTripleDesCrc**, and 16 bytes for **AlgAes128**, **AlgAes192**, or **AlgAes256**

EXTERNAL AUTHENTICATE must be the next command after **GET CHALLENGE**; any intervening command cancels the Challenge. If *Response to Challenge* is correct, the Access Condition **ExtAuth** (*KeyCID*) will be satisfied, until the next **EXTERNAL AUTHENTICATE** command is received or the card is reset.

The pre-defined variable **ExtAuthKeyCID** is set equal to *KeyCID* if this command is successful, or to zero if not.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is not equal to *n*+1, or **Le** is present
swDataNotFound **GET CHALLENGE** was not the most recently received command, or the Challenge requested was less than *n* bytes
swKeyNotFound A Key with the given *KeyCID* was not found
swKeyUsage The Key's **Usage** attribute does not have **kuExtAuth** enabled
swKeyAlgorithm The Key's **Algorithm** attribute does not have the given *Algorithm* enabled
swKeyTooShort The Key is too short for the given *Algorithm*
swUnknownAlgorithm *Algorithm* is not one of the five listed above
swBadAuthenticate *Response to Challenge* is incorrect

To call **EXTERNAL AUTHENTICATE** from a Terminal program:

```
#Include COMPONNT.DEF
Call ExternalAuthenticate (P1P2=KeyCID%, Algorithm@, Response$)
```

Note: If you need to avoid a name clash with the ISO **EXTERNAL AUTHENTICATE** command, just define the constant **NoISONames**, at the start of the Terminal program (with **Const NoISONames = True**) or as a compiler option. You can still call the BasicCard command, using the name **ZCExternalAuthenticate**.

8.7.18 The INTERNAL AUTHENTICATE Command

INTERNAL AUTHENTICATE – Authenticate the BasicCard to the Terminal program

Command syntax:

CLA	INS	P1P2	Lc	IDATA	Le
C0	**44**	*KeyCID*	*n*+1	*Algorithm* (1 byte); *Challenge*	*n*

Response:

ODATA	SW1	SW2
Response to Challenge	**90**	**00**

The **INTERNAL AUTHENTICATE** command is used to prove to the Terminal program that the BasicCard has access to a given Key. It does this by encrypting *Challenge* using the Algorithm's block encryption primitive.

Algorithm One of **AlgSingleDesCrc**, **AlgTripleDesCrc**, **AlgAes128**, **AlgAes192**, **AlgAes256**

n Block length of *Algorithm*: 8 bytes for **AlgSingleDesCrc** or **AlgTripleDesCrc**, and 16 bytes for **AlgAes128**, **AlgAes192**, or **AlgAes256**

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is not equal to *n*+1, or **Le** is absent
swKeyNotFound A Key with the given *KeyCID* was not found
swKeyUsage The Key's **Usage** attribute does not have **kuIntAuth** enabled
swKeyAlgorithm The Key's **Algorithm** attribute does not have the given *Algorithm* enabled
swKeyTooShort The Key is too short for the given *Algorithm*
swUnknownAlgorithm *Algorithm* is not one of the five listed above

To call **INTERNAL AUTHENTICATE** from a Terminal program:

```
#Include COMPONNT.DEF
Call InternalAuthenticate (P1P2=KeyCID%, Algorithm@, Challenge$)
Response$ = Chr$(Algorithm@) + Challenge$ ' Construct response
```

Note: If you need to avoid a name clash with the ISO **INTERNAL AUTHENTICATE** command, just define the constant **NoISONames**, at the start of the Terminal program (with **Const NoISONames = True**) or as a compiler option. You can still call the BasicCard command, using the name **ZCInternalAuthenticate**.

8.7.19 The VERIFY Command

VERIFY – Verify the user's password or PIN

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**46**	*KeyCID*	*n*	*Password*

Response:

SW1	SW2
90	**00**

The **VERIFY** command is used to prove to the BasicCard that the user knows a given password or PIN. The user types the password, which is sent unencrypted in the **IDATA** field (unless automatic encryption of Commands and Responses has been activated with the **START ENCRYPTION** command). If *Password* matches the data field of the given Key, the Access Condition **Verify** (*KeyCID*) will be satisfied, until the next **VERIFY** command is received or the card is reset.

The pre-defined variable **VerifyKeyCID** is set equal to *KeyCID* if this command is successful, or to zero if not.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Le** is present
swKeyNotFound	A Key with the given *KeyCID* was not found
swKeyUsage	The Key's **Usage** attribute does not have **kuVerify** enabled
swBadAuthenticate	*Password* is incorrect

To call **VERIFY** from a Terminal program:

```
#Include COMPONNT.DEF
Call Verify (P1P2=KeyCID%, Password$)
```

Note: If you need to avoid a name clash with the ISO **VERIFY** command, just define the constant **NoISONames**, at the start of the Terminal program (with **Const NoISONames = True**) or as a compiler option. You can still call the BasicCard command, using the name **ZCVerify**.

8.7.20 *The GET FREE MEMORY Command*

GET FREE MEMORY – Get the amount of free memory available in the global heap

Command syntax:

CLA	INS	P1	P2	Le
C0	48	00	00	04

Response:

ODATA	SW1	SW2
TotalFreeMemory (2 bytes); *LargestFreeBlock* (2 bytes)	90	00

The **GET FREE MEMORY** command returns the total free memory, and the size of the largest free block, in the card's global heap.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present, or **Le** is absent
swP1P2Error	**P1P2 <> 0**
swBadEepromHeap	The global heap is invalid. Contact ZeitControl for assistance

To call **GET FREE MEMORY** from a Terminal program:

```
#Include COMPONNT.DEF
Call GetFreeMemory (TotalFreeMemory%, LargestFreeBlock%)
```

8.7.21 The SELECT APPLICATION Command

SELECT APPLICATION – Select an Application

Command syntax:

CLA	INS	P1	P2	Lc	IDATA
C0	**A0**	**00**	**00**	*len*	*filename*

Response:

SW1	SW2
90	**00**

The **SELECT APPLICATION** command selects a File as the current Application.

To succeed, the caller must have **Execute** access to File *filename*. In addition, if there exists an ACR with the name "**Executable**" in the Root Directory, this ACR must be satisfied by File *filename* (not by the caller) for **Execute** access. In other words, when checking whether ACR "**Executable**" is satisfied, the three ACR types that depend on the current Application – **Privilege**, **Signed**, and **Application** – are evaluated as if *filename* were the current Application file.

If this call fails, the current Application remains unchanged.

Command-Specific Error Codes in SW1-SW2:

swLcLeError — **Lc** is absent, or **Le** is present
swP1P2Error — **P1P2 <> 0**
swApplicationNotFound — File *filename* not found
swAppFileOpen — File *filename* is currently open for reading or writing
swExecutableAcrDenied — ACR "**\Executable**" exists, and is not satisfied by File *filename*
swAccessDenied — The caller does not have Execute access to File *filename*
swBadAppFile — *filename* is not a valid executable File
swSecureTransportActive — No Application may be selected during Secure Transport

To call **SELECT APPLICATION** from a Terminal program:

```
#Include COMPONNT.DEF
Call SelectApplication (filename$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **SelectApplication** is implemented as a System Library procedure, not as a Command definition.

8.7.22 The CREATE COMPONENT Command

CREATE COMPONENT – Create a Component

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**A2**	*type*	**00**	*len*	See below	**02**

Response:

ODATA	SW1	SW2
CID of new Component (2 bytes)	**90**	**00**

The **CREATE COMPONENT** command creates a Component in the BasicCard. It requires **Write** access to the Component's parent directory.

type the type of the Component: **ctFile**, **ctACR**, **ctPrivilege**, **ctFlag**, or **ctKey**.

IDATA *pathlen*, the length of *pathname* (1 byte);
pathname, the pathname of the Component (absolute, or relative to the current directory);
attrlen, the length of *attributes* (1 byte);
attributes, the Attributes field of the Component;
data, the Data field of the Component.

The length of the *data* field can be deduced from **Lc** (*datalen* = **Lc** – *pathlen* – *attrlen* – 2), so it is not required in **IDATA**. The format of the Attributes and Data fields depends on the Component type; a full description can be found in **5.8 Component Details**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is less than 2, or **Le** is absent
swP1P2Error	**P2 <> 0**
swBadComponentName	*pathlen* is invalid, or *pathname* is not a valid Component name
swBadComponentType	**P1** is not a valid Component type
swBadComponentAttr	*attrlen* is invalid, or *attributes* is invalid for the Component type
swBadComponentData	*data* is invalid for the Component type
swComponentAlreadyExists	A Component of type P1 with the given pathname already exists

To call **CREATE COMPONENT** from a Terminal program:

```
#Include COMPONNT.DEF
Call CreateComponent (type@, name$, attributes$, data$)
```

The format of the *attributes* field for each Component type is available as a user-defined structure type in COMPONNT.DEF. **5.8 Component Details** gives the details, and shows how to pass a user-defined structure in a **String** parameter.

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **CreateComponent** is implemented as a System Library procedure, not as a Command definition.

8.7.23 The DELETE COMPONENT Command

DELETE COMPONENT – Delete a Component

Command syntax:

CLA	INS	P1P2
C0	A4	*CID*

Response:

SW1	SW2
90	00

The **DELETE COMPONENT** command deletes a Component from the BasicCard. **Delete** access to the Component is required.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** is present
swComponentNotFound	No Component with the given *CID* exists
swLoadSequenceActive	No Component may be deleted during a Load Sequence – see **8.7.33 The LOAD SEQUENCE Command** for more information
swComponentReferenced	The Component is referenced by other Components, and may therefore not be deleted An ACR may be referenced as the **Lock** attribute of another Component; any Component type may be referenced as the parameter to an ACR. If a Privilege or Key is referenced only from the Rights List of a File, it will be automatically deleted from the Rights List, and will not generate this error. See **8.7.32 The READ RIGHTS LIST Command** for information on Rights Lists.

To call **DELETE COMPONENT** from a Terminal program:

```
#Include COMPONNT.DEF
Call DeleteComponent (CID%)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **DeleteComponent** is implemented as a System Library procedure, not as a Command definition.

8.7.24 The WRITE COMPONENT ATTR Command

WRITE COMPONENT ATTR – Write a Component's attributes

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	A6	*CID*	*len*	*attributes*

Response:

SW1	SW2
90	00

The **WRITE COMPONENT ATTR** command writes the Attributes field of a Component. **Write** and **Delete** access to the Component are required. The format of a Component's Attributes field depends on the type of the Component; a full description can be found in **5.8 Component Details**.

This is the command to use if you want to change a Component's Access Control Rule. If the Component is a Flag or a Key, then it has other writable attributes; if you want to leave these attributes unchanged, you should read them with **READ COMPONENT ATTR**, change the **ACRCID%** field, and write them with **WRITE COMPONENT ATTR**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is absent or **Le** is present
swComponentNotFound No Component with the given *CID* exists
swBadComponentAttr The *attributes* field is invalid for the Component type

To call **WRITE COMPONENT ATTR** from a Terminal program:

```
#Include COMPONNT.DEF
Call WriteComponentAttr (CID%, attributes$)
```

The format of the *attributes* field for each Component type is available as a user-defined structure type in COMPONNT.DEF. **5.8 Component Details** gives the details, and shows how to pass a user-defined structure in a **String** parameter.

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **WriteComponentAttr** is implemented as a System Library procedure, not as a Command definition.

8.7.25 The READ COMPONENT ATTR Command

READ COMPONENT ATTR – Read a Component's attributes

Command syntax:

CLA	INS	P1P2	Le
C0	**A8**	*CID*	**00**

Response:

ODATA	SW1	SW2
attributes	**61**	*len*

The **READ COMPONENT ATTR** command reads the Attributes field of a Component. **Read** access is required to the Component's parent directory, but not to the Component itself. The format of a Component's Attributes field depends on the type of the Component; a full description can be found in **5.8 Component Details**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is present or **Le** is absent
swComponentNotFound No Component with the given *CID* exists

To call **READ COMPONENT ATTR** from a Terminal program:

```
#Include COMPONNT.DEF
Call ReadComponentAttr (CID%, attributes$)
```

The format of the *attributes* field for each Component type is available as a user-defined structure type in COMPONNT.DEF. **5.8 Component Details** gives the details, and shows how to pass a user-defined structure in a **String** parameter.

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **ReadComponentAttr** is implemented as a System Library procedure, not as a Command definition.

8.7.26 The WRITE COMPONENT DATA Command

WRITE COMPONENT DATA– Write a Component's data

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**AA**	*CID*	*len*	*data*

Response:

SW1	SW2
90	**00**

The **WRITE COMPONENT DATA** command writes the Data field of a Component. **Write** access to the Component is required. The format of a Component's Data field depends on the type of the Component; a full description can be found in **5.8 Component Details**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError **Lc** is absent or **Le** is present
swComponentNotFound No Component with the given *CID* exists
swBadComponentData The *data* field is invalid for the Component type

To call **WRITE COMPONENT DATA** from a Terminal program:

```
#Include COMPONNT.DEF
Call WriteComponentData (CID%, data$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **WriteComponentData** is implemented as a System Library procedure, not as a Command definition.

8.7.27 The READ COMPONENT DATA Command

READ COMPONENT DATA – Read a Component's data

Command syntax:

CLA	INS	P1P2	Le
C0	**AC**	*CID*	**00**

Response:

ODATA	SW1	SW2
data	**61**	*datalen*

The **READ COMPONENT DATA** command reads the Data field of a Component. **Read** access to the Component is required. The format of a Component's Data field depends on the type of the Component; a full description can be found in **5.8 Component Details**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present or **Le** is absent
swComponentNotFound	No Component with the given *CID* exists

To call **READ COMPONENT DATA** from a Terminal program:

```
#Include COMPONNT.DEF
Call ReadComponentData (CID%, data$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **ReadComponentData** is implemented as a System Library procedure, not as a Command definition.

8.7.28 The FIND COMPONENT Command

FIND COMPONENT – Get the CID of a Component from its name

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**AE**	*type*	**00**	*len*	*pathname*	**02**

Response:

ODATA	SW1	SW2
CID (2 bytes)	**90**	**00**

The **FIND COMPONENT** command finds the CID of a Component given its type and pathname. **Read** access is required to all directories in the path, but not to the Component itself.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** is absent
swP1P2Error	**P2 <> 0**
swBadComponentType	*type* is not a valid Component type
swBadComponentName	*pathname* is not a valid Component name
swComponentNotFound	No such Component exists

To call **FIND COMPONENT** from a Terminal program:

```
#Include COMPONNT.DEF
CID% = FindComponent (type@, name$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **FindComponent** is implemented as a System Library procedure, not as a Command definition.

8.7.29 The COMPONENT NAME Command

COMPONENT NAME – Get the name of a Component from its CID

Command syntax:

CLA	INS	P1P2	Le
C0	**B0**	*CID*	**00**

Response:

ODATA	SW1	SW2
pathname	**61**	*len*

The **COMPONENT NAME** command returns the full pathname of a Component given its CID. **Read** access is required to all directories in the path, but not to the Component itself.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is present, or **Le** is absent
swBadComponentType	The top four bits of *CID* do not form a valid Component type
swComponentNotFound	There is no Component with the gven CID

To call **COMPONENT NAME** from a Terminal program:

```
#Include COMPONNT.DEF
pathname$ = ComponentName (CID%)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **ComponentName** is implemented as a System Library procedure, not as a Command definition.

8.7.30 The GRANT PRIVILEGE Command

GRANT PRIVILEGE – Grant a Privilege to a File

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**B2**	*PrivilegeCID*	*len*	*filename*

Response:

SW1	SW2
90	**00**

The **GRANT PRIVILEGE** command grants a Privilege to a File. This command requires **Grant** access to the Privilege, and **Write** access to the File. If the command is successful, *PrivilegeCID* is added to the File's Rights List; this causes the Access Condition **Privilege** (*PrivilegeCID*) to be satisfied whenever File is the currently selected Application.

If the **IDATA** field is empty, the command grants the Privilege to the Terminal program. The Terminal program is allowed to grant itself a Privilege in this way, as long as it has Grant access to the Privilege.

More precisely:

- If an operation is initiated from user code in an Application, then the Access Condition **Privilege** (*Privilege*) is satisfied if the Privilege is contained in the Rights List of the Application File.
- If an operation is initiated from the Terminal program, then the Access Condition **Privilege** (*Privilege*) is satisfied if the Privilege has been granted to the Terminal program since the card was last reset. (But the card only remembers the three most recent such Privileges.)

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is absent, or **Le** is present
swBadComponentType	*PrivilegeCID* is not a valid CID for a Component of type Privilege
swBadComponentName	*filename* is not a valid filename
swComponentNotFound	Either the Privilege or the File does not exist

To call **GRANT PRIVILEGE** from a Terminal program:

```
#Include COMPONNT.DEF
Call GrantPrivilege (PrivilegeCID%, filename$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **GrantPrivilege** is implemented as a System Library procedure, not as a Command definition.

8.7.31 The AUTHENTICATE FILE Command

AUTHENTICATE FILE – Authenticate a File with a Signature

Command syntax:

CLA	INS	P1P2	Lc	IDATA
C0	**B4**	*KeyCID*	*len*	See below

Response:

SW1	SW2
90	**00**

The **AUTHENTICATE FILE** command authenticates a File with an Elliptic Curve signature or a Message Authentication Code (MAC). It requires **Read** access to the File.

KeyCID The CID of the Key used to verify the signature or authenticate the MAC

IDATA *algorithm*, the cryptographic algorithm used to sign or authenticate the File
namelen, the length of *filename*
filename, the path name of the File
signature, the signature or MAC

Valid algorithms are **AlgEC167**, **AlgOmacAes128**, **AlgOmacAes192**, and **AlgOmacAes256**.

- If *algorithm* is equal to **AlgEC167**, then *KeyCID* is the CID of an Elliptic Curve Public Key; *signature* is a 42-byte digital signature of the contents of the File, computed using the corresponding Private Key, as if by the **EC167** System Library procedure **EC167HashAndSign** (see **7.3.5 Generating a Digital Signature** for details).
- If *algorithm* is equal to **AlgOmacAes128**, **AlgOmacAes192**, or **AlgOmacAes256**, then *signature* is the 16-byte MAC of the contents of the File, computed with the **OMAC** algorithm, as if by the System Library procedure **OMAC** (see **7.6 The OMAC Library**).

If the command is successful, *KeyCID* is added to the File's Rights List; this causes the Access Condition **Signed** (*KeyCID*) to be satisfied whenever File is the currently selected Application.

For another method of authenticating a File, see **5.5.2 Automatic File Authentication**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** is absent, or **Le** is present
swBadComponentType	*KeyCID* is not a valid CID for a Component of type Key
swBadComponentName	*filename* is not a valid filename
swKeyNotFound	The Key does not exist
swComponentNotFound	The File does not exist
swKeyUsage	The Key's **Usage** attribute does not have **kuSign** enabled
swKeyAlgorithm	The Key's **Algorithm** attribute does not have *algorithm* enabled
swKeyTooShort	The Key is too short for the given *algorithm*
swUnknownAlgorithm	*algorithm* is not one of the four listed above
swBadSignature	The signature or MAC is incorrect

To call **AUTHENTICATE FILE** from a Terminal program:

```
#Include COMPONNT.DEF
Call AuthenticateFile (KeyCID%, algorithm@, filename$, signature$)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **AuthenticateFile** is implemented as a System Library procedure, not as a Command definition.

8.7.32 The READ RIGHTS LIST Command

READ RIGHTS LIST – Read the Privileges and Signatures of a File

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**B6**	*start*	**00**	*len*	*filename*	2*nmax*

Response:

ODATA	SW1	SW2
RightsList%(*start*) to *RightsList%*(*start+n–1*)	**61**	2*n*

The **READ RIGHTS LIST** command returns the Rights List of a File. This list contains the CID of every Privilege that has been granted to the File (with the **GRANT PRIVILEGE** command or the **GrantPrivilege** System Library procedure), and every Key that has been used to authenticate the File (with the **AUTHENTICATE FILE** command or the **AuthenticateFile** System Library procedure). The Rights List is used by the MultiApplication BasicCard operating system to evaluate the Access Conditions **Privilege** (*PrivilegeCID*) and **Signed** (*KeyCID*). **Read** access is required to every directory on the path, but not to the File itself.

In principle, a File can have a Rights List with more than 127 entries; such a list is too long to be returned in the **ODATA** field. In this case, you can request the Rights List entries *RightsList%*(*start*) to *RightsList%*(*start+nmax–1*) by setting **P1** and **Le** accordingly; if **Le** is zero, *nmax* is taken to be 127. (Here the *RightsList%*( ) array is taken to be zero-based.)

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** is absent, or **Le** is odd
swP1P2Error	**P2 <> 0**
swBadComponentName	*filename* is not a valid filename
swComponentNotFound	File *filename* does not exist
swDataNotFound	The Rights List contains at most *start* entries, so there is no data to return

To call **READ RIGHTS LIST** from a Terminal program:

```
#Include COMPONNT.DEF
nRights% = ReadRightsList (filename$, RightsList%())
```

The **ReadRightsList** System Library procedure automatically handles the case where the number of Rights List entries is greater than 127.

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **ReadRightsList** is implemented as a System Library procedure, not as a Command definition.

8.7.33 The LOAD SEQUENCE Command

LOAD SEQUENCE – Start, end, or abort a Load Sequence session

Command syntax:

CLA	INS	P1	P2
C0	**B8**	*phase*	**00**

Response:

SW1	SW2
90	**00**

The **LOAD SEQUENCE** command implements a form of data commitment for use during Application loading. Sometimes the Application Loader will fail before loading is complete – for instance, the card may lose power during loading, or it may have insufficient memory to create all the required Components. In this case, none of the Application's Components that were created before the error occurred will be required. This command provides a simple method to ensure that these unwanted Components are automatically deleted.

The *phase* parameter must be **LoadSequenceStart**, **LoadSequenceEnd**, or **LoadSequenceAbort**. These constants are defined in COMPONNT.DEF. They are used as follows:

- Before the Application Loader starts to load an Application, it calls **LOAD SEQUENCE** with *phase*=**LoadSequenceStart**. After this, all newly created Components will be flagged as Uncommitted.
- If the Application loads successfully, the Application Loader calls **LOAD SEQUENCE** with *phase*=**LoadSequenceEnd**; these new Components will then be flagged as Permanent.
- If the Application fails to load for any reason, the Application Loader calls **LOAD SEQUENCE** with *phase*=**LoadSequenceAbort**; this tells the BasicCard to delete all Components that are flagged as Uncommitted. If the Application Loader can't do this, because the card is no longer responsive (or because the Application Loader itself lost power), then the next time the card is reset, it will delete these Components automatically.

Components cannot be deleted while a Load Sequence is active; an attempt to delete a Component will result in the error code **SW1-SW2=swLoadSequenceActive**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** or **Le** is present
swP1P2Error	**P2 <> 0**
swLoadSequencePhase	**P1** is not one ot the three values listed above
swLoadSequenceActive	*phase*= **LoadSequenceStart**, but Load Sequence is already active
swLoadSequenceNotActive	*phase*=**LoadSequenceEnd** or **LoadSequenceAbort**, but no Load Sequence is active

To call **LOAD SEQUENCE** from a Terminal program:

```
#Include COMPONNT.DEF
Call LoadSequence (phase@)
```

Note: For compatibility with the **COMPONENT** System Library in the MultiApplication BasicCard, **LoadSequence** is implemented as a System Library procedure, not as a Command definition.

8.7.34 The SECURE TRANSPORT Command

SECURE TRANSPORT – Start or end a Secure Transport session

Start session:

CLA	INS	P1P2	Lc	IDATA
C0	BA	*KeyCID*	*len*	*algorithm* (1 byte); *Nonce*

Response:

SW1	SW2
90	00

End session:

CLA	INS	P1	P2
C0	BA	00	00

Response:

SW1	SW2
90	00

The **SECURE TRANSPORT** command enables Files and Keys to be stored in an Image file in encrypted form, using a Secure Transport Key known only to the issuer and the BasicCard. While Secure Transport is active, the Access Condition **SecTrans** (*KeyCID*) is satisfied. See **5.5 Secure Transport** for an explanation of the Secure Transport mechanism.

Valid algorithms: **AlgEaxAes128**, **AlgEaxAes192**, **AlgEaxAes256**.

Command-Specific Error Codes in SW1-SW2:

swLcLeError	**Lc** absent (**P1P2 <> 0**), or **Lc** present (**P1P2 = 0**), or **Le** present
swKeyNotFound	The Key does not exist
swKeyUsage	The Key's **Usage** attribute does not have **kuSecTrans** enabled
swKeyAlgorithm	The Key's **Algorithm** attribute does not have *algorithm* enabled
swKeyTooShort	The Key is too short for the given *algorithm*
swUnknownAlgorithm	*algorithm* is not one of those listed above
swSecureTransportActive	Attempt to start Secure Transport while already active
swSecureTransportInactive	Attempt to end a non-existent Secure Transport session

To start **SECURE TRANSPORT** from a Terminal program:

```
#Include COMPONNT.DEF
Call SecureTransport (P1P2=KeyCID%, algorithm@, Nonce$)
```

To end **SECURE TRANSPORT** from a Terminal program:

```
#Include COMPONNT.DEF
Call SecureTransport (Lc=0, 0, "")
```

8.8 The Command Definition File COMMANDS.DEF

The file COMMANDS.DEF can be found in the directory `BasicCardPro\Inc`. It contains:

- declarations of all the pre-defined commands;
- definitions of the ZC-Basic **SW1-SW2** status codes; and
- definitions of P-Code error codes.

See **8.6 Status Bytes SW1 and SW2** for descriptions of the status and error codes.

Here is the file COMMANDS.DEF:

```
Rem Pre-defined BasicCard commands

#IfNotDef CommandsDefIncluded ' Prevent multiple inclusion
Const CommandsDefIncluded = True

#Include AlgID.DEF

Declare Command &HC0 &H00 GetState(Lc=0, State@, Version$)
Declare Command &HC0 &H02 EepromSize(Lc=0, Start%, Length%)
Declare Command &HC0 &H04 ClearEeprom(Length%, Disable Le)

Rem  Since Version 3.01, the WRITE EEPROM command is no longer supported.
Rem  Use it at your own risk!
Rem
Rem  Declare Command &HC0 &H06 WriteEeprom(Data$, Disable Le)

Declare Command &HC0 &H08 ReadEeprom(Lc=0, Data$)
Declare Command &HC0 &H0A EepromCRC(Length%)
Declare Command &HC0 &H0A EepromCRC32(Lc=2, CRCHi%, CRCLo%, Le=4)
Declare Command &HC0 &H0C SetState()
Declare Command &HC0 &H0E GetApplicationID(Lc=0, Name$)
Declare Command &HC0 &H10 StartEncryption(RA&, Le=0)
Declare Command &HC0 &H10 ProEncryption(RAHi&, RALo&, Le=0)
Declare Command &HC0 &H10 SMEncryption(Algorithm@, RAHi&, RALo&, Le=0)
Declare Command &HC0 &H10 SMAuthentication(Algorithm@, Le=0)
Declare Command &HC0 &H12 EndEncryption()
Declare Command &HC0 &H14 Echo(S$)
Declare Command &HC0 &H16 AssignNAD()

Rem BasicCard operating system errors

Const swCommandOK              = &H9000
Const swRetriesRemaining       = &H63C0
Const swEepromWriteError       = &H6581
Const swBadEepromHeap          = &H6582
Const swBadFileChain           = &H6583
Const swKeyNotFound            = &H6611
Const swPolyNotFound           = &H6612
Const swKeyTooShort            = &H6613
Const swKeyDisabled            = &H6614
Const swUnknownAlgorithm       = &H6615
Const swAlreadyEncrypting      = &H66C0
Const swNotEncrypting          = &H66C1
Const swBadCommandCRC          = &H66C2
Const swDesCheckError          = &H66C3
Const swCoprocessorError       = &H66C4
Const swAesCheckError          = &H66C5
Const swBadSignature           = &H66C6
Const swBadAuthenticate        = &H66C7
Const swLcLeError              = &H6700
Const swCommandTooLong         = &H6781
Const swResponseTooLong        = &H6782
```

```
Const swInvalidState           = &H6985
Const swCardUnconfigured       = &H6986
Const swNewStateError          = &H6987
Const swP1P2Error              = &H6A00
Const swOutsideEeprom          = &H6A02
Const swDataNotFound           = &H6A88
Const swINSNotFound            = &H6D00
Const swCLANotFound            = &H6E00
Const swInternalError          = &H6F00

Rem SW1=&H61 is Le warning:

Const sw1LeWarning             = &H61

Rem SW1=&H6C is La warning (T=0 protocol only):

Const sw1LaWarning             = &H6C

Rem P-Code interpreter errors (SW1=&H64, SW2=P-Code error)

Const sw1PCodeError            = &H64

Const pcStackOverflow          = &H01
Const pcDivideByZero           = &H02
Const pcNotImplemented         = &H03
Const pcBadRamHeap             = &H04
Const pcBadEepromHeap          = &H05
Const pcReturnWithoutGoSub     = &H06
Const pcBadSubscript           = &H07
Const pcBadBounds              = &H08
Const pcInvalidReal            = &H09
Const pcOverflow               = &H0A
Const pcNegativeSqrt           = &H0B
Const pcDimensionError         = &H0C
Const pcBadStringCall          = &H0D
Const pcOutOfMemory            = &H0E
Const pcArrayNotDynamic        = &H0F
Const pcArrayTooBig            = &H10
Const pcDeletedArray           = &H11
Const pcPCodeDisabled          = &H12
Const pcBadSystemCall          = &H13
Const pcBadKey                 = &H14
Const pcBadLibraryCall         = &H15
Const pcStackUnderflow         = &H16
Const pcInvalidAddress         = &H17

Rem Error codes generated by the Terminal

Const swNoCardReader           = &H6790
Const swCardReaderError        = &H6791
Const swNoCardInReader         = &H6792
Const swCardPulled             = &H6793
Const swT1Error                = &H6794
Const swCardError              = &H6795
Const swCardNotReset           = &H6796
Const swKeyNotLoaded           = &H6797
Const swPolyNotLoaded          = &H6798
Const swBadResponseCRC         = &H6799
Const swCardTimedOut           = &H679A
Const swTermOutOfMemory        = &H679B
Const swBadDesResponse         = &H679C
Const swInvalidComPort         = &H679D
Const swNoPcscDriver           = &H679F
Const swPcscReaderBusy         = &H67A0
Const swPcscError              = &H67A1
```

```
Const swComPortBusy            = &H67A2
Const swBadATR                 = &H67A3
Const swT0Error                = &H67A4
Const swPTSError               = &H67A7
Const swDataOverrun            = &H67A8
Const swBadAesResponse         = &H67A9
Const swReservedINS            = &H6D80
Const swReservedCLA            = &H6E80

Rem  MuliApplication BasicCard errors
Rem  (corresponding to Component Library errors in COMPONNT.DEF)

Const swBadComponentName          = &H69C0
Const swComponentNotFound         = &H69C1
Const swAccessDenied              = &H69C2
Const swComponentAlreadyExists    = &H69C3
Const swBadComponentChain         = &H69C4
Const swNameTooLong               = &H69C5
Const swOutOfMemory               = &H69C6
Const swInvalidACR                = &H69C7
Const swBadComponentType          = &H69C8
'Const swKeyNotFound              = &H69CC swKeyNotFound already exists
Const swKeyUsage                  = &H69CD
Const swKeyAlgorithm              = &H69CE
'Const swKeyDisabled              = &H69CF swKeyDisabled already exists
Const swTooManyTempFlags          = &H69D0
Const swExecutableAcrDenied       = &H69D1
Const swApplicationNotFound       = &H69D2
Const swACRDepth                  = &H69D3
Const swBadComponentAttr          = &H69D4
Const swBadComponentData          = &H69D5
Const swBadAppFile                = &H69D6
Const swLoadSequenceActive        = &H69D7
Const swLoadSequenceNotActive     = &H69D8
Const swLoadSequencePhase         = &H69D9
'Const swKeyTooShort              = &H69DA swKeyTooShort already exists
'Const swUnknownAlgorithm         = &H69DB swUnknownAlgorithm already exists
Const swBadEaxTag                 = &H69DC
Const swSecureTransportActive     = &H69DD
Const swSecureTransportInactive   = &H69DE
Const swComponentReferenced       = &H69DF
Const swFileNotContiguous         = &H69E0
Const swAppFileOpen               = &H69E1

#IfDef TerminalProgram

Rem  AutoEncryption handles StartEncryption for the different card types.
Rem  To use:
Rem          Call AutoEncryption (KeyNum@, KeyName$)
Rem          Call CheckSW1SW2()
Rem
Rem  KeyNum@ is the key number, for all card types. Encrypting for the
Rem  MultiApplication BasicCard also requires the key's path name, in
KeyName$.

#Include MISC.DEF
#Include COMPONNT.DEF

Sub AutoEncryption (KeyNum@, KeyName$)

  Private TryAES : TryAES = (Len (Key(KeyNum@)) >= 16)
  If TryAES Then
    Call ProEncryption (P2=KeyNum@, Rnd, Rnd)
    If SW1SW2 = swLcLeError Then Call StartEncryption (P2=KeyNum@, Rnd)
```

```
  Else
    Call StartEncryption (P2=KeyNum@, Rnd)
  End If

  Select Case SW1SW2

    Case swUnknownAlgorithm ' Compact BasicCard doesn't support P1=0
      Call StartEncryption (P1=&H12, P2=KeyNum@, Rnd)

    Case swBadComponentType ' MultiApplication BasicCard
      Private CID : CID = FindComponent (ctKey, KeyName$)
      Call AddIndexedKey (CID, Key(KeyNum@))
      If TryAES Then
        Call SMEncryption (P1P2=CID, 0, Rnd, Rnd)
      Else
        Call SMEncryption (P1P2=CID, Lc=5, 0, Rnd, 0)
      End If

  End Select

End Sub

Rem  Sub SMEncryptionByCID (KeyCID%, KeyVal$, Algorithm@)
Rem  Sub SMEncryptionByName (KeyName$, KeyVal$, Algorithm@)
Rem
Rem  These procedures activate encryption in the MultiApplication BasicCard.
Rem  SMEncryptionByName is simpler; SMEncryptionByCID is faster, saving
Rem  a call to FincComponent.

Sub SMEncryptionByCID (KeyCID%, KeyVal$, Algorithm@)

  Rem  Tell the Terminal program interpreter the value of the key
  Call AddIndexedKey (KeyCID%, KeyVal$)

  If Algorithm@ < AlgOmacAes128 Then

    Rem  Encryption algorithm - initialisation data required

    If Algorithm@ <= AlgTripleDesCrc Then ' Four-byte initialisation data
      Call SMEncryption (P1P2=KeyCID%, Lc=5, Algorithm@, Rnd, 0)
    Else                               ' Eight-byte initialisation data
      Call SMEncryption (P1P2=KeyCID%, Algorithm@, Rnd, Rnd)
    End If

  Else

    Rem  Authentication algorithm - no initialisation data required
    Call SMEncryption (P1P2=KeyCID%, Lc=1, Algorithm@, 0, 0)

  End If

End Sub

Sub SMEncryptionByName (KeyName$, KeyVal$, Algorithm@)
  Private CID : CID = FindComponent (ctKey, KeyName$)
  If SW1SW2 = swCommandOK Then _
    Call SMEncryptionByCID (CID, KeyVal$, Algorithm@)
End Sub

#EndIf ' TerminalProgram

#EndIf ' CommandsDefIncluded
```

9. Encryption Algorithms

The Compact BasicCard supports the following two encryption algorithms:

Algorithm	
AlgSgLfsr	**SG-LFSR** (Shrinking Generator – Linear Feedback Shift Register)
AlgSgLfsrCrc	**SG-LFSR** with **CRC-16**

The Enhanced BasicCard supports the following two encryption algorithms:

Algorithm	
AlgSingleDes	**Single DES** (Data Encryption Standard, 8-byte key)
AlgTripleDes	**Triple DES-EDE2** (Data Encryption Standard, 16-byte key)

The Professional and MultiApplication BasicCards support some or all of the following encryption algorithms:

Algorithm	
AlgSingleDesCrc	**Single DES** with CRC (8-byte key)
AlgTripleDesEDE2Crc	**Triple DES-EDE2** with CRC (16-byte key)
AlgTripleDesEDE3Crc	**Triple DES-EDE3** with CRC (24-byte key)
AlgAes128	**AES-128** (Advanced Encryption Standard, 128-bit key)
AlgAes192	**AES-192** (Advanced Encryption Standard, 192-bit key)
AlgAes256	**AES-256** (Advanced Encryption Standard, 256-bit key)
AlgEaxAes128	**EAX** (Authenticated Encryption) using **AES-128**
AlgEaxAes192	**EAX** (Authenticated Encryption) using **AES-192**
AlgEaxAes256	**EAX** (Authenticated Encryption) using **AES-256**
AlgOmacAes128	**OMAC** (One-Key CBC MAC) using **AES-128**
AlgOmacAes192	**OMAC** (One-Key CBC MAC) using **AES-192**
AlgOmacAes256	**OMAC** (One-Key CBC MAC) using **AES-256**

This chapter describes these algorithms in detail, to give interested readers the opportunity to evaluate them. But you don't need to know how these algorithms work in order to use them; if you only want to know how to use them from ZC-Basic, skip this chapter and see instead **3.17.1 Implementing Encryption**.

9.1 The DES Algorithm

The **DES** algorithm is the internationally recognised Data Encryption Standard, defined in the ANSI standard documents *X3.92-1981 (Data Encryption Algorithm)* and *X3.106-1983 (Data Encryption Algorithm – Modes of Operation)*. See these documents for a definition of the **DES** algorithm itself; for a fuller treatment, including 'C' source code, see Bruce Schneier's *Applied Cryptography* (Second Edition, John Wiley & Sons, Inc., 1996).

As you can see from the dates of the ANSI documents, the **DES** algorithm is no longer young. In fact, the original **DES** algorithm is usually referred to as **Single DES**, and must now be regarded as less than completely secure. Special-purpose hardware can be constructed for several tens of thousands of dollars, that can break **Single DES** encryption in less than a day. For this reason, stronger versions, **Triple DES-EDE2** and **Triple DES-EDE3**, have become *de facto* standards in the banking world. **Triple DES-EDE2** is generally believed to be safe against all currently feasible attacks, and **Triple**

DES-EDE3 is believed to be safe against any imaginable future attacks. However, **Single DES** is still used for protecting confidential but financially worthless data, such as a patient's medical records.

The original ANSI *X3.92* document defines **DES** as an encryption function that takes a 56-bit, 8-byte key **K** and an 8-byte data block **P** as input, and returns an 8-byte data block **C** as output:

$$\mathbf{C} = \mathbf{E_K}\ (\mathbf{P})$$

The inverse of this is the **DES** decryption function:

$$\mathbf{P} = \mathbf{D_K}\ (\mathbf{C})$$

(This notation is taken from Bruce Schneier's *Applied Cryptography*: **P** and **C** denote plaintext and ciphertext, **E** and **D** are encryption and decryption, and **K** is the key.)

Note that an 8-byte **Single DES** key contains only 56 significant bits. This is because the top bit of each byte is not used. This bit can be used as a parity check, or simply ignored (which is what the BasicCard does).

The **Triple DES-EDE2** algorithm takes a 112-bit, 16-byte key **K** and splits it into two 8-byte keys **KL** and **KR**. Then the encryption and decryption functions are given by

$$\mathbf{C} = \mathbf{EDE2_K}\ (\mathbf{P}) = \mathbf{E_{KL}}\ (\mathbf{D_{KR}}\ (\mathbf{E_{KL}}\ (\mathbf{P}))) \text{ and}$$

$$\mathbf{P} = \mathbf{DED2_K}\ (\mathbf{C}) = \mathbf{D_{KL}}\ (\mathbf{E_{KR}}\ (\mathbf{D_{KL}}\ (\mathbf{C})))$$

The **Triple DES-EDE3** algorithm takes a 168-bit, 24-byte key **K** and splits it into three 8-byte keys **K1**, **K2**, and **K3**. Then the encryption and decryption functions are given by

$$\mathbf{C} = \mathbf{EDE3_K}\ (\mathbf{P}) = \mathbf{E_{K3}}\ (\mathbf{D_{K2}}\ (\mathbf{E_{K1}}\ (\mathbf{P}))) \text{ and}$$

$$\mathbf{P} = \mathbf{DED3_K}\ (\mathbf{C}) = \mathbf{D_{K1}}\ (\mathbf{E_{K2}}\ (\mathbf{D_{K3}}\ (\mathbf{C})))$$

(The six functions $\mathbf{E_K}$, $\mathbf{D_K}$, $\mathbf{EDE2_K}$, $\mathbf{DED2_K}$, $\mathbf{EDE3_K}$, and $\mathbf{DED3_K}$ can be called directly from ZC-Basic – see **3.17.7 DES Encryption Primitives**.)

Given such encryption and decryption functions, there are several ways that they can be used to encrypt and decrypt a message of arbitrary length. The method used by the Enhanced BasicCard is described in the next section.

9.2 Implementation of DES in the BasicCard

Apart from their encryption and decryption functions (**E** and **D** versus $\mathbf{E}^3$ and $\mathbf{D}^3$), the implementations of **Single DES**, **Triple DES-EDE2**, and **Triple DES-EDE3** in the BasicCard are identical. To start with, we need to know how to encrypt a message that is longer than 8 bytes. (All commands and responses encrypted with **DES** in the BasicCard are at least 8 bytes long.)

9.2.1 *The Message Encryption Functions* $\mathbf{ME_K}$, $\mathbf{MEDE2_K}$, *and* $\mathbf{MEDE3_K}$

The **Single DES** message encryption function $\mathbf{C} = \mathbf{ME_K}\ (\mathbf{P})$ is defined as follows. We are given:

- a message **P**, at least 8 bytes in length;
- an 8-byte key **K**;
- the **Single DES** encryption and decryption functions $\mathbf{E_K}$ and $\mathbf{D_K}$;
- an 8-byte *initialisation vector* $\mathbf{C}_0$ (more about this in **9.2.3 The Initialisation Vector**).

First, split the message **P** into 8-byte blocks $\mathbf{P}_1$, $\mathbf{P}_2$,..., $\mathbf{P}_{n-1}$, plus a final block $\mathbf{P}_n$ that may be shorter than 8 bytes. Pad this final block with m zeroes to a length of 8 bytes (so 0 <= m <= 7). Then compute, for 1 <= i <= n:

$$\mathbf{C}_i = \mathbf{E_K}\ (\mathbf{C}_{i-1}\ \mathbf{Xor}\ \mathbf{P}_i)$$

(Note that the initialisation vector $\mathbf{C}_0$ is needed to compute $\mathbf{C}_1$.) Then throw away the last m bytes of the *penultimate* block $\mathbf{C}_{n-1}$, and concatenate the resulting blocks $\mathbf{C}_1$,..., $\mathbf{C}_n$ to get the encrypted ciphertext **C**.

If we threw away the last m bytes of the *last* block $\mathbf{C}_n$, then the message **C** couldn't be decrypted by its recipient. But the recipient can reconstruct the last m bytes of $\mathbf{C}_{n-1}$, as follows:

The last block is computed from $\mathbf{C}_n = \mathbf{E_K}(\mathbf{C}_{n-1}\ \mathbf{Xor}\ \mathbf{P}_n)$

Therefore, $\mathbf{D_K}(\mathbf{C}_n) = \mathbf{C}_{n-1}\ \mathbf{Xor}\ \mathbf{P}_n$

which means that $\mathbf{C}_{n-1} = \mathbf{D_K}(\mathbf{C}_n)\ \mathbf{Xor}\ \mathbf{P}_n$

But the last m bytes of $\mathbf{P}_n$ are all zero, so the last m bytes of $\mathbf{C}_{n-1}$ are equal to the last m bytes of $\mathbf{D_K}(\mathbf{C}_n)$, which can be computed without prior knowledge of the plaintext **P**. This trick is called *ciphertext stealing*, and it allows us to keep encrypted messages to their original size.

The **Triple DES** message encryption functions $\mathbf{MEDE2_K}$ and $\mathbf{MEDE3_K}$ are defined in exactly the same way, except that the key **K** is 16 or 24 bytes long, and the **Triple DES** encryption function $\mathbf{EDE2_K}$ or $\mathbf{EDE3_K}$ is substituted for the **Single DES** function $\mathbf{E_K}$.

9.2.2 The Message Decryption Functions MD_K , $MDED2_K$, and $MDED3_K$

The **Single DES** message decryption function $\mathbf{P} = \mathbf{MD_K}(\mathbf{C})$ is the inverse of $\mathbf{ME_K}$. First restore the penultimate block $\mathbf{C}_{n-1}$ to 8 bytes, as described in the previous section. Then compute, for $1 <= i <= n$:

$$\mathbf{P}_i = \mathbf{C}_{i-1}\ \mathbf{Xor}\ \mathbf{D_K}(\mathbf{C}_i)$$

Throw away the last m bytes in $\mathbf{P}_n$ (which should all be zero), and concatenate all the resulting blocks $\mathbf{P}_1$,..., $\mathbf{P}_n$ to get the original plaintext message **P**.

The **Triple DES** message decryption functions $\mathbf{MDED2_K}$ and $\mathbf{MDED3_K}$ are defined in exactly the same way, except that the **Triple DES** decryption function $\mathbf{DED2_K}$ or $\mathbf{DED3_K}$ is substituted for the **Single DES** function $\mathbf{D_K}$.

9.2.3 The Initialisation Vector

The initialisation vector $\mathbf{C}_0$ is determined as follows:

For the first command following a **START ENCRYPTION** command, the initialisation vector $\mathbf{C}_0$ depends on the command and response fields of the **START ENCRYPTION** command:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**10**	*algorithm*	*key*	**04**	*Random number* **RA** (4 bytes)	**04**

Response:

ODATA	SW1	SW2
Random number **RB** (4 bytes)	**90**	**00**

In this case, $\mathbf{C}_0$ consists of the first two bytes of **RA**, followed by all four bytes of **RB**, followed by the last two bytes of **RA**.

For subsequent commands and responses, $\mathbf{C}_0$ is simply the last ciphertext block $\mathbf{C}_n$ of the previous message.

9.2.4 Encryption of Commands in the Enhanced BasicCard

A command has the following structure (shaded blocks are optional):

CLA	INS	P1	P2		Lc	IDATA		Le

Encryption consists of the following steps:

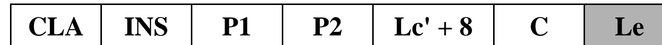
- If the **Lc** or **Le** fields are absent, insert **Lc' = 00** and/or **Le' = 00**:

CLA	INS	P1	P2	Lc'	IDATA	Le'

- Append two zeroes (the resulting command now contains at least 8 bytes):

- Encrypt the whole command **P**, with **C = ME$_K$ (P)** or **C = MEDE2$_K$ (P)**:

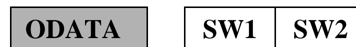
- Wrap the resulting ciphertext **C** in the original command parameters:



The resulting command is 8 bytes longer than the original command. These 8 bytes of redundancy enable an authentication check to be done: the command parameters **CLA INS P1 P2 Lc' Le' 00 00** in the decrypted command must match the wrapping, otherwise the command is rejected, with **SW1-SW2 = swDesCheckError**.

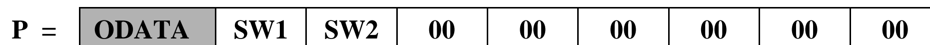
9.2.5 Encryption of Responses in the Enhanced BasicCard

A response has the following structure (the shaded block is optional):

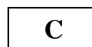


Encryption consists of the following steps:

- Append six zeroes:



- Encrypt the resulting response **P**, with **C = ME$_K$ (P)** or **C = MEDE2$_K$ (P)**:



- Append the original **SW1-SW2**:

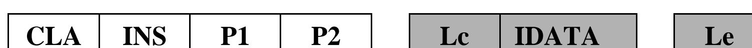
The resulting response is always exactly 8 bytes longer than the original response. As with command encryption, these 8 bytes of redundancy enable an authentication check to be done on the response: if the decrypted response doesn't end with **SW1-SW2** followed by six zeroes, the response is rejected, and **SW1-SW2 = swBadDesResponse** is returned to the caller in the Terminal program.

Note: If status bytes **SW1 SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not encrypted.

9.2.6 Encryption of Commands in the Professional BasicCard

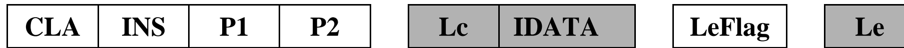
The Professional BasicCard required a new encryption algorithm, because the algorithms described above for the Enhanced BasicCard are not compatible with the **T=0** protocol.

A command has the following structure (shaded blocks are optional):



Encryption consists of the following steps:

- Insert an **LeFlag** byte: **01** if **Le** is present, **00** if **Le** is absent:



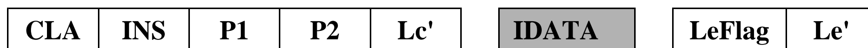
- If the **Le** field is absent, append **Le' = 00**:

- Calculate the 32-bit **CRC** of the resulting data:

  CRC = CRC32 (**CLA || INS || P1 || P2** [**|| Lc || IDATA**] **|| LeFLag || Le'**)

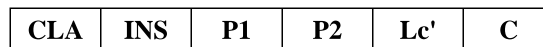
  The **CRC32** function is defined in **7.10.4 CRC Calculations**.

- If the **Lc** field is absent, insert **Lc' = 00**:

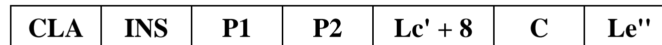


- Append two zeroes, followed by the **CRC** (now the command tail **P** is at least 8 bytes long):

- Encrypt the command tail **P**, with **C** = $\mathbf{ME_K}$ (**P**) , **C** = $\mathbf{MEDE2_K}$ (**P**) , or **C** = $\mathbf{MEDE3_K}$ (**P**):



- Adjust **Lc'**, and append **Le''**:



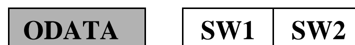
Le'' is computed as follows (this is where **T=0** compatibility comes in):

- If **Le** was absent, then **Le'' = 08**
- If **Le = 00**, then **Le'' = 00**
- Otherwise, **Le'' = Le + 08**

The resulting command is 8 or 9 bytes longer than the original command. When the BasicCard receives the command, it checks that the decrypted command tail **P** is valid, and that the **CRC** is correct. If not, the command is rejected, with **SW1-SW2 = swDesCheckError**.

9.2.7 Encryption of Responses in the Professional BasicCard

A response has the following structure (the shaded block is optional):



Encryption consists of the following steps:

- Calculate the 32-bit **CRC** of the response:

  CRC = CRC32 ([**ODATA ||**] **SW1 || SW2**)

  The **CRC32** function is defined in **7.10.4 CRC Calculations**.

- Append two zeroes and the **CRC**:

- Encrypt the resulting response **P**, with **C** = $\mathbf{ME_K}$ (**P**) , **C** = $\mathbf{MEDE2_K}$ (**P**) , or **C** = $\mathbf{MEDE3_K}$ (**P**):

C

- Append the original **SW1-SW2**:

C	SW1	SW2

The resulting response is 8 bytes longer than the original response. If the decrypted response doesn't end in **SW1 SW2 00 00 CRC**, the response is rejected, and **SW1-SW2 = swBadDesResponse** is returned to the caller in the Terminal program.

Note: If status bytes **SW1-SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not encrypted.

9.3 Certificate Generation Using DES

The ZC-Basic **Certificate** command is described in **3.17.8 Certificate Generation**. The certificate generation algorithm is as follows:

Let **P** be the data to be signed. Append the byte **80** to **P** (this ensures that messages differing only in the number of trailing zeroes will have different certificates). Split the resulting **P** into 8-byte blocks $\mathbf{P}_1$,..., $\mathbf{P}_n$, padding the last block $\mathbf{P}_n$ with zeroes if necessary. Fill the initialisation vector $\mathbf{C}_0$ with zeroes, and then compute, for $1 <= i <= n$:

$\mathbf{C}_i = \mathbf{EDE3}_\mathbf{K}\ (\mathbf{C}_{i-1}\ \mathbf{Xor}\ \mathbf{P}_i)$ (for keys **K** 24 bytes or longer, if supported)
$\mathbf{C}_i = \mathbf{EDE2}_\mathbf{K}\ (\mathbf{C}_{i-1}\ \mathbf{Xor}\ \mathbf{P}_i)$ (for keys **K** 16 bytes or longer)
$\mathbf{C}_i = \mathbf{E}_\mathbf{K}\ (\mathbf{C}_{i-1}\ \mathbf{Xor}\ \mathbf{P}_i)$ (for keys **K** shorter than 16 bytes)

The certificate is the final ciphertext block $\mathbf{C}_n$.

9.4 The AES Algorithm

On 28th February 2001, the US National Institute of Standards and Technology announced the Advanced Encryption Standard (**AES**), the long-awaited replacement for the **DES** standard. **AES** is described in "Draft Federal Information Processing Standard for the AES". This document is available from NIST's web site, at http://csrc.nist.gov/encryption/aes. **AES** uses the *Rijndael* algorithm, designed by Joan Daemen and Vincent Rijmen, as its cryptographic primitive. In its original specification, the Rijndael algorithm encrypts and decrypts data blocks of length 128, 192, or 256 bits, using a key of length 128, 192, or 256 bits. The **AES** specification fixes the block length at 128 bits (i.e. 16 bytes), but retains the three key length options.

AES with a 128-bit key length (or **AES-128**) is considered equal or superior in security to Triple DES. However, it is roughly six times faster. Longer key lengths are correspondingly more secure. For details of how to call the **AES** encryption primitives from a ZC-Basic program, see **7.2 AES: The Advanced Encryption Standard Library**.

9.5 Implementation of AES in the Professional BasicCard

This section parallels **9.2 Implementation of DES in the BasicCard**. Here the functions $\mathbf{E}_\mathbf{K}$ and $\mathbf{D}_\mathbf{K}$ are the **AES-***xxx* encryption and decryption primitives, where *xxx* is the key length in bits: 128, 192, or 256. To start with, we need to know how to encrypt a message that is longer than 16 bytes. (All commands and responses encrypted with **AES** in the BasicCard are at least 16 bytes long.)

9.5.1 The Message Encryption Function $\mathbf{AES\text{-}ME}_\mathbf{K}$

The **AES-***xxx* message encryption function $\mathbf{C} = \mathbf{AES\text{-}ME}_\mathbf{K}\ (\mathbf{P})$ is defined as follows. We are given:

- a message **P**, at least 16 bytes in length;
- a 16-byte key **K**;

- the **AES-** *xxx* encryption and decryption functions $\mathbf{E_K}$ and $\mathbf{D_K}$;
- a 16-byte *initialisation vector* $\mathbf{C_0}$ (more about this in **9.5.3 The Initialisation Vector**).

First, split the message **P** into 16-byte blocks $\mathbf{P_1}$, $\mathbf{P_2}$,..., $\mathbf{P_{n-1}}$, plus a final block $\mathbf{P_n}$ that may be shorter than 16 bytes. Pad this final block with m zeroes to a length of 16 bytes (so 0 <= m <= 15). Then compute, for 1 <= i <= n:

$$\mathbf{C_i = E_K (C_{i-1} \text{ Xor } P_i)}$$

(Note that the initialisation vector $\mathbf{C_0}$ is needed to compute $\mathbf{C_1}$.) Then throw away the last m bytes of the *penultimate* block $\mathbf{C_{n-1}}$, and concatenate the resulting blocks $\mathbf{C_1}$,..., $\mathbf{C_n}$ to get the encrypted ciphertext **C**. For an explanation of why bytes are discarded from the penultimate block, see the description of ciphertext stealing in **9.2.1 The Message Encryption Functions $\mathbf{ME_K}$ and $\mathbf{ME^3_K}$**.

9.5.2 The Message Decryption Function *AES-MD*$_K$

The **AES-***xxx* message decryption function **P = AES-MD$_K$ (C)** is the inverse of **AES-ME$_K$**. First restore the penultimate block $\mathbf{C_{n-1}}$ to 16 bytes, as described for **DES** in **9.2.1 The Message Encryption Functions $\mathbf{ME_K}$ and $\mathbf{ME^3_K}$**. Then compute, for 1 <= i <= n:

$$\mathbf{P_i = C_{i-1} \text{ Xor } D_K (C_i)}$$

Throw away the last m bytes in $\mathbf{P_n}$ (which should all be zero), and concatenate all the resulting blocks $\mathbf{P_1}$,..., $\mathbf{P_n}$ to get the original plaintext message **P**.

9.5.3 The Initialisation Vector

The initialisation vector $\mathbf{C_0}$ is determined as follows:

For the first command following a **START ENCRYPTION** command, the initialisation vector $\mathbf{C_0}$ depends on the command and response fields of the **START ENCRYPTION** command:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**10**	*algorithm*	*key*	**08**	*Random number* **RA** (8 bytes)	**00**

Response:

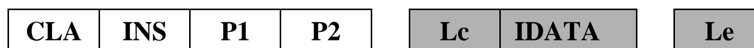
ODATA	SW1	SW2
algorithm (1 byte); *Random number* **RB** (8 bytes)	**90**	**00**

In this case, $\mathbf{C_0}$ consists of the first four bytes of **RA**, followed by all eight bytes of **RB**, followed by the last four bytes of **RA**.

For subsequent commands and responses, $\mathbf{C_0}$ is simply the last ciphertext block $\mathbf{C_n}$ of the previous message.

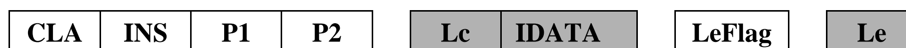
9.5.4 Encryption of Commands

A command has the following structure (shaded blocks are optional):



Encryption consists of the following steps:

- Insert an **LeFlag** byte: **01** if **Le** is present, **00** if **Le** is absent:



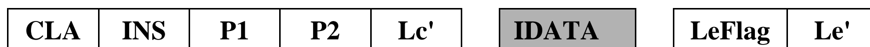
- If the **Le** field is absent, append **Le' = 00**:

- Calculate the 32-bit **CRC** of the resulting data:

CRC = CRC32 (**CLA || INS || P1 || P2** [|| **Lc || IDATA**] || **LeFLag || Le'**)

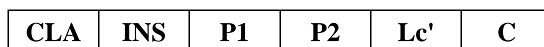
The **CRC32** function is defined in **7.10.4 CRC Calculations**.

- If the **Lc** field is absent, insert **Lc' = 00**:

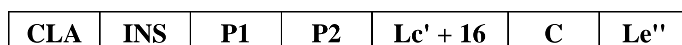


- Append ten zeroes, followed by the **CRC** (now the command tail **P** is at least 16 bytes long):

- Encrypt the command tail **P**, with **C = AES-ME$_K$** (**P**):



- Adjust **Lc'**, and append **Le''**:



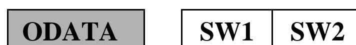
Le'' is computed as follows:

- If **Le** was absent, then **Le''** = **10**
- If **Le** = **00**, then **Le''** = **00**
- Otherwise, **Le''** = **Le** + **10**

The resulting command is 16 or 17 bytes longer than the original command. When the BasicCard receives the command, it checks that the decrypted command tail **P** is valid, and that the **CRC** is correct. If not, the command is rejected, with **SW1-SW2 = swAesCheckError**.

9.5.5 Encryption of Responses

A response has the following structure (the shaded block is optional):



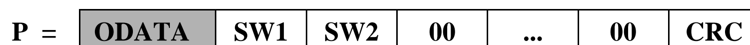
Encryption consists of the following steps:

- Calculate the 32-bit **CRC** of the response:

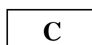
  CRC = CRC32 ([**ODATA** ||] **SW1** || **SW2**)

  The **CRC32** function is defined in **7.10.4 CRC Calculations**.

- Append ten zeroes and the **CRC**:



- Encrypt the resulting response **P**, with **C = AES-ME$_K$** (**P**):



- Append the original **SW1-SW2**:

The resulting response is 16 bytes longer than the original response. If the decrypted response doesn't end in **SW1 SW2 00...00 CRC**, the response is rejected, and **SW1-SW2 = swBadAesResponse** is returned to the caller in the Terminal program.

Note: If status bytes **SW1-SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not encrypted.

9.6 The EAX Algorithm

EAX is an algorithm for Authenticated Encryption, designed by M.Bellare, P. Rogaway, and D. Wagner. A brief explanation of the algorithm follows; the full description is available from NIST's web site, at http://csrc.nist.gov/CryptoToolkit/modes/proposedmodes/.

The **EAX** algorithm was designed to achieve the dual aims of secrecy and authentication, using a single cryptographic key. For encryption it uses the **CTR** algorithm; for authentication it uses a generalisation of the **OMAC** algorithm (described in **9.8 The OMAC Algorithm**), which the authors call "tweaked **OMAC**".

The **EAX** algorithm uses a block cipher $\mathbf{E_K}$ (**B**), which operates on blocks **B** of length **n** bits. The choice of block cipher is left to the implementer. ZeitControl's implementation of **EAX** uses **AES** as its block cipher, with key length 128, 192, or 256 bits; the block length **n** is equal to 128 bits (16 bytes) in all cases.

9.6.1 The CTR Algorithm

CTR is short for counter-mode encryption. The **CTR** algorithm is a standard encryption algorithm, that takes a Key **K** and a Nonce **N** as input parameters, and encrypts a Message **M** to produce ciphertext **C** of the same length as **M**:

$$\mathbf{C} = \mathbf{CTR_K^N}\ (\mathbf{M})$$

Suppose $\mathbf{M} = \mathbf{M}_1 \parallel \mathbf{M}_2 \parallel \ldots \parallel \mathbf{M}_m$, with all blocks (except possibly the last) **n** bits long. Define

$$\mathbf{S}_1 = \mathbf{E_K}\ (\mathbf{N}),\ \mathbf{S}_2 = \mathbf{E_K}\ (\mathbf{N} + 1),\ \ldots,\ \mathbf{S}_m = \mathbf{E_K}\ (\mathbf{N} + m - 1)$$

where addition is performed modulo $2^{\mathbf{n}}$, treating **N** as an integer $0 \le \mathbf{N} < 2^{\mathbf{n}}$. Then let

$$\mathbf{C}_i = \mathbf{M}_i\ \mathbf{Xor}\ \mathbf{S}_i \quad (1 \le i \le m)$$

with $\mathbf{C}_m$ truncated to the same length as $\mathbf{M}_m$. Then the ciphertext **C** is given by

$$\mathbf{CTR_K^N}\ (\mathbf{M}) = \mathbf{C}_1 \parallel \mathbf{C}_2 \parallel \ldots \parallel \mathbf{C}_m$$

The Nonce **N** does not have to be secret, but it must be different for each invocation of **CTR** for a given Key **K**.

9.6.2 Tweaked OMAC

The **EAX** algorithm requires a parameterised version of the **OMAC** algorithm, which it calls "tweaked **OMAC**". The parameter is an integer *t*:

$$\mathbf{OMAC_K^{\mathit{t}}}(\mathbf{M}) = \mathbf{OMAC_K}\ ([t]_{\mathbf{n}} \parallel \mathbf{M})$$

where $[t]_{\mathbf{n}}$ denotes the **n**-bit binary representation of *t* (with most significant bit first).

9.6.3 EAX

Now we can define the **EAX** algorithm. It takes the following items as input:

- A Key **K**, for use by the block encryption algorithm $\mathbf{E_K}$.
- A Nonce **N**, of any length. **N** does not have to be secret, but it must be different for each invocation of **EAX** for a given Key **K**. The BasicCard uses a 16-byte Nonce for the encryption of Commands and Responses.
- A Header **H**, of any length. **H** is authenticated, but not encrypted, by the **EAX** algorithm. **H** is often referred to as *Associated Data*.
- A Message **M**, which will be encrypted by the **EAX** algorithm.

EAX computes as output a ciphertext **C** and a Tag **T**, as follows:

- $\mathbf{U = OMAC_K^0(N)}$
- $\mathbf{V = OMAC_K^1(H)}$
- $\mathbf{C = CTR_K^U\ (M)}$
- $\mathbf{W = OMAC_K^2(C)}$
- **T = U Xor V Xor W**

We write this as

$$\mathbf{CT = EAX.Encrypt_K^{N\,H}\ (M)}$$

C is the same length as **M**; the Tag **T** is **n** bits long. (The full definition of the **EAX** algorithm, in the original paper, defines a parameter τ as the length of the desired Tag; **T** is truncated to τ bits. ZeitControl's implementation does not use this parameter.)

The **CTR** algorithm is its own inverse, so decryption follows the same steps as encryption, with $\mathbf{M = CTR_K^U\ (C)}$ instead of $\mathbf{C = CTR_K^U\ (M)}$. After the last step, the recipient can check that the computed Tag **T** is equal to the Tag received with the ciphertext. If not, the message is rejected.

9.7 Implementation of EAX in the BasicCard

The **EAX** algorithm is currently available in Professional BasicCard **ZC5.5** and MultiApplication BasicCard **ZC6.5**. It has a user-callable interface, described in **7.5 The EAX Library**; and it can also be specified in the **START ENCRYPTION** command for the authentication of Commands and Responses. The three constants **AlgEaxAes128**, **AlgEaxAes192**, and **AlgEaxAes256** are defined in the file AlgID.DEF for this purpose.

This section describes the encryption of Commands and Responses using **EAX**.

9.7.1 The Nonce

The Nonce **N** is always 16 bytes long. It is determined as follows:

For the first command following a **START ENCRYPTION** command, **N** depends on the command and response fields of the **START ENCRYPTION** command:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	10	*algorithm*	*key*	08	*Random number* **RA** (8 bytes)	09

Response:

ODATA	SW1	SW2
algorithm (1 byte); *Random number* **RB** (8 bytes)	90	00

In this case, **N** consists of the first four bytes of **RA**, followed by all eight bytes of **RB**, followed by the last four bytes of **RA**.

For subsequent commands and responses, **N** is simply the Tag field **T** of the previous message.

9.7.2 Encryption of Commands

A command has the following structure (shaded blocks are optional):

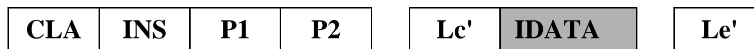
CLA	INS	P1	P2	Lc	IDATA	Le

Encryption consists of the following steps:

- If **Le** is absent, set **Le' = 16**; if **Le** is zero, set **Le' = 0**; otherwise set **Le' = Le+16**:

CLA	INS	P1	P2	Lc	IDATA	Le'

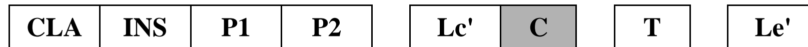
- If **Lc** is absent, set **Lc'** = **16**; otherwise set **Lc'** = **Lc**+**16**:



- Authenticate **CLA || INS || P1 || P2 || Lc' || Le'**, encrypt the **IDATA** field, and compute the Tag **T**:

  H = CLA || INS || P1 || P2 || Lc' || Le'
  $\mathbf{CT = EAX.Encrypt_K^{NH}\ (IDATA)}$

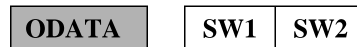
- Replace **IDATA** with **C**, and insert the Tag **T**:



Then, if the **T=0** protocol is active, the last byte of **T** is replaced by **Le'**. The resulting command is 16-18 bytes longer than the original command. When the BasicCard receives the command, it checks that the **EAX** Tag **T** is correct. If not, the command is rejected, with **SW1-SW2 = swAesCheckError**.

9.7.3 Encryption of Responses

A response has the following structure (the shaded block is optional):

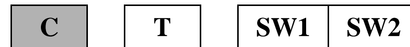


Encryption consists of the following steps:

- Authenticate **SW1-SW2**, encrypt the **ODATA** field, and compute the Tag **T**:

  H = SW1 || SW2
  $\mathbf{CT = EAX.Encrypt_K^{NH}\ (ODATA)}$

- Replace **ODATA** with **C**, and insert the Tag **T**:



The resulting response is 16 bytes longer than the original response. If the **EAX** Tag **T** is incorrect, the response is rejected, and **SW1-SW2 = swBadAesResponse** is returned to the caller in the Terminal program.

Note: If status bytes **SW1-SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not authenticated.

9.8 The OMAC Algorithm

The **OMAC** algorithm, designed by Tetsu Iwata and Kaoru Kurosawa, is a Message Authentication algorithm: it computes a Tag **T** = $\mathbf{OMAC_K}$ **(M)** from a Message **M** using a Key **K**. This Tag authenticates **M** to anybody who knows **K**. In other words, if I receive a Message **M** and a Tag **T**, with **T** equal to $\mathbf{OMAC_K}$ **(M)**, then I can be sure that

- **K** was known by whoever computed **T**;
- **M** has not been changed since it was used to compute **T**.

Only the Key **K** needs to be kept secret; **M** and **T** can be sent unencrypted.

We give a brief explanation of the **OMAC** algorithm here; a full description is available from NIST's web site, at http://csrc.nist.gov/CryptoToolkit/modes/proposedmodes/. (In the published description, algorithms **OMAC1** and **OMAC2** are defined; we describe here the **OMAC1** variant, as used by the BasicCard and by the **EAX** algorithm.)

The **OMAC** algorithm uses a block cipher $\mathbf{E_K}$ **(B)**, which operates on blocks **B** of length **n** bits. The choice of block cipher is left to the implementer. ZeitControl's implementation of **OMAC** uses **AES** as

its block cipher, with key length 128, 192, or 256 bits; the block length **n** is equal to 128 bits (16 bytes) in all cases.

OMAC is an abbreviation for "One-key CBC MAC". CBC MAC is a Message Authentication algorithm that requires the length of the Message **M** to be a multiple of **n** bits; so we can write

$$\mathbf{M} = \mathbf{M}_1 \parallel \mathbf{M}_2 \parallel \ldots \parallel \mathbf{M}_m$$

where each $\mathbf{M}_i$ is **n** bits long. Then we define

$\mathbf{C}_0 = \mathbf{0}^\mathbf{n}$ ($\mathbf{0}^\mathbf{n}$ denotes the block consisting of **n** zero bits)

$\mathbf{C}_i = \mathbf{E_K}\ (\mathbf{M}_i\ \mathbf{Xor}\ \mathbf{C}_{i-1})$ $(1 \le i \le m)$

$\mathbf{CBC_K}\ (\mathbf{M}) = \mathbf{C}_m$

If **M** is not a multiple of **n** bits, we must pad it in some way. Appending zeroes is not good enough; it would fail to distinguish between messages differing only in their number of trailing zeroes. One simple method is to append 1, followed by enough zeroes to bring the length to a multiple of **n**. The disadvantage of this method is that it may require an extra call to the block encryption algorithm $\mathbf{E_K}$. The **OMAC** algorithm avoids this extra call at the cost of increased theoretical complexity, but with negligible practical overhead. Let **u** be any non-zero element of the finite field $\mathbf{GF}(2^\mathbf{n})$, and let $\mathbf{L} = \mathbf{E_K}\ (\mathbf{0^n})$; we can interpret **L** as an element of the field, and multipy it by **u** to get **Lu**, $\mathbf{Lu}^2$ etc. The reason for introducing the field $\mathbf{GF}(2^\mathbf{n})$ is that it allows a concrete proof of security to be given; interested readers can consult the published description on the above web site. In practice, when **n** is equal to 128 we can choose **u** so that multiplication by **u** reduces to the following simple procedure:

- rotate **L** left by one bit;
- if the least significant bit is now 1, then **Xor** the least significant byte with **86**.

(The computation of **L** requires a call to the block encryption algorithm $\mathbf{E_K}$, which we were supposed to be trying to avoid; but this call is only required once for a given **K**, after which **L** can be re-used for subsequent messages.)

Now we can define the padding function. Suppose $\mathbf{M} = \mathbf{M}_1 \parallel \mathbf{M}_2 \parallel \ldots \parallel \mathbf{M}_m$, with all blocks (except possibly the last) **n** bits long. (If **M** itself is zero bits long, set m=1 and let $\mathbf{M}_m$ be the empty block.) Then if $|\mathbf{M}_m|$ is equal to **n**, set $\mathbf{P} = \mathbf{M}_m\ \mathbf{Xor}\ \mathbf{Lu}$; otherwise, pad $\mathbf{M}_m$ to length **n** by appending a 1 followed by $\mathbf{n} - |\mathbf{M}_m| - 1$ zeroes, and set $\mathbf{P} = (\mathbf{M}_m \parallel 100\ldots00)\ \mathbf{Xor}\ \mathbf{Lu}^2$. Then

$$\mathbf{Pad_K}\ (\mathbf{M}) = \mathbf{M}_1 \parallel \mathbf{M}_2 \parallel \ldots \parallel \mathbf{M}_{m-1} \parallel \mathbf{P}$$

The **OMAC** algorithm computes the following **n**-bit Tag:

$$\mathbf{OMAC_K}\ (\mathbf{M}) = \mathbf{CBC_K}\ (\mathbf{Pad_K}\ (\mathbf{M}))$$

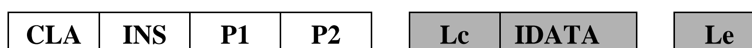
9.9 Implementation of OMAC in the BasicCard

The **OMAC** algorithm is currently available in Professional BasicCard **ZC5.5** and MultiApplication BasicCard **ZC6.5**. It has a user-callable interface, described in **7.6 The OMAC Library**; and it can also be specified in the **START ENCRYPTION** command for the authentication of Commands and Responses. The three constants **AlgOmacAes128**, **AlgOmacAes192**, and **AlgOmacAes256** are defined in the file AlgID.DEF for this purpose.

This section describes the authentication of Commands and Responses using **OMAC**.

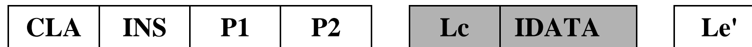
9.9.1 Authentication of Commands

A command has the following structure (shaded blocks are optional):

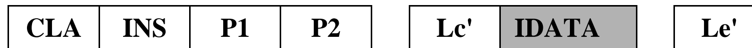


Authentication consists of the following steps:

- If **Le** is absent, set **Le' = 16**; if **Le** is zero, set **Le' = 0**; otherwise set **Le' = Le+16**:



- If **Lc** is absent, set **Lc' = 16**; otherwise set **Lc' = Lc+16**:



- Calculate the **OMAC** Tag of the resulting data:

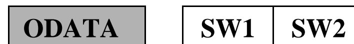
  T = OMAC$_K$ (CLA || INS || P1 || P2 || Lc' [|| IDATA] || Le')

- Append **T** to **IDATA**:

Then, if the **T=0** protocol is active, the last byte of **T** is replaced by **Le'**. The resulting command is 16-18 bytes longer than the original command. When the BasicCard receives the command, it checks that the **OMAC** Tag **T** is valid. If not, the command is rejected, with **SW1-SW2 = swAesCheckError**.

9.9.2 Authentication of Responses

A response has the following structure (the shaded block is optional):



Authentication consists of the following steps:

- Calculate the **OMAC** Tag of the response:

  T = OMAC$_K$ ([ODATA ||] SW1 || SW2)

- Append **T** to **ODATA**:

The resulting response is 16 bytes longer than the original response. If the **OMAC** Tag **T** is incorrect, the response is rejected, and **SW1-SW2 = swBadAesResponse** is returned to the caller in the Terminal program.

Note: If status bytes **SW1-SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not authenticated.

9.10 The SG-LFSR Algorithm

This algorithm was designed by D. Coppersmith, H. Krawczyk, and Y. Mansour ("The Shrinking Generator", *Advances in Cryptology – CRYPTO '93 Proceedings,* Springer-Verlag, 1994). It uses two Linear Feedback Shift Registers, **A** and **S**, to generate a stream of bits: the registers are run in parallel until register **S** generates a **1** bit, at which point the bit generated simultaneously by register **A** is used as the next bit in the stream.

The Compact BasicCard implements this algorithm with Linear Feedback Shift Registers **A** and **S** of length 31 and 32 respectively. In order for the system to be secure against attack with registers of this size, it is necessary to use generating polynomials **PolyA** and **PolyS** that are unknown to the attacker. To this end, we supply a program for the generation of random cryptographic keys and primitive polynomials – see **6.9.4 The Key Generator KEYGEN.EXE**.

C++ source code for the **SG-LFSR** algorithm is provided in the development kit, in the directory `BasicCardPro\Source\SG-LFSR`.

9.11 Implementation of SG-LFSR in the Compact BasicCard

The BasicCard implementation uses primitive polynomials **PolyA** and **PolyS** of degree 31 and 32 respectively, and a cryptographic key **K**, all of which are known only to the two communicating parties. (The **KEYGEN** program generates random polynomials and keys – see **6.9.4 The Key Generator KEYGEN.EXE**.) The **START ENCRYPTION** command is called to enable encryption:

Command syntax:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	**10**	*algorithm*	*key*	**04**	*Random number* **RA** (4 bytes)	**04**

Response:

ODATA	SW1	SW2
Random number **RB** (4 bytes)	**90**	**00**

The caller and responder both contribute 4-byte random numbers to the register initialisation procedure. **RA** may take any value; for maximum security, a different **RA** should be generated for each session. **RB** is generated by the BasicCard.

To describe how the encryption mechanism is initialised, we split all the parts into two-byte words: **RA(0):RA(1)**, **RB(0):RB(1)**, and **K(0):K(1):K(2):K(3)**, where **K** is the (eight-byte) key number *key*.

Then the two registers **A** and **S** are initialised as follows:

```
A(0) = (RA(0) Xor K(0)) And &H7FFF
A(1) = RB(0) Xor K(1)
S(0) = RB(1) Xor K(2)
S(1) = RA(1) Xor K(3)
```

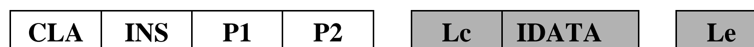
So the initial value of each register depends on both of the random numbers, and on the key.

Zero is an invalid initialisation value, so as a final step:

```
If A(0) = 0 And A(1) = 0 Then A(1) = 1
If S(0) = 0 And S(1) = 0 Then S(1) = 1
```

Encryption starts with the first command after the **START ENCRYPTION** command is received, and remains in effect for commands and responses until an **END ENCRYPTION** command is received (the responses to the **START ENCRYPTION** and **END ENCRYPTION** commands themselves are not encrypted). A ZC-Basic command can tell what kind of encryption is currently active, by looking at the pre-defined variables **Encryption** (the algorithm ID) and **KeyNumber**. (If encryption is currently inactive, then **Encryption** is zero.) Encryption and decryption are identical, and consist of **Xor**-ing each byte with the result of the function **SG_LFSR::GetByte()** (defined in the C++ source file `BasicCardPro\Source\SG-LFSR\sg_lfsr.cpp`).

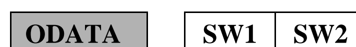
A command has the following structure (shaded blocks are optional):



Only the data field **IDATA** is encrypted. The command bytes **CLA**, **INS**, **P1**, **P2**, **Lc**, and **Le** are not encrypted, for two reasons:

- The value of these bytes is often predictable. The number of predictable bytes that are encrypted should be kept as low as possible, to make it harder to break the key.
- Compatibility with ISO standards is lost if these bytes are altered.

A response has the following structure (the shaded block is optional):

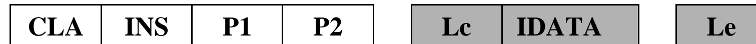


Again, only the data field **ODATA** is encrypted. The status bytes **SW1** and **SW2** are not encrypted.

9.12 SG-LFSR with CRC

The **SG-LFSR** algorithm is simple to implement, and runs efficiently. However, it provides no authentication for the data it encrypts – I don't need to know the key in order to send encrypted messages. It's true that I won't know what I'm sending, and I won't understand the response. But I could still cause problems by sending random data. If authentication is important (and it usually is), then you should use encryption algorithm **12**: **SG-LFSR with CRC** (Cyclic Redundancy Check). The same 16-bit CRC is used as in the **EEPROM CRC** command. 'C' source code for calculating the CRC is given in **7.10.4 CRC Calculations**.

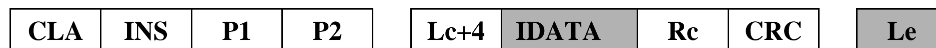
A command has the following structure (shaded blocks are optional):



It is encrypted as follows:

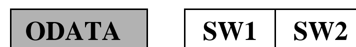
- A two-byte random number **Rc** is appended to **IDATA**, and **Lc** is amended accordingly. (Without this random number, the CRC would be predictable in the case of a command with no **IDATA** field. As the CRC is later encrypted, we want to avoid this.)

- The CRC is calculated over the whole of the resulting message (**CLA INS P1 P2 Lc+2 IDATA Rc Le**). It is then appended to the two-byte random number, and **Lc** is updated accordingly.



- The resulting message is encrypted using **SG-LFSR**, as described in section **9.11**.

A response has the following structure (the shaded block is optional):



It is encrypted in a similar fashion:

- A two-byte random number **Rr** is appended to **ODATA**.

- The CRC is calculated over the whole of the resulting response (**ODATA Rr SW1 SW2**), and appended to the two-byte random number.

- The resulting response is encrypted using **SG-LFSR**, as described in section **9.11**.

Note: If status bytes **SW1-SW2** indicate an error (i.e. **SW1SW2 <> swCommandOK** and **SW1 <> sw1LeWarning**), then the response is not encrypted.

9.13 Encryption – a Worked Example

This section shows the progression from ZC-Basic source code to encrypted messages. All source files are supplied with the software development kit, in the `BasicCardPro\Examples\EchoTest` directory. Two encryption algorithms are exhibited: **AlgTripleDesEDE2Crc** (**Triple DES-EDE2** with **CRC**) and **AlgEaxAes192** (**EAX** using **AES-192**).

9.13.1 The Source Code

We ran the **KEYGEN** program to generate cryptographic keys and a pair of primitive polynomials:

```
KEYGEN TestKeys –K108 –K116(16) –K124(24) –K132(32) –P
```

This produced output file **TestKeys.bas**:

```
Declare Polynomials = &H4CE8CE37,&HBCE65374
Declare Key 108 = &H03,&HAF,&H59,&H92,&HC9,&HE5,&H0D,&HC6
Declare Key 116(16) = &H1D,&HE1,&HFA,&HB0,&HC8,&H1F,&HC2,&HE6,_
        &H95,&H3B,&H46,&H1C,&HE7,&HFD,&HCB,&H53
Declare Key 124(24) = &HD6,&HB4,&HCE,&HAC,&H3A,&H43,&H62,&H88,_
        &HEF,&H0B,&HAD,&HF0,&H41,&H6D,&HED,&H74,_
        &H2A,&H01,&H73,&H27,&HD3,&H7F,&HCE,&H15
Declare Key 132(32) = &HC7,&H5D,&HB1,&H37,&H52,&HC0,&HB6,&HFF,_
        &H2E,&H9D,&H55,&H06,&HD2,&H07,&H81,&H57,_
        &HAC,&H0C,&H81,&H73,&H27,&HB9,&HD4,&H1C,_
        &H05,&H76,&H6D,&H52,&H0D,&H40,&H21,&H67
```

Then we wrote a simple ZC-Basic Terminal program **EchoTest.bas** to send encrypted **ECHO** commands. The **EchoTest** program takes a list of algorithm names as parameters. The BasicCard source file, **EchoCard.bas**, reduces to just the following statements if compiled for a single-application BasicCard:

```
#Include TestKeys.bas
Declare ApplicationID = "Single-application EchoTest"
```

The file **Compile.bat** in the `BasicCardPro\Examples\EchoTest` directory compiles the **EchoTest.bas** source file, along with a separate BasicCard image file for each card type.

Executing **Sim.bat** from this directory tests all encryption algorithms, for all card types, and generates log files for each run. We will look at a simpler example, generated by executing **DocGen.bat**:

```
..\..\ZCMSim –CPro –LExample EchoTest AlgNone AlgTripleDesEDE2Crc AlgEaxAes192
```

This sends three **ECHO** commands:

- unencrypted;
- using **Triple DES-EDE2** with **CRC**;
- using **EAX** with **AES-192**.

This creates the log file **Example.log**:

```
Port 1
ATR: 3B FB 13 00 FF 81 31 80 75 5A 43 35 2E 35 20 52 45 56 20 45 61
-> 00 00 05 C0 0E 00 00 00 CB
<- 00 00 1D 53 69 6E 67 6C 65 2D 61 70 70 6C 69 63 61 74 69 6F 6E
   20 45 63 68 6F 54 65 73 74 61 1B 3D
-> 00 40 09 C0 14 01 00 03 61 62 63 03 FC
<- 00 40 05 62 63 64 90 00 B0
-> 00 00 0A C0 10 24 74 04 9C 13 E7 F7 00 11
<- 00 00 07 24 29 72 6A 36 61 05 40
-> 00 40 11 C0 14 01 00 0B 4D 0F 9C 3E A8 19 68 C8 01 85 19 0B E8
<- 00 40 0D EF 0A F4 EB 4F 28 9D AF AE F4 3A 90 00 12
-> 00 00 0E C0 12 00 00 08 0F 73 E5 9E 4E FD 68 CA 08 CA
<- 00 00 02 90 00 92
-> 00 40 0E C0 10 42 7C 08 E0 0A 92 C8 11 F8 ED 54 00 48
<- 00 40 0B 42 D8 C5 67 B3 28 8D B0 79 61 09 C4
-> 00 00 19 C0 14 01 00 13 42 4B 97 15 2C 56 AD C5 D6 00 81 1D 99
   5B 20 45 6A A3 47 13 36
<- 00 00 15 2B 58 1C 6E D8 31 47 57 6C 33 A3 FF 8C 89 26 17 30 D5
   A2 90 00 0D
-> 00 40 16 C0 12 00 00 10 CE C0 E4 7D 8B 47 F3 9B E8 E9 3D 5D ED
   72 60 5D 10 74
<- 00 40 02 90 00 D2
```

Note: If you run the **EchoTest** program yourself, your log file will be different, due to the different random numbers generated by the Terminal program interpreter.

If we strip the **T=1** protocol bytes **NAD PCB LEN . . . LRC** from each command and response, we get the following:

```
❶ ATR: 3B FB 13 00 FF 81 31 80 75 5A 43 35 2E 35 20 52 45 56 20 45 61
❷ -> C0 0E 00 00 00
  <- 53 69 6E 67 6C 65 2D 61 70 70 6C 69 63 61 74 69 6F 6E 20 45 63
     68 6F 54 65 73 74 61 1B
❸ -> C0 14 01 00 03 61 62 63 03
  <- 62 63 64 90 00
❹ -> C0 10 24 74 04 9C 13 E7 F7 00
  <- 24 29 72 6A 36 61 05
❺ -> C0 14 01 00 0B 4D 0F 9C 3E A8 19 68 C8 01 85 19 0B
  <- EF 0A F4 EB 4F 28 9D AF AE F4 3A 90 00
❻ -> C0 12 00 00 08 0F 73 E5 9E 4E FD 68 CA 08
  <- 90 00
❼ -> C0 10 42 7C 08 E0 0A 92 C8 11 F8 ED 54 00
  <- 42 D8 C5 67 B3 28 8D B0 79 61 09
❽ -> C0 14 01 00 13 42 4B 97 15 2C 56 AD C5 D6 00 81 1D 99 5B 20 45
     6A A3 47 13
  <- 2B 58 1C 6E D8 31 47 57 6C 33 A3 FF 8C 89 26 17 30 D5 A2 90 00
❾ -> C0 12 00 00 10 CE C0 E4 7D 8B 47 F3 9B E8 E9 3D 5D ED 72 60 5D
     10
  <- 90 00
```

❶ **ATR** (Answer To Reset) from the simulated BasicCard, including the text "**ZC5.5 REV E**"
❷ **GET APPLICATION ID** command and response
❸ **ECHO** command and response
❹ **START ENCRYPTION** command (algorithm = **&H24 = AlgTripleDesEDE2Crc**) and response
❺ **ECHO** command and response, encrypted with **AlgTripleDesEDE2Crc**
❻ **END ENCRYPTION** command and response
❼ **START ENCRYPTION** command (algorithm = **&H42 = AlgEaxAes192**) and response
❽ **ECHO** command and response, encrypted with **AlgEaxAes192**
❾ **END ENCRYPTION** command and response

We will look at these commands one by one.

9.13.2 GET APPLICATION ID Command and Response

The **EchoTest** program calls **GET APPLICATION ID** to find out whether it is dealing with a single-application BasicCard or a MultiApplication BasicCard:

Command:

CLA	INS	P1	P2	Le
C0	0E	00	00	00

Response:

ODATA	SW1	SW2
"Single-application EchoTest"	61	1B

The BasicCard returns **"Single-application EchoTest"**, declared in **EchoCard.bas**.

9.13.3 Unencrypted ECHO Command and Response

The parameter "abc" is **61 62 63** in hexadecimal. The **ECHO** command adds **P1=01** to every byte:

Command:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	14	01	00	03	61 62 63	03

Response:

ODATA	SW1	SW2
62 63 64	90	00

9.13.4 START ENCRYPTION (Algorithm = AlgTripleDesEDE2Crc)

The **Rnd** function in the Terminal program returned **RA = &H4E9225DB**, and the random-number generator in the BasicCard operating system returned **RB = &H29726A36**. This led to the following **START ENCRYPTION** command-response pair (the first byte of **ODATA** confirms the choice of algorithm):

Command:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	10	24	74	04	9C 13 E7 F7	00

Response:

ODATA	SW1	SW2
24 29 72 6A 36	61	05

We build the initialisation vector C_0 from **RA** and **RB**, as described in section **9.2.3**:

C_0 **= 9C 13 29 72 6A 36 E7 F7**

9.13.5 Encrypted ECHO Command (Algorithm = AlgTripleDesEDE2Crc)

The unencrypted **ECHO** command:

Command:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	14	01	00	03	61 62 63	03

- Insert an **LeFlag** byte:

CLA	INS	P1	P2	Lc	IDATA	LeFlag	Le
C0	14	01	00	03	61 62 63	01	03

- Calculate the 32-bit **CRC** of the resulting data:

  CRC = CRC32 (C0 14 01 00 03 61 62 63 01 03) = &H9D95964E

- Append two zeroes, followed by the **CRC**:

CLA	INS	P1	P2	Lc	IDATA	LeFlag	Le		CRC
C0	14	01	00	03	61 62 63	01	03	00 00	9D 95 96 4E

- Now we must encrypt the command tail

  P = 61 62 63 01 03 00 00 9D 95 96 4E

  using the **Triple DES** message encryption function $\mathbf{MEDE2_K}$. Referring back to **9.2.1 The Message Encryption Functions** $\mathbf{ME_K}$ **,** $\mathbf{MEDE2_K}$ **, and** $\mathbf{MEDE3_K}$:

  K = 1D E1 FA B0 C8 1F C2 E6 95 3B 46 1C E7 FD CB 53 is key number 116 from TestKeys.bas;
  C_0 **= 9C 13 29 72 6A 36 E7 F7** from the **START ENCRYPTION** command;
  P_1 **= 61 62 63 01 03 00 00 9D** is the first message block;
  P_2 **= 95 96 4E (00 00 00 00 00)** is the second message block;
  m = 5 is the length of padding required in $\mathbf{P_2}$.

  So we compute (you can check these in ZC-Basic, using the **DES** function):

  $C_1 = EDE2_K(C_0\ Xor\ P_1) = EDE2_K$ **(FD 71 4A 73 69 36 E7 6A) = 4D 0F 9C 01 35 81 DA E8**
  $C_2 = EDE2_K(C_1\ Xor\ P_2) = EDE2_K$ **(D8 99 D2 01 35 81 DA E8) = 3E A8 19 68 C8 01 85 19**

and we throw away the last **m** bytes of C_1 to get:

C = MEDE2$_K$ (P) = 4D 0F 9C 3E A8 19 68 C8 01 85 19

- To get the final version, **C** is wrapped in the original **CLA INS P1 P2 . . . Le**, with **Lc** and **Le** adjusted appropriately:

CLA	INS	P1	P2	Lc	C	Le
C0	14	01	00	0B	4D 0F 9C 3E A8 19 68 C8 01 85 19	0B

The unencrypted response to the **ECHO** command:

Response:

ODATA	SW1	SW2
62 63 64	90	00

- Calculate the 32-bit **CRC** of the response:

CRC = CRC32 (62 63 64 90 00) = **&HCF2CB422**

- Append two zeroes and the **CRC**:

ODATA	SW1	SW2	
62 63 64	90	00	00 00 CF 2C B4 22

- Encrypt **P = 62 63 64 90 00 00 00 CF 2C B4 22** using **MEDE2$_K$**, where

K = 1D E1 FA B0 C8 1F C2 E6 95 3B 46 1C E7 FD CB 53 is key number 116 from TestKeys.bas;
C_0 = 3E A8 19 68 C8 01 85 19 is **C_2** from the **ECHO** command just received;
P_1 = 62 63 64 90 00 00 00 CF is the first message block;
P_2 = 2C B4 22 (00 00 00 00 00) is the second message block;
m = 5 is the length of padding required in **P_2** .

So we compute:

C_1 = EDE2$_K$ (C_0 Xor P_1) = EDE2$_K$ (5C CB 7D F8 C8 01 85 D6) = EF 0A F4 E4 7F A9 43 AC

C_2 = EDE2$_K$ (C_1 Xor P_2) = EDE2$_K$ (C3 BE D6 E4 7F A9 43 AC) = EB 4F 28 9D AF AE F4 3A

and we throw away the last **m** bytes of **C_1** to get:

C = MEDE2$_K$ (P) = EF 0A F4 EB 4F 28 9D AF AE F4 3A

- Now the original **SW1-SW2** are appended, to get:

C	SW1	SW2
EF 0A F4 EB 4F 28 9D AF AE F4 3A	90	00

9.13.6 END ENCRYPTION

The unencrypted **END ENCRYPTION** command:

Command:

CLA	INS	P1	P2
C0	12	00	00

- Insert an **LeFlag** byte and append **Le' = 00**:

CLA	INS	P1	P2	LeFlag	Le'
C0	12	00	00	00	00

- Calculate the 32-bit **CRC** of the resulting data:

  CRC = CRC32 (**C0 12 00 00 00 00**) = **&H13ED6700**

- Insert **Lc' = 00**, and append two zeroes followed by the **CRC**:

CLA	INS	P1	P2	Lc'	LeFlag	Le'	
C0	12	00	00	00	00	00	00 00 13 ED 67 00

- Encrypt the command tail **P = 00 00 00 00 13 ED 67 00** with $\mathbf{MEDE2_K}$, where

  K = 1D E1 FA B0 C8 1F C2 E6 95 3B 46 1C E7 FD CB 53 is key number 116 from TestKeys.bas;
  $\mathbf{C_0}$ = **EB 4F 28 9D AF AE F4 3A** is $\mathbf{C_2}$ from the **ECHO** response;
  $\mathbf{P_1}$ = **00 00 00 00 13 ED 67 00** is the only message block;
  m = 0 is the length of padding required in $\mathbf{P_1}$.

  So we compute:

  $\mathbf{C_1} = \mathbf{EDE2_K}(\mathbf{C_0}\ \mathbf{Xor}\ \mathbf{P_1}) = \mathbf{EDE2_K}$(**EB 4F 28 9D BC 43 93 3A**) = **0F 73 E5 9E 4E FD 68 CA**

  and **C** = $\mathbf{MEDE2_K}$ (**P**) is simply $\mathbf{C_1}$.

- Append **Le'' = 08** to get the final version:

CLA	INS	P1	P2	Lc	C	Le''
C0	12	00	00	08	0F 73 E5 9E 4E FD 68 CA	08

The response is not encrypted:

Response:

SW1	SW2
90	00

9.13.7 START ENCRYPTION (Algorithm = AlgEaxAes192)

The two calls to the **Rnd** function in the Terminal program returned **&HE00A92C8** and **&H11F8ED54**, giving **RA = E0 0A 92 C8 11 F8 ED 54**; and the random-number generator in the BasicCard operating system returned **RB = D8 C5 67 B3 28 8D B0 79**. This led to the following **START ENCRYPTION** command-response pair (the first byte of **ODATA** confirms the choice of algorithm):

Command:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	10	42	7C	08	E0 0A 92 C8 11 F8 ED 54	00

Response:

ODATA	SW1	SW2
42 D8 C5 67 B3 28 8D B0 79	61	09

We build the Nonce **N** from **RA** and **RB**, as described in section **9.7.1**:

N = E0 0A 92 C8 D8 C5 67 B3 28 8D B0 79 11 F8 ED 54

9.13.8 Encrypted ECHO Command (Algorithm = AlgEaxAes192)

The unencrypted **ECHO** command:

Command:

CLA	INS	P1	P2	Lc	IDATA	Le
C0	14	01	00	03	61 62 63	03

- Set **Le' = Le+10**, **Lc' = Lc+10**:

CLA	INS	P1	P2	Lc'	IDATA	Le'
C0	14	01	00	13	61 62 63	13

- Set **H = CLA || INS || P1 || P2 || Lc' || Le' = C0 14 01 00 13 13**, encrypt **IDATA**, and compute the Tag **T**:

  $\mathbf{CT = EAX.Encrypt_K^{NH}\ (IDATA)}$

  You can compute **C** and **T** in a ZC-Basic Terminal program, using the **EAX** System Library:

```
#Include EAX.DEF
#Include TestKeys.bas

Private N$ = Chr$(&HE0,&H0A,&H92,&HC8,&HD8,&HC5,&H67,&HB3,_
                  &H28,&H8D,&HB0,&H79,&H11,&HF8,&HED,&H54)
Private H$ = Chr$(&HC0,&H14,&H01,&H00,&H13,&H13)
Private C$ = Chr$(&H61,&H62,&H63)

Private EaxState$ : EaxState$ = EaxInit (192, Key(124))
Call EaxProvideNonce (EaxState$, Key(124), N$)
Call EaxProvideHeader (EaxState$, Key(124), H$)
Call EAXComputeCiphertext (EaxState$, Key(124), C$)

Private T$ : T$ = EaxComputeTag (EaxState$, Key(124))
```

  We get:

  C = 42 4B 97
  T = 15 2C 56 AD C5 D6 00 81 1D 99 5B 20 45 6A A3 47

  So the encrypted command is:

CLA	INS	P1	P2	Lc'	C
C0	14	01	00	13	42 4B 97

T	Le'
15 2C 56 AD C5 D6 00 81 1D 99 5B 20 45 6A A3 47	13

The unencrypted response to the **ECHO** command:

Response:

ODATA	SW1	SW2
62 63 64	90	00

- Set **N** equal to **T** from the **START ENCRYPTION** command:

  N = 15 2C 56 AD C5 D6 00 81 1D 99 5B 20 45 6A A3 47

- Set **H = SW1 || SW2 = 90 00**, encrypt **ODATA**, and compute the Tag **T**:

  $\mathbf{CT = EAX.Encrypt_K^{NH}\ (ODATA)}$

We get:

C = 2B 58 1C
T = 6E D8 31 47 57 6C 33 A3 FF 8C 89 26 17 30 D5 A2

So the encrypted response is:

C	T	SW1	SW2
2B 58 1C	6E D8 31 47 57 6C 33 A3 FF 8C 89 26 17 30 D5 A2	90	00

9.13.9 END ENCRYPTION

The unencrypted **END ENCRYPTION** command:

Command:

CLA	INS	P1	P2
C0	12	00	00

- Set **N** equal to **T** from the **ECHO** response:

  N = 6E D8 31 47 57 6C 33 A3 FF 8C 89 26 17 30 D5 A2

- Insert **Le' = 10**, **Lc' = 10**:

CLA	INS	P1	P2	Lc'	Le'
C0	12	00	00	10	10

- Set **H = CLA || INS || P1 || P2 || Lc' || Le' = C0 12 00 00 10 10**, and compute the Tag **T**:

  CT = EAX.Encrypt$_{\mathbf{K}}^{\mathbf{NH}}$ (“”)

  We get:

  T = CE C0 E4 7D 8B 47 F3 9B E8 E9 3D 5D ED 72 60 5D

  So the encrypted command is:

CLA	INS	P1	P2	Lc'
C0	12	00	00	10

T	Le'
CE C0 E4 7D 8B 47 F3 9B E8 E9 3D 5D ED 72 60 5D	10

10. The ZC-Basic Virtual Machine

Note: Throughout this chapter, **bold** numbers are hexadecimal.

10.1 The BasicCard Virtual Machine

10.1.1 The Compact BasicCard

The Compact BasicCard contains **100** bytes of RAM (= 256 in decimal), and **3E0** bytes of EEPROM (= 992 in decimal). Of this, the operating system uses the first **47** bytes of RAM and the first **23** bytes of EEPROM. The memory available for use by an application written in ZC-Basic is thus **B9** bytes of RAM and **3BD** bytes of EEPROM.

10.1.2 The Enhanced BasicCard

The Enhanced BasicCard contains **100** bytes of RAM (= 256 in decimal), and up to **3FE0** bytes of EEPROM (= 16352 in decimal). Of this, the operating system uses the first **6B** bytes of RAM, and the first **15D** bytes of EEPROM. If the file system is not disabled, it requires **7** bytes of RAM, plus **6** bytes for each file slot. (Files and directories themselves are allocated from the **EEPHEAP** region.)

10.1.3 The Professional BasicCard

The Professional BasicCard contains up to **800** bytes of RAM (= 2048 in decimal), and up to **7FE0** bytes of EEPROM (= 32736 in decimal). The amount of RAM and EEPROM used by the operating system varies from version to version, but the figures in **10.1.2 The Enhanced BasicCard** give a rough guide.

10.1.4 The MultiApplication BasicCard

The MultiApplication BasicCard contains up to **800** bytes of RAM (= 2048 in decimal), and up to **7FE0** bytes of EEPROM (= 32736 in decimal). The amount of RAM and EEPROM used by the operating system varies from version to version, but the figures in **10.1.2 The Enhanced BasicCard** give a rough guide. When an Application's ZC-Basic code runs in the MultiApplication BasicCard, all addresses are virtual; this lets the operating system protect an Application from unauthorised access by other Applications in the same card.

10.1.5 Memory Layout in the BasicCard

RAM and EEPROM are divided into regions, in the following order:

	RAM Regions		EEPROM Regions
RAMSYS	System RAM	**EEPSYS**	System EEPROM
STACK	The P-Code stack	**STRVAL**	Single-to-String code*
RAMDATA	**Public** and **Static** data	**CMDTAB**	Command descriptor table
RAMHEAP	Run-time memory allocation	**PCODE**	The ZC-Basic program code
FILEINFO	Open file slots + file system workspace	**STRCON**	String constants
(**FRAME**)	Procedure frame (contained in **STACK**)	**KEYTAB**	Keys for encryption
		EEPDATA	**Eeprom** data
		EEPHEAP	Run-time memory allocation
		Libraries	Plug-In Libraries

* The **STRVAL** region is only present for Enhanced BasicCard programs that use Single-to-String conversion – see **3.23.5 Single-to-String Conversion**.

The ZC-Basic compiler calculates how much static memory is required for each region, and assigns any remaining memory to **RAMHEAP** and **EEPHEAP**, for run-time memory allocation of strings, arrays, and files. The map file lists the sizes of all these regions – see **11.5 Map File Format**.

10.2 The Terminal Virtual Machine

A Terminal program contains a **CODE** segment and a **DATA** segment, each of which may be up to 64 kilobytes long. The **CODE** segment contains only the **PCODE** region. The **DATA** segment contains RAM and EEPROM regions (see **2.2.4 Permanent Data** for the meaning of EEPROM data in a Terminal program). The regions occur in the following order (RAM before EEPROM):

	RAM Regions		**EEPROM Regions**
STACK	The P-Code stack	**EEPDATA**	**Eeprom** data
RAMSYS	System RAM	**EEPHEAP**	Run-time memory allocation
RAMDATA	**Public** and **Static** data		
RAMHEAP	Run-time memory allocation		
STRCON	String constants		
(**FRAME**)	Procedure frame (contained in **STACK**)		

10.3 The P-Code Stack

The P-Code Virtual Machine has three registers:

PC	Program counter (2 bytes)
SP	Stack Pointer (1 or 2 byte)
FP	Frame Pointer (1 or 2 bytes)

SP and **FP** are 1 byte if RAM is 256 bytes (the Compact and Enhanced BasicCards), otherwise 2 bytes (the Professional and MultiApplication BasicCards, and the Terminal).

The P-Code stack grows upwards; the **SP** register contains the address of the first free byte on the stack. The stack contains four kinds of data:

- Command parameters, received from the I/O port (BasicCard only). These are located at the bottom of the stack.
- Procedure parameters and return addresses. Before a procedure is called, its parameters are pushed onto the P-Code stack. (If the procedure is a **Function**, space is reserved below the parameters for the function return value.)
- **FRAME** data, consisting of **Private** data and compiler-generated temporary variables. Each procedure has its own **FRAME** region, of a fixed size, that is allocated from the stack when the procedure is called. The **FP** register points to the base of the **FRAME** region.
- Intermediate results of computations. The Virtual Machine has no data registers; all computation is performed on the top of the P-Code stack.

The first P-Code instruction in a procedure is

ENTER *frame-size*

This instruction sets up the **FRAME** region as follows:

- Push **FP**
- Push **SP** + *frame-size* + size of SP (i.e. **SP** + *frame-size* + 1 or **SP** + *frame-size* + 2)
- **FP** = **SP**
- **SP = SP** + *frame-size*

The last instruction in every procedure is

LEAVE

This undoes the effect of the **ENTER** instruction before returning to the caller:

- **SP** = **FP –** size of **FP** (i.e. **FP** – 1 or **FP** – 2)
- Pop **FP**
- Pop **PC**

10.4 Run-Time Memory Allocation

The Virtual Machine has two heaps for the run-time allocation of strings and arrays: **RAMHEAP** and **EEPHEAP**. Each is composed of variable-length blocks, that are either *allocated* or *free*; adjacent free blocks are concatenated as soon as they are created. In addition, an allocated block in **EEPHEAP** is either *permanent* or *temporary*. Each block consists of a *block header* followed by a *data area*. The block header contains the length of the data area, and one or two bits describing the block:

EEPHEAP block

F	T	Len (14 bits)
Data area (**Len** bytes)		

RAMHEAP block (small RAM)

F	Len (7 bits)
Data area (**Len** bytes)	

RAMHEAP block (large RAM)

F	Len (15 bits)
Data area (**Len** bytes)	

F = 1 if the block is free, **0** if the block is allocated.

T = 1 if the block is temporary, **0** if the block is permanent. A temporary block is automatically freed the next time the BasicCard is reset or the Terminal program is run.

Notes:

1. If **F** is **1**, then **T** is not used as a temporary block flag. This means that, although allocated blocks in **EEPHEAP** are limited to 16383 bytes, a free block (and thus the total size of the heap) may be up to 32767 bytes long.
2. An Application in the MultiApplication BasicCard has a **RAMHEAP** region and an **EEPHEAP** region, like other cards. These regions are contained in the Application File. In addition, the operating system in the MultiApplication BasicCard has a global EEPROM heap, for Files and Components. See **5.2.4 Memory Allocation** for further information.

10.5 Data Types

The BasicCard Virtual Machine implements the following data types:

CHAR	1-byte unsigned integer
WORD	2-byte signed integer
LONG	4-byte signed integer
REAL	4-byte IEEE-format floating-point number
STRING	See *Strings* below

These types correspond to the ZC-Basic data types **Byte**, **Integer**, **Long**, **Single**, and **String** respectively. Arithmetic operations are provided for **WORD**, **LONG**, and **REAL** data; **CHAR** data must be converted to **WORD** before performing arithmetic on it.

10.5.1 Strings

There are two types of string: variable-length and fixed-length.

- A variable-length string is a 2-byte pointer to a Pascal-type string, which consists of a length byte followed by the string contents.
- A fixed-length string is a sequence of characters, whose length is known at compile time.

Both types are restricted to 254 bytes in length; if an operation would result in a longer string, it truncates the result.

String variables take various forms, depending on the storage type:

Eeprom	A fixed-length **Eeprom** string variable is a sequence of characters in the **EEPDATA** region. A variable-length **Eeprom** string variable is a 2-byte pointer, in the **EEPDATA** region, to a Pascal-type string in the **EEPHEAP** region.
Public, **Static**	A fixed-length **Public** or **Static** string variable is a sequence of characters in the **RAMDATA** region. A variable-length **Public** or **Static** string variable is a 2-byte pointer, in the **RAMDATA** region, to a Pascal-type string, which may be in **RAMHEAP** or **EEPHEAP**. Strings are allocated from **RAMHEAP** if there is room, but if not they are allocated from **EEPHEAP**. In this case they are marked as temporary, so that they can be deleted when the BasicCard is reset or the Terminal program is restarted.
Private	A fixed-length **Private** string variable is a sequence of characters in the **FRAME** region. A variable-length **Private** string variable is a 2-byte pointer, in the **FRAME** region, to a Pascal-type string, which may be in **RAMHEAP** or **EEPHEAP**.
String parameters	A **String** parameter takes up 3 bytes on the stack: a one-byte *length* followed by a two-byte *address*. If *length* <= 254, the address points directly to a fixed-length string. If *length* = 255, the address is a handle, and points to a variable-length string variable. (This is the reason for the 254-byte length restriction on all strings.)

10.6 P-Code Instructions

In this section, names in *italics* obey the following conventions:

- Initial characters *s* and *u* denote signed and unsigned values respectively.
- Initial character *r*, or second character *c*, *w*, *l*, denote **REAL**, **CHAR**, **WORD**, and **LONG** data respectively.
- *A* is the address of an array descriptor.
- *X$*, *Y$*, *Z$* are **STRING**s.

10.6.1 Miscellaneous Instructions

Name	OpCode	Param	Description
NOP	**00**		No operation
ADDSP	**01**	*scDelta*	**SP** += *scDelta*. If *scDelta* > **0**, 'pushed' bytes are initialised to zero.
DUP	**02**	*ucLen*	Push the top *ucLen* stack bytes
COMPL	**03**		Pop *slY* ; pop *slX* ; compare ; push for **WORD** comparison
RAND	**04**		Push a **LONG** random number
ERROR	**05**	*ucError*	Generate a P-Code error condition
SYSTEM	**06**	*ucSysCode*	Operating system call – see **10.7 The SYSTEM** Instruction.

10.6.2 Data Conversion Instructions

Name	OpCode	Description
CVTCW	**07**	Pop *ucX* ; *swY* = *ucX* ; push *swY*
CVTWC	**08**	Pop *swX* ; *ucY* = *swX* ; push *ucY*
CVTWL	**09**	Pop *swX* ; *slY* = *swX* ; push *slY*
CVTLW	**0A**	Pop *slX* ; *swY* = *slX* ; push *swY*

10.6.3 Data Access Instructions (Push and Pop)

Name	OpCode	Param	Description
PUCCB	**0B**	*ucConst*	Push constant **CHAR** *ucConst*
PUCWB	**0C**	*scConst*	Push constant *scConst* sign-extended to **WORD**
PUCWC	**0D**	*ucConst*	Push constant *ucConst* zero-extended to **WORD**
PUCWW	**0E**	*swConst*	Push constant **WORD** *swConst*
PURCB	**0F**	*ucAddr*	Push **CHAR** at address *ucAddr*
PURWB	**10**	*ucAddr*	Push **WORD** at address *ucAddr*
PURLB	**11**	*ucAddr*	Push **LONG** at address *ucAddr*
PURSB	**12**	*ucAddr*	Push **STRING** at address *ucAddr*
PUECW	**13**	*uwAddr*	Push **CHAR** at address *uwAddr*
PUEWW	**14**	*uwAddr*	Push **WORD** at address *uwAddr*
PUELW	**15**	*uwAddr*	Push **LONG** at address *uwAddr*
PUESW	**16**	*uwAddr*	Push **STRING** at address *uwAddr*
PUFCB	**17**	*scAddr*	Push **CHAR** at address **FP** + *scAddr*
PUFWB	**18**	*scAddr*	Push **WORD** at address **FP** + *scAddr*
PUFLB	**19**	*scAddr*	Push **LONG** at address **FP** + *scAddr*
PUFSB	**1A**	*scAddr*	Push **STRING** at address **FP** + *scAddr*
PUFAB	**1B**	*scAddr*	Push **FP** + *scAddr* as **WORD**
PUSAB	**1C**	*ucAddr*	Push **SP –** *ucAddr* as **WORD**
PUPSB	**1D**	*scAddr*	Push 3-byte **STRING** parameter at address **FP** + *scAddr*
PUINC	**1E**		Pop *uwAddr* ; push **CHAR** at address *uwAddr*
PUINW	**1F**		Pop *uwAddr* ; push **WORD** at address *uwAddr*
PUINL	**20**		Pop *uwAddr* ; push **LONG** at address *uwAddr*
PORCB	**21**	*ucAddr*	Pop **CHAR** at address *ucAddr*
PORWB	**22**	*ucAddr*	Pop **WORD** at address *ucAddr*
PORLB	**23**	*ucAddr*	Pop **LONG** at address *ucAddr*
POECW	**24**	*uwAddr*	Pop **CHAR** at address *uwAddr*
POEWW	**25**	*uwAddr*	Pop **WORD** at address *uwAddr*
POELW	**26**	*uwAddr*	Pop **LONG** at address *uwAddr*
POFCB	**27**	*scAddr*	Pop **CHAR** at address **FP** + *scAddr*
POFWB	**28**	*scAddr*	Pop **WORD** at address **FP** + *scAddr*
POFLB	**29**	*scAddr*	Pop **LONG** at address **FP** + *scAddr*
POINC	**2A**		Pop *uwAddr* ; pop **CHAR** at address *uwAddr*
POINW	**2B**		Pop *uwAddr* ; pop **WORD** at address *uwAddr*
POINL	**2C**		Pop *uwAddr* ; pop **LONG** at address *uwAddr*

10.6.4 Integer Arithmetic Instructions

Name	OpCode	Description
ADDW	**2D**	Pop *swY* ; pop *swX* ; push *swX* + *swY*
ADDL	**2E**	Pop *slY* ; pop *slX* ; push *slX* + *slY*
SUBW	**2F**	Pop *swY* ; pop *swX* ; push *swX* – *swY*
SUBL	**30**	Pop *slY* ; pop *slX* ; push *slX* – *slY*
MULW	**31**	Pop *swY* ; pop *swX* ; push *swX* * *swY*
MULL	**32**	Pop *slY* ; pop *slX* ; push *slX* * *slY*
DIVW	**33**	Pop *swY* ; pop *swX* ; push *swX* / *swY*
DIVL	**34**	Pop *slY* ; pop *slX* ; push *slX* / *slY*
MODW	**35**	Pop *swY* ; pop *swX* ; push *swX* **Mod** *swY*
MODL	**36**	Pop *slY* ; pop *slX* ; push *slX* **Mod** *slY*
ANDW	**37**	Pop *uwY* ; pop *uwX* ; push *uwX* **And** *uwY*
ANDL	**38**	Pop *ulY* ; pop *ulX* ; push *ulX* **And** *ulY*
ORW	**39**	Pop *uwY* ; pop *uwX* ; push *uwX* **Or** *uwY*
ORL	**3A**	Pop *ulY* ; pop *ulX* ; push *ulX* **Or** *ulY*
XORW	**3B**	Pop *uwY* ; pop *uwX* ; push *uwX* **Xor** *uwY*
XORL	**3C**	Pop *ulY* ; pop *ulX* ; push *ulX* **Xor** *ulY*
NEGW	**3D**	Pop *swX* ; push –*swX*
NEGL	**3E**	Pop *slX* ; push –*slX*
ABSW	**3F**	Pop *swX* ; push **Abs(***swX***)**
ABSL	**40**	Pop *slX* ; push **Abs(***slX***)**
INCW	**41**	Pop *swX* ; push *swX* + 1
INCL	**42**	Pop *slX* ; push *slX* + 1
NOTW	**43**	Pop *uwX* ; push **Not(***uwX***)**
NOTL	**44**	Pop *ulX* ; push **Not(***ulX***)**

10.6.5 Program Control Instructions

(In the **ENTER** and **LEAVE** instructions, *F* denotes the size of the FP register, as defined in **10.3 The P-Code Stack**.)

Name	OpCode	Param	Description
CALL	**45**	*uwAddr*	Procedure call or **GoSub**: push **PC+3** as **WORD** ; **PC** = *uwAddr*
ENTER	**46**	*ucFrmSiz*	Push **FP** ; push **SP** + *ucFrmSiz* + *F* ; **FP = SP** ; **SP = SP** + *ucFrmSiz*
LEAVE	**47**		Return from procedure: **SP = FP –** *F* ; pop **FP** ; pop **PC**
RETURN	**48**		Return from **GoSub**: pop **PC**
JUMPB	**49**	*scDisp*	**PC = PC** + *scDisp* + 2
JUMPW	**4A**	*uwAddr*	**PC** = *uwAddr*
JZRWB	**4B**	*scDisp*	Pop *swX* ; if *swX* = 0 then **PC = PC** + *scDisp* + 2
JNZWB	**4C**	*scDisp*	Pop *swX* ; if *swX* <> 0 then **PC = PC** + *scDisp* + 2
JEQWB	**4D**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* = *swY* then **PC = PC** + *scDisp* + 2
JNEWB	**4E**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* <> *swY* then **PC = PC** + *scDisp* + 2
JLEWB	**4F**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* <= *swY* then **PC = PC** + *scDisp* + 2
JGTWB	**50**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* > *swY* then **PC = PC** + *scDisp* + 2
JGEWB	**51**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* >= *swY* then **PC = PC** + *scDisp* + 2
JLTWB	**52**	*scDisp*	Pop *swY* ; pop *swX* ; if *swX* < *swY* then **PC = PC** + *scDisp* + 2
LOOP	**53**	*scDisp*	Pop *swX* ; if *swX* >= 0 then execute **JLEWB** else execute **JGEWB**
EXIT	**54**		Exit the Virtual Machine

10.6.6 Array Instructions

Name	OpCode	Param	Description
ARRAY	**55**		Pop *A* ; pop subscript *swIr* for each dimension *r*, in reverse order ; push address of array element *A* (*swI1, swI2, . . . , swIn*)
CHKDIM	**56**	*ucNdims*	Pop *A* ; push *A* ; if Dim(*A*) <> *ucNdims* then execute **ERROR 0C**
ALLOCA	**57**		Pop *A* ; pop bounds word *uwBr* for each dimension *r*, in reverse order; allocate data area of *A* and initialise all elements to 0
FREEA	**58**		Pop *A* ; if **Dynamic** then deallocate *A*, else set all elements of *A* to 0
FREEA$	**59**		Pop string array *A* ; free all strings in *A* ; if **Dynamic** then deallocate *A*
BOUNDA	**5A**		Pop *swHi* ; pop *swLo* ; push **400***swLo* + (*swHi* – *swLo*) as **WORD**
LBOUND	**5B**		Pop *A* ; pop *ucDim* ; push lower bound of subscript *ucDim* as **WORD**
UBOUND	**5C**		Pop *A* ; pop *ucDim* ; push upper bound of subscript *ucDim* as **WORD**

10.6.7 String Instructions

Name	OpCode	Description
COPY$	**5D**	Pop *X$* ; pop *Y$* ; *X$* = *Y$*
FREE$	**5E**	Pop 2-byte handle to variable-length string *X$* ; *X$* = empty string
ADD$	**5F**	Pop *X$* ; pop *Z$* ; pop *Y$* ; *X$* = *Y$* + *Z$*
MID$	**60**	Pop *swLen* ; pop *swStart* ; pop *X$* ; push **Mid$(***X$*, *swStart*, *swLen***)**
LEFT$	**61**	Pop *swLen* ; pop *X$* ; push **Left$(***X$*, *swLen***)**
RIGHT$	**62**	Pop *swLen* ; pop *X$* ; push **Right$(***X$*, *swLen***)**
LTRIM$	**63**	Pop *X$* ; push **LTrim$(***X$***)**
RTRIM$	**64**	Pop *X$* ; push **RTrim$(***X$***)**
UCASE$	**65**	Pop *X$* ; pop *Y$* ; *X$* = **UCase$(***Y$***)**
LCASE$	**66**	Pop *X$* ; pop *Y$* ; *X$* = **LCase$(***Y$***)**
STRING$	**67**	Pop *X$* ; pop *ucChar* ; pop *swLen* ; *X$* = **String$(***swLen*, *ucChar***)**
STRL$	**68**	Pop *X$* ; pop *slX* ; *X$* = **Str$(***slX***)**
HEX$	**69**	Pop *X$* ; pop *slX* ; *X$* = **Hex$(***slX***)**
ASC$	**6A**	Pop *X$* ; push **Asc(***X$***)** as **CHAR**
LEN$	**6B**	Pop *X$* ; push **Len(***X$***)** as **CHAR**
COMP$	**6C**	Pop *Y$* ; pop *X$* ; compare ; push for **WORD** comparison
VALL$	**6D**	Pop *X$* ; *slVal* = **Val&(***X$, ucLen***)** ; push *slVal* ; push *ucLen*
VALHL$	**6E**	Pop *X$* ; *slVal* = **ValH(***X$, ucLen***)** ; push *slVal* ; push *ucLen*

10.6.8 Data Initialisation Instructions

Name	OpCode	Params	Description
RDATA	**6F**	*ucAddr*, *ucLen*, *data*	Copy *data* (*ucLen* bytes) to address *ucAddr*
FDATA	**70**	*scAddr*, *ucLen*, *data*	Copy *data* (*ucLen* bytes) to address **FP** + *scAddr*

10.6.9 Floating-Point Instructions

Note: These instructions are not implemented in the Compact BasicCard.

Name	OpCode	Description
COMPR	**71**	Pop *rY* ; pop *rX* ; compare ; push for **WORD** comparison
CVTWR	**72**	Pop *swX* ; push *swX* as **REAL**
CVTRW	**73**	Pop *rX* ; push *rX* as **WORD**
CVTLR	**74**	Pop *slX* ; push *slX* as **REAL**
CVTRL	**75**	Pop *rX* ; push *rX* as **LONG**
ADDR	**76**	Pop *rY* ; pop *rX* ; push *rX + rY*
SUBR	**77**	Pop *rY* ; pop *rX* ; push *rX – rY*
MULR	**78**	Pop *rY* ; pop *rX* ; push *rX * rY*
DIVR	**79**	Pop *rY* ; pop *rX* ; push *rX / rY*
NEGR	**7A**	Pop *rX* ; push *–rX*
ABSR	**7B**	Pop *rX* ; push **Abs(***rX***)**
SQRTR	**7C**	Pop *rX* ; push **Sqrt(***rX***)**
STRR$	**7D**	Pop *X$* ; pop *rX* ; *X$* = **Str$(***rX***)**
VALR$	**7E**	Pop *X$* ; *rVal* = **Val!(***X$, ucLen***)** ; push *rVal* ; push *ucLen*

10.6.10 The XMIT Command Call Instruction

Note: This instruction is available only in a Terminal program.

Name	OpCode	Params	Description
XMIT	**7F**	*ucType, ucLen*	Send command and process response

Before this instruction is executed, a command must be pushed onto the P-Code stack:

CLA	INS	P1	P2	Lc	IDATA padded to *ucLen* bytes	Le

Then the command is transmitted according to *ucType*, as follows:

ucType	
0	Send **Lc** bytes in **IDATA** (no **Le**)
1	Send **Lc** bytes in **IDATA**, followed by **Le**
2	The top 3 bytes of the **IDATA** field contain a variable-length string parameter *X$*. Send *ucLen – 3* bytes in **IDATA**, followed by *X$*.
3	The same as *ucType* = **2**, with **Le** appended to **IDATA**.
4	The top 3 bytes of the **IDATA** field contain a variable-length string parameter *X$*. Send up to **Lc** bytes of (*ucLen – 3* bytes followed by *X$*).
5	The same as *ucType* = **4**, with **Le** appended to **IDATA**.
7	The same as *ucType* = **3**, but *X$* was passed **ByVal**.
9	The same as *ucType* = **5**, but *X$* was passed **ByVal**.

10.6.11 Abbreviated Instructions

Instructions from **80** to **FF** are single-byte abbreviations of 2-byte **PUF*x*B / POF*x*B** instructions. For example, **PUFLF1** (instruction **A6**) is an abbreviation of **PUFLB F1**.

Name	OpCode	Description
PUFWED – PUFWFC	**80-8F**	Push **WORD** at address **FP – (93 – OpCode)**
PUFW00 – PUFW0F	**90-9F**	Push **WORD** at address **FP** + **(OpCode – 90)**
PUFLEB – PUFLFA	**A0-AF**	Push **LONG** at address **FP – (B5 – OpCode)**
PUFL00 – PUFL0F	**B0-BF**	Push **LONG** at address **FP** + **(OpCode – B0)**
POFWED – POFWFC	**C0-CF**	Pop **WORD** at address **FP – (D3 – OpCode)**
POFW00 – POFW0F	**D0-DF**	Pop **WORD** at address **FP** + **(OpCode – D0)**
POFLEB – POFLFA	**E0-EF**	Pop **LONG** at address **FP – (F5 – OpCode)**
POFL00 – POFL0F	**F0-FF**	Pop **LONG** at address **FP** + **(OpCode – F0)**

10.7 The SYSTEM Instruction

The **SYSTEM** P-Code instruction (OpCode **06**) calls an operating system function, according to the first parameter, *SysCode*.

10.7.1 SYSTEM Functions in the Compact BasicCard

The Compact BasicCard has just three **SYSTEM** functions:

OpCode	*SysCode*	*Name*	
06	**00**	**WTX**	Send a Waiting Time Extension request
06	**01**	**CommandString**	Convert a command parameter to a variable-length string
06	**02**	**ResponseString**	Convert a variable-length string to a response parameter

10.7.2 SYSTEM Functions in Later BasicCards

The Enhanced, Professional, and MultiApplication BasicCards have some or all of the following **SYSTEM** functions with *SysCode* < **80**:

OpCode	*SysCode*	*Name*	
06	**00**	**WTX**	Send a Waiting Time Extension request
06	**03**	**EnableKey**	Enable or disable a cryptographic key or its error counter
06	**40**	**Certificate**	Calculate a cryptographic certificate
06	**41**	**DES**	DES block encryption primitives
06	**4C**	**EnableOvCheck**	Enable overflow checking (the default)
06	**4D**	**DisableOvCheck**	Disable overflow checking
06	**55**	**Key**	Built-in **Key**() function
06	**58**	**Shift**	Shift/rotate operator

In addition, these BasicCards support the **FILE SYSTEM** functions – see **10.7.4 FILE SYSTEM Functions**. Professional and MultiApplication BasicCards also support some subset of the System Library procedures – see **10.7.5 System Library Procedures**.

10.7.3 SYSTEM Functions in the Terminal

OpCode	*SysCode*	*Name*	
06	**00**	**WTX**	Give the card more time
06	**40**	**Certificate**	Calculate a cryptographic certificate
06	**41**	**DES**	Des block encryption primitives
06	**42**	**Cls**	Clear the screen
06	**43**	**UpdateScreen**	Update the screen
06	**44**	**InKey$**	Check for keyboard input
06	**45**	**CardReader**	Look for a card reader
06	**46**	**CardInReader**	Check whether a card is in the reader
06	**47**	**ResetCard**	Reset the card in the card reader
06	**48**	**WriteEeprom**	Write EEPROM data back to the image file
06	**49**	**KeyFile**	Load a key file
06	**4A**	**EnableEncrypt**	Enable auto-encryption (the default)
06	**4B**	**DisableEncrypt**	Disable auto-encryption
06	**4C**	**EnableOvCheck**	Enable overflow checking (the default)
06	**4D**	**DisableOvCheck**	Disable overflow checking
06	**4E**	**Time$**	Date and time as e.g. "Wed Jun 20 15:50:35 1998"
06	**4F**	**ChDrive**	Change the current disk drive
06	**50**	**CurDrive**	Retrieve the current disk drive
06	**51**	**LongSeed**	Seed the random number generator with a **LONG** value
06	**52**	**StringSeed**	Seed the random number generator with a **STRING**
06	**53**	**OpenLogFile**	Start logging of I/O to file
06	**54**	**CloseLogFile**	End logging of I/O to file
06	**56**	**PcscCount**	Number of configured PC/SC card readers
06	**57**	**PcscReaderName**	Name of a PC/SC card reader
06	**58**	**Shift**	Shift/rotate operator

In addition, the Terminal supports the **FILE SYSTEM** functions listed in the next section.

10.7.4 FILE SYSTEM Functions

The file system functionality in the ZC-Basic interpreter is implemented through the **SYSTEM** P-Code instruction. Such **FILE SYSTEM** commands all have **80** <= *SysCode* <= **BF**:

OpCode	*SysCode*	*Name*	
06	**80**	**MkDir**	Create a directory
06	**81**	**RmDir**	Delete a directory
06	**82**	**ChDir**	Change the current directory
06	**83**	**CurDir**	Retrieve the current directory
06	**84**	**DirCount**	Count the filenames that match a wild-card spec
06	**85**	**DirFile**	Return the *n*th matching filename
06	**86**	**EraseFile**	Delete a data file
06	**87**	**RenameFile**	Rename or move a file or directory
06	**88**	**OpenFile**	Open a file
06	**89**	**OpenFreeFile**	Open a file after finding a free file slot for it
06	**8A**	**CloseFile**	Close a file
06	**8B**	**CloseAll**	Close all files
06	**8C**	**FreeFile**	Find a free file slot
06	**8D**	**FileLength**	Return the length of an open file
06	**8E**	**GetFilepos**	Return the read/write pointer of an open file
06	**8F**	**SetFilepos**	Set the read/write pointer of an open file
06	**90**	**EOF**	Return **True** if at the end of an open file
06	**91**	**Get**	Read from a binary file
06	**92**	**GetPos**	**Get** after setting the read/write pointer
06	**93**	**Put**	Write to a binary file
06	**94**	**PutPos**	**Put** after setting the read/write pointer
06	**95**	**StartInput**	Set the counter of matched input items to 0
06	**96**	**EndInput**	Return the counter of matched input items
06	**97**	**Read**	Read a specified number of bytes from a sequential file
06	**98**	**ReadLong**	Read a formatted **LONG** value from a sequential file
06	**99**	**ReadSingle**	Read a formatted **SINGLE** value from a sequential file
06	**9A**	**ReadString**	Read a formatted **STRING** from a sequential file
06	**9B**	**ReadBlock**	Read a formatted fixed-size block from a sequential file
06	**9C**	**ReadLine**	Read a line from a sequential file
06	**9D**	**WriteLong**	Write a formatted **LONG** value to a sequential file
06	**9E**	**WriteSingle**	Write a formatted **SINGLE** value to a sequential file
06	**9F**	**WriteString**	Write a formatted **STRING** to a sequential file
06	**A0**	**PrintLong**	Write an ASCII **LONG** value to a sequential file
06	**A1**	**PrintSingle**	Write an ASCII **SINGLE** value to a sequential file
06	**A2**	**PrintString**	Write an ASCII **STRING** to a sequential file

OpCode	*SysCode*	*Name*	
06	**A3**	**PrintSpaces**	Write a specified number of spaces to a sequential file
06	**A4**	**PrintTab**	Advance to the next 14-character output field
06	**A5**	**SetColumn**	Advance to a specified output column
06	**A6**	**PrintNewLine**	Print a new-line character
06	**A7**	**LockFile**	Set the access conditions on a file or directory
06	**A8**	**GetLocks**	Retrieve the access conditions on a file or directory
06	**A9**	**GetAttr**	Retrieve the attributes of a file or directory
06	**AA**	**SetAttr**	Set the attributes of a file or directory (Terminal only)

10.7.5 System Library Procedures

Values of *SysCode* between **C0** and **FF** are reserved for System Library procedures – see **3.13.2 System Library Procedures**. For details of which codes are assigned to which procedures, see the individual *Library*.**DEF** files supplied with ZeitControl's development software.

11. Output File Formats

This chapter describes the formats of the various output files generated by the ZC-Basic compiler:

- Image file: program and data in binary format, for use by **ZCMSIM** and **BCLOAD** programs.
- Debug file: symbolic debugging information, for the **ZCMDTERM** and **ZCMDCARD** debuggers.
- Application file: selectable Application file in the MultiApplication BasicCard
- List file: source program, compiled P-Code, and data in human-readable text format.
- Map file: the addresses of all symbols in the program, ordered by name and by location.

Note: Throughout this chapter, **bold** numbers are hexadecimal.

11.1 ZeitControl Image File Format

Debug and Image files consist of Sections, each of which starts with a 4-byte ASCII name, followed by a 4-byte section length. In an Image file, Sections are guaranteed to occur in the following order:

For a BasicCard program:

'ZCIF'	Signature Section – "ZeitControl Image File"
'VERS'	Version Section – File format version
'VMTP'	Virtual Machine Type Section – target machine
'CONF'	Configuration File Section (Professional BasicCard only)
'EEPR'	EEPROM Image Section – **EEPSYS**, **CMDTAB**, **PCODE**, **STRCON**, **KEYTAB**, **EEPDATA**, and **EEPHEAP** regions (absent for MultiApplication BasicCard)
'LOAD'	Program Load Section, containing the commands to download to the BasicCard
'CERT'	Code Certification Section (certain Enhanced BasicCard versions)

For a Terminal program:

'ZCIF'	Signature Section – "ZeitControl Image File"
'VERS'	Version Section – File format version
'VMTP'	Virtual Machine Type Section – target machine
'CODE'	P-Code Section – Contents of **PCODE** region
'DATA'	Data Section – **RAMSYS**, **STRCON**, **RAMDATA**, and **RAMHEAP** regions
'EEPR'	EEPROM Image Section – **EEPDATA** and **EEPHEAP** regions

Numerical 2-byte and 4-byte fields are stored lsb to msb, Intel-style (or Little-Endian). This is in contrast to the Virtual Machine, which is Big-Endian.

Some sections contain string tables. A string table consists of consecutive null-terminated strings. Whenever a name occurs in a Section field, it is to be interpreted as an offset into the string table of the current Section.

11.1.1 Signature Section

Length	
4	**'ZCIF'** ("ZeitControl Image File")
4	Total length of all remaining sections (= file length – 8)

11.1.2 Version Section

Length	
4	**'VERS'**
4	Section length = **04**
1	Major version of software that created this file

1	Minor version of software that created this file
1	Major version of oldest software compatible with this file
1	Minor version of oldest software compatible with this file

11.1.3 Virtual Machine Type Section

Length	
4	**‘VMTP’**
4	Section length *len*
len	*MachineType*

If *len* = 2, the first byte of *MachineType* is as follows:

00 Terminal
01 Compact BasicCard
02 Enhanced BasicCard
06 MultiApplication BasicCard

and the second byte is the Machine Sub-type (**00** for Terminal or MultiApplication BasicCard, **01** for Compact BasicCard, various values for Enhanced BasicCard).

If *len* > 2, the Image File contains a Professional BasicCard program, and *MachineType* is an ASCII string containing the version ID of the card.

11.1.4 Configuration File Section (Professional BasicCard only)

Length	
4	**‘CONF’**
4	Section length *len*
len	Full path name of **.ZCF** BasicCard Configuration File

11.1.5 P-Code Section (Terminal only)

Length	
4	**‘CODE’**
4	Section length *len*
2	Program entry point
len-2	P-Code. The P-Code in the Terminal starts at address **0000**.

11.1.6 Data Section (Terminal only)

Length	
4	**‘DATA’**
4	Section length
2	Start address of RAM data
2	Length of RAM data
2	Number of records *n*
2	Start address of record **0**
2	Length len_0 of record **0**
len_0	Contents of record **0**

. . .	
2	Start address of record $n - 1$
2	Length len_{n-1} of record $n - 1$
len_{n-1}	Contents of record $n - 1$

All RAM bytes not contained in a record must be initialised to **00**.

The Data Section contains the **RAMSYS**, **STRCON**, **RAMDATA**, and **RAMHEAP** regions.

11.1.7 EEPROM Image Section

Length	
4	**'EEPR'**
4	Section length
2	Start address of EEPROM data
2	Length of EEPROM data
2	Number of records n
2	Start address of record **0**
2	Length len_0 of record **0**
len_0	Contents of record **0**
. . .	
2	Start address of record $n - 1$
2	Length len_{n-1} of record $n - 1$
len_{n-1}	Contents of record $n - 1$

All EEPROM bytes not contained in a record must be initialised to **FF**.

In the Terminal, the EEPROM Image Section contains just the **EEPDATA** and **EEPHEAP** regions. In the BasicCard, it contains the **EEPSYS**, **CMDTAB**, **PCODE**, **STRCON**, **KEYTAB**, **EEPDATA**, and **EEPHEAP** regions.

11.1.8 Program Load Section (Single-Application BasicCards)

Length	
4	**'LOAD'**
4	Section length
1	State of BasicCard after download (from **#State** directive or **–S** parameter)
2	Number n_{WE} of **WRITE EEPROM** commands
2	Number n_{CRC} of **EEPROM CRC** commands
2	Address of **WRITE EEPROM** command **0**
1	Length len_0 of **WRITE EEPROM** command **0**
len_0	Contents of **WRITE EEPROM** command **0**
. . .	
2	Address of **WRITE EEPROM** command $n_{WE} - 1$
1	Length len_{n-1} of **WRITE EEPROM** command $n_{WE} - 1$
len_{n-1}	Contents of **WRITE EEPROM** command $n_{WE} - 1$

2	Address of **EEPROM CRC** command **0**
2	Length of **EEPROM CRC** command **0**
2	CRC of **EEPROM CRC** command **0**
. . .	
2	Address of **EEPROM CRC** command $n_{CRC} - 1$
2	Length of **EEPROM CRC** command $n_{CRC} - 1$
2	CRC of **EEPROM CRC** command $n_{CRC} - 1$

11.1.9 Application Load Section (MultiApplication BasicCard)

Length	
4	**'LOAD'**
4	Section length
1	State of BasicCard after download (from **#State** directive or **–S** parameter)
1	Loader Action code
1	Loader Action subcode
	Loader Action data
. . .	
1	Loader Action code
1	Loader Action subcode
	Loader Action data

A Debug File contains source file information between the Loader Action subcode and the Loader Action data. It consists of File number (2 bytes), Line number (2 bytes), and File position (4 bytes).

A Loader Action code other than **20** is an instruction to the Application Loader. In this case, the Loader Action data consists of the number of parameters (1 byte), followed by a Parameter Field for each parameter. A Parameter Field consists of *ParamType* (1 byte), followed by the value of the Parameter, as follows:

ParamType	*Meaning*	*Format*
00	**Byte**	1 byte
01	**Integer**	2 bytes, lsb first
02	**Long**	4 bytes, lsb first
04	**String**	*len* (1 byte) followed by *val* (*len* bytes)
10	**ctFile**	4-byte Reference number of a Component of type File
20	**ctAcr**	4-byte Reference number of a Component of type ACR
30	**ctPrivilege**	4-byte Reference number of a Component of type Privilege
40	**ctFlag**	4-byte Reference number of a Component of type Flag
70	**ctKey**	4-byte Reference number of a Component of type Key

The following table gives the parameter types of each Application Loader instruction:

Code	*Subcode*	
10	**82**	Push current directory and change directory (*Directory* **As String**)
10	**83**	Pop current directory (no parameters)
10	**49**	**LCReadKeyFile** (*KeyFile* **As String**)
C0	**10**	**LCStartEncryption** (*Key* **As ctKey**, *Algorithm* **As Byte**)

C0	**12**	**LCEndEncryption** (no parameters)
C0	**42**	**LCExternalAuthenticate** (*Key* **As ctKey**, *Algorithm* **As Byte**)
C0	**44**	**LCInternalAuthenticate** (*Key* **As ctKey**, *Algorithm* **As Byte**)
C0	**46**	**LCVerify** (*Key* **As ctKey**)
C0	**92**	**LCGrantPrivilege** (*Privilege* **As ctPrivilege**, *File* **As ctFile**)
C0	**94**	**LCAuthenticateFile** (*Key* **As ctKey**, *Algorithm* **As Byte**, *File* **As ctFile**, *Signature* **As String**)
C0	**98**	**LCLoadSequence** (*Phase* **As Byte**)
C0	**9A**	**LCStartSecureTransport** (*Key* **As ctKey**, *Algorithm* **As Byte**, *Nonce* **As String**)
C0	**9B**	**LCEndSecureTransport** (no parameters)
C0	**9C**	**LCCheckSerialNumber** (*SerialNumber* **As String**)

A Loader Action code of **20** is a Component Action:

Code	*Subcode*	
20	**10**	File Action
20	**20**	ACR Action
20	**30**	Privilege Action
20	**40**	Flag Action
20	**50**	Directory Action
20	**70**	Key Action

Component Action data begins with the following fields, common to all Component types:

Ref	Component Reference (4 bytes)
Create	Create Option (1 byte): **0/1/2/3 = Always/Once/Update/Never**
Name	*len* (1 byte), *name* (*len* bytes): absent (because known) if top bit is set in *Create*
Lock	Component Reference number of ACR (4 bytes)
Spec	Bit mask of attributes specified in the source code (1 byte)

Bit 0 of *Spec* (here denoted by *Spec*.0) is set if the **Lock** field was specified in the corresponding Component Definition. The other bits of *Spec*, and the remainder of the Component Action data, depend on the Component type. See **5.8 Component Details** for background information:

Subcode 10: File Action

Spec.1	*BlockLen* (2 bytes)
	FileLength (2 bytes)
Spec.2	Contents of file (*FileLength* bytes)

The first two fields are always present; the file contents are only present if *Spec*.2 is set.

Subcode 20: ACR Action

Spec.1	*ACRType* (1 byte)
	ACRData

These fields are described in **5.8.2 ACRs**. If *Spec*.1 is not set, then neither field is present.

Subcode 30: Privilege Action

A Privilege Action contains no further Component Action data.

Subcode 40: Flag Action

Spec.1	*Attributes* (1 byte)

This field is always present.

Subcode 50: Directory Action

A Directory Action contains no further Component Action data.

Subcode 70: Key Action

*Spec.*1	*UsageMask* (2 bytes)
*Spec.*2	*AlgorithmMask* (2 bytes)
*Spec.*3	*ErrorCounter* (1 byte)
*Spec.*4	*ECResetValue* (1 byte)
Spec.5	*Data*

The first four fields are always present. If *Spec.*5 is set, then the *Data* field is also present; it takes the form of a Parameter Field of type **BinaryData**, as follows:

ParamType	*Meaning*	*Format*
80	**BinaryData**	1-byte **BinaryData** sub-type code, followed by parameters:
	Subtype	
	81	**bdString**: *len* (1 byte), *val* (*len* bytes)
	82	**bdLCIndexedKey**: *KeyIndex* (1 byte)
	83	**bdLCSerialNumber**: no parameters
	84	**bdLCBuildKey**: *Key* (**ctKey** parameter) *Len* (**Byte** parameter) *Seed* (**BinaryData** parameter)
	85	**bdLCKey**: *Key* (**ctKey** parameter)

11.1.10 Code Certification Section

This Section is only required for Enhanced BasicCards **ZC3.1**, **ZC3.2**, and **ZC3.31**.

Length	
4	**'CERT'**
4	Section length *len*
2	Start address of Certified Code
len–**2**	Code Certificate, to be sent in the **SET STATE** command

11.2 ZeitControl Debug File Format

A debug file has the same format as an image file, with additional sections containing debug information. The Signature Section has a different name:

'ZCDF' Signature Section – "ZeitControl Debug File"

The debug information sections occur immediately after the **'CONF'** Configuration File Section if present, otherwise the **'VMTP'** Virtual Machine Type Section:

'OPTS'	Compiler Options Section – Options with which the source file was compiled
'FILE'	Files Section – Names of all source files
'TYPE'	Types Section – Descriptions of all data types used in the program
'SYMB'	Symbols Sections – Labels and variables, one Section for each scope
'LINE'	Line Numbers Section – Source line number information
'FIXU'	Fixups Section – Cross-references

11.2.1 Signature Section

Length	
4	**'ZCDF'** ("ZeitControl Debug File")
4	Total length of all remaining sections (= file length – 8)

11.2.2 Compiler Options Section

This section contains the compiler options with which the source file was compiled.

Length	
4	**'OPTS'**
4	Section length
1	–**S***state* parameter: State of the BasicCard
4	–**S***stack* parameter: Stack size requested
4	–**H***heap* parameter: Heap size requested
4	Length len_I of –**I***include-path* parameter
len_I	–**I***include-path* parameter: search paths for included files
4	Length len_D of –**D***constants* parameter
len_D	–**D***constants* parameter: command-line constant definitions
4	Length len_N of –**N***serial-number* parameter
len_N	–**N***serial-number* parameter: serial number of MultiApplication BasicCard

All these fields are present, even if they are not allowed for the given Machine Type.

11.2.3 Files Section

This section contains the names and timestamps of all the source files in the program:

Length	
4	**'FILE'**
4	Section length
2	String table length len_{ST}
len_{ST}	String table
2	Number of files *n*
2	Name of file **0**
4	Number of lines in file **0**
2	Length of longest line in file **0**
4	Timestamp of file **0**
. . .	
2	Name of file $n-1$
4	Number of lines in file $n-1$
2	Length of longest line in file $n-1$
4	Timestamp of file $n-1$

11.2.4 Types Section

This section contains definitions of every data type that occurs in the program.

Length	
4	**'TYPE'**
4	Section length

2	String table length len_{ST}
len_{ST}	String table
2	Number of type entries n
7	Type **0**
. . .	
7	Type $n - 1$

Type format (shaded bytes are zero):

Byte	**0**						
Integer	**1**						
Long	**2**						
Single	**3**						
String	**4**						
String*n	**5**	**n**					
Array	**6**	*ElementType*		*nDims*			
UserType	**7**	*TypeName*		*nMembers*			
Member	**8**	*MemberName*		*MemberType*		*Offset*	

ElementType, *MemberType*	Indices of types in the Types section
TypeName, MemberName	Offsets in the string table
nDims	Number of dimensions of the array
nMembers	Number of members in the user-defined type
Offset	Offset of the member in its user-defined type *UserType*

A *UserType* entry is immediately followed by ***nMembers*** type entries of type *Member*.

11.2.5 Symbols Sections

The first Symbols Section contains global symbols. Each subsequent Symbols Section contains the local symbols for a single procedure. Symbols are sorted by name (according to the ‘C’ library function `stricmp`). Symbols beginning with ‘$’ are compiler-generated names.

Length	
4	**‘SYMB’**
4	Section length
2	Procedure start address (**0000** for the global Symbols Section)
2	Procedure end address (**0000** for the global Symbols Section)
2	String table length len_{ST}
len_{ST}	String table
2	Number of symbols n
8	Symbol **0**
. . .	
8	Symbol $n - 1$

Symbol format (shaded bytes are zero):

Const Long	**0**	*SymbolName*	4-byte integer				
Const Single	**1**	*SymbolName*	4-byte floating-point number				
Const String	**2**	*SymbolName*	*String*		*Len*		
Label	**3**	*SymbolName*	Address				
Variable	**4**	*SymbolName*	Address		*Type*		*Storage*
Library Proc	**5**	*SymbolName*	*Code*	*Subcode*			
Command	**6**	*SymbolName*	Address		**CLA**	**INS**	

SymbolName, String 2-byte offsets in the string table

Type Index in the Types section

Storage
0 = 2-byte absolute
1 = 1-byte absolute
2 = 1-byte signed, FP-relative (procedure parameters, **Private** data)
3 = indirect 1-byte signed, FP-relative (**String** and array parameters)

Code, Subcode **SYSTEM** code and subcode

11.2.6 Line Numbers Section

Line-number entries are sorted in increasing code address order.

Length	
4	**'LINE'**
4	Section length
2	Number of line-number entries *n*
10	Line-number entry **0**
. . .	
10	Line-number entry *n* – 1

Line-number entry format:

Code address (2 bytes)	File number (2 bytes)	Line number (2 bytes)	File position (4 bytes)

11.2.7 Fixups Section

This Section contains two tables: Labels and Operands. Entries in the Labels table give the label(s) at a given address. Entries in the Operands table give the operand of a P-Code instruction as a symbol (*Label* or *Variable*).

Length	
4	**'FIXU'**
4	Section length
2	Number of entries in Labels table *nLabs*
6	Label entry **0**
. . .	
6	Label entry *nLabs* – 1
2	Number of entries in Operands table *nOps*

6	Operand entry **0**
. . .	
6	Operand entry *nOps* – 1

Label entries and Operand entries have the same format:

Code address (2 bytes)	Symbols Section (2 bytes)	Index of symbol in Symbols Section (2 bytes)

11.3 Application File Format

An Application File in the MultiApplication BasicCard has the following format:

Length		
4	**'ZCAF'**	"ZeitControl Application File"
2	**Version**	Major/Minor Version Number (currently 10.1)
2	**CompatibilityMask**	For future expansion – currently **&H0001**
2	**RamAddressOffset**	Virtual RAM starts here
2	**AppFileAddressOffset**	Virtual EEPROM starts here
2	**StackSize**	P-Code Stack size required by Application
2	**UserRamSize**	Size of User RAM Data + User RAM Heap
2	**ApplIDPtr**	Application ID string
2	**RamInitCodePtr**	Address of compiler-generated RAM initialisation code
2	**InitCodePtr**	Address of user's Application initialisation code
2	**CommandTablePtr**	Table of user-defined commands
2	**AppFileData**	Start of Application's **Eeprom** Data
2	**AppFileHeap**	Start of Application's **Eeprom** Heap
2	**AppFileHeapEnd**	End of Application's **Eeprom** Heap
2	**ErrorHandler**	User-defined **ErrorHandler** procedure
2	**DefaultHandler**	User-defined **Command Else** command
2	**ClaInsFilter**	User-defined **ClaInsFilter** procedure
1	**OptionMask**	**#Pragma** options
		Application Code and Data

11.4 List File Format

The format of the list file is illustrated by means of a small example program:

```
Declare ApplicationID = "Small Example Program"
Eeprom MonthLength(1 To 12) = 1,28,31,30,31,30,31,31,30,31,30,31
Const InvalidMonth = &H6F01
Command &H80 &H00 GetMonthLength (N)
    If N < 1 Or N > 12 Then
        SW1SW2 = InvalidMonth
    Else
        N = MonthLength (N)
    End If
End Command
```

This program was compiled for the Compact BasicCard version ZC1.1, with list file and map file requested:

```
ZCBASIC MONTHLEN -CC1 -OL -OM
```

The list file, **MONTHLEN.LST:**

```
❶ File: MONTHLEN.BAS
    ❷ 1  Declare ApplicationID = "Small Example Program"
❸ $ApplicationID:
    ❹    EEPDATA      8082:  15 53 6D 61 6C 6C 20 45 78 61 6D 70 6C 65 20 50
         EEPDATA      8092:  72 6F 67 72 61 6D
      2  Eeprom MonthLength(1 To 12) = 1,28,31,30,31,30,31,31,30,31,30,31
❺ MonthLength:
         EEPDATA      8098:  80 A0 02 01 04 0B 00 18
  MonthLength Data:
         EEPDATA      80A0:  00 01 00 1C 00 1F 00 1E 00 1F 00 1E 00 1F 00 1F
         EEPDATA      80B0:  00 1E 00 1F 00 1E 00 1F
  Const80008000:
         EEPDATA      80B8:  80 00 80 00
      3  Const InvalidMonth = &H6F01
      4  Command &H80 &H00 GetMonthLength (N)
  GetMonthLength:
    ❻    PCODE      ❼ 804E: ❽46 00    ❾ ENTER 00
         CMDTAB       8043:  02 80 00 02 80 4E C0 18 07 80 77
      5      If N < 1 Or N > 12 Then
         PCODE        8050:  8F         PUFWFC (N) ❿
         PCODE        8051:  0C 01      PUCWB 01
         PCODE        8053:  15 80B8    PUELW Const80008000
         PCODE        8056:  3C         XORL
         PCODE        8057:  52 09      JLTWB $If001
         PCODE        8059:  8F         PUFWFC (N)
         PCODE        805A:  0C 0C      PUCWB 0C
         PCODE        805C:  15 80B8    PUELW Const80008000
         PCODE        805F:  3C         XORL
         PCODE        8060:  4F 06      JLEWB $Else001
      6          SW1SW2 = InvalidMonth
  $If001:
         PCODE        8062:  0E 6F01    PUCWW 6F01
         PCODE        8065:  22 45      PORWB SW1SW2
         PCODE        8067:  54         EXIT
      7      Else
      8          N = MonthLength (N)
  $Else001:
         PCODE        8068:  8F         PUFWFC (N)
         PCODE        8069:  0E 8098    PUCWW MonthLength
```

```
        PCODE       806C:  55       ARRAY
        PCODE       806D:  1F       PUINW
        PCODE       806E:  CF       POFWFC (N)
     9      End If
    10  End Command
        PCODE       806F:  54       EXIT
$InitCode:
        PCODE       8070:  46 00    ENTER 00
        PCODE       8072:  6F 80 01 RDATA 80 01
                           FF             FF
        PCODE       8076:  47       LEAVE
```

➊ Input filename
➋ Source code, with line number
➌ Compiler-generated label (begins with '$')
➍ Eeprom data (**EEPDATA** is the name of the region)
➎ User-generated label (no initial '$')
➏ P-Code (**PCODE** is the name of the region)
➐ Address of P-Code instruction
➑ P-Code instruction and operands, in hexadecimal
➒ P-Code instruction and operands, in text
➓ Implicit operand of abbreviated P-Code instruction, in parentheses

11.5 Map File Format

The map file **`MONTHLEN.MAP`** from the example program in the previous section, **11.4 List File Format:**

```
❶ Input file: MONTHLEN.BAS

❷ ===== RAM regions =====

  Name        Start  End    Length
  ----        -----  ---    ------
  RAMSYS      00     4B     4C
  STACK       4C     7F     34
  RAMDATA                   00
  RAMHEAP     80     FF     80

❸ ===== EEPROM regions =====

  Name        Start  End    Length
  ----        -----  ---    ------
  EEPSYS      8020   8042   0023
  CMDTAB      8043   804D   000B
  PCODE       804E   8081   0034
  STRCON                    0000
  KEYTAB                    0000
  EEPDATA     8082   80BB   003A
  EEPHEAP     80BC   83FF   0344

❹ ===== Symbols by name =====

  Name                     Scope                 Address Type
  ----                     -----                 ------- ----
  Algorithm                Global                23      PUBLIC BYTE
  CardMajorVersion         Global                        CONST=0001
  CardMinorVersion         Global                        CONST=0001
  CLA                      Global                47      PUBLIC BYTE
  CompactBasicCard         Global                        CONST=0001
  Const80008000            GetMonthLength        80B8    EEPROM LONG
  False                    Global                        CONST=0000
  GetMonthLength           Global                804E    COMMAND &H80 &H00
  INS                      Global                48      PUBLIC BYTE
  InvalidMonth             Global                        CONST=6F01
  KeyNumber                Global                40      PUBLIC BYTE
  Lc                       Global                4B      PUBLIC BYTE
  Le                       Global                44      PUBLIC BYTE
  MonthLength              Global                8098    EEPROM INTEGER ARRAY
  MonthLength Data         Global                80A0    ARRAY DATA
  N                        GetMonthLength        FC      PARAM INTEGER
  P1                       Global                49      PUBLIC BYTE
  P1P2                     Global                49      PUBLIC INTEGER
  P2                       Global                4A      PUBLIC BYTE
  PCodeError               Global                41      PUBLIC BYTE
  ResponseLength           Global                43      PUBLIC BYTE
  SW1                      Global                45      PUBLIC BYTE
  SW1SW2                   Global                45      PUBLIC INTEGER
  SW2                      Global                46      PUBLIC BYTE
  True                     Global                        CONST=FFFFFFFF

❺ ===== Symbols by location =====
```

```
RAM system data:

Name                    Scope               Address Type
----                    -----               ------- ----
Algorithm               Global              23      PUBLIC BYTE
KeyNumber               Global              40      PUBLIC BYTE
PCodeError              Global              41      PUBLIC BYTE
ResponseLength          Global              43      PUBLIC BYTE
Le                      Global              44      PUBLIC BYTE
SW1                     Global              45      PUBLIC BYTE
SW1SW2                  Global              45      PUBLIC INTEGER
SW2                     Global              46      PUBLIC BYTE
CLA                     Global              47      PUBLIC BYTE
INS                     Global              48      PUBLIC BYTE
P1                      Global              49      PUBLIC BYTE
P1P2                    Global              49      PUBLIC INTEGER
P2                      Global              4A      PUBLIC BYTE
Lc                      Global              4B      PUBLIC BYTE

EEPROM user data:

Name                    Scope               Address Type
----                    -----               ------- ----
MonthLength             Global              8098    EEPROM INTEGER ARRAY
MonthLength Data        Global              80A0    ARRAY DATA
Const80008000           GetMonthLength      80B8    EEPROM LONG

❻ User code:

Name                    Scope               Address Type
----                    -----               ------- ----
GetMonthLength          Global              804E    COMMAND &H80 &H00
Initialisation Code     Global              8070    SUB

❼ Local variables:

Name                    Scope               Address Type
----                    -----               ------- ----
N                       GetMonthLength      FC      PARAM INTEGER
```

❶ Input filename.
❷ RAM regions: The addresses and lengths of the regions in RAM.
❸ EEPROM regions: The addresses and lengths of the regions in EEPROM.
❹ Symbols by name: All the symbols in alphabetical order.
❺ Symbols by location: All the symbols, ordered according to location and address.
❻ User code: The addresses of all the procedures and labels in the source program.
❼ Local variables: The signed FP-relative addresses of parameters and **Private** data.

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