AN2646
Application note

Smartcard interface with the STM8S microcontroller

Introduction

This document describes a firmware and hardware smartcard interface solution based on the STM8 UART1 peripheral. The main purpose of this firmware and hardware package is to provide resources that facilitate the development of an application using the UART1 peripheral in smartcard mode.

The firmware interface consists of library source files developed so as to support the ISO 7816-3/4 specification. An application example is also provided.

This document and its associated firmware are available for download from the STMicroelectronics website: *www.st.com.*

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1 Smartcard interface description

1.1 Introduction

The smartcard interface is developed using the UART1 smartcard mode. For the description of the UART1 registers, please refer to the STM8S/STM8A reference manual (RM0009). The UART1 smartcard mode supports asynchronous protocol smartcards as defined in the ISO 7816-3 (Class A) standard, please refer to the ISO 7816-3 specification for more details.

With the smartcard mode enabled, the UART1 must be configured as:

- Eight data bits plus parity
- 0.5 or 1.5 stop bits

A 5-bit prescaler and the smartcard clock generator provide the clock to the smartcard. GPIO pins in conjunction with software are used to provide the rest of the functions required to interface to the smartcard.

The inverse signalling convention as defined in ISO 7816-3, inverted data and MSB first, is not handled in the software.

There are three types of card that operate at different voltages:

- 5V (ISO7816-3 Class A)
- 3V (ISO7816-3 Class B)
- 1.8V (ISO7816-3 Class C)

1.2 External interface

Table 1. Smartcard pins

STM8S20x pin	Smartcard pin	Function
UART1_CK	CLK	Smartcard clock
UART1_TX	IO	IO serial data: open drain
Any GPIO	RST	Reset to card
Any GPIO	V_{CC}	Supply voltage
Any GPIO	V_{PP}	Programming voltage

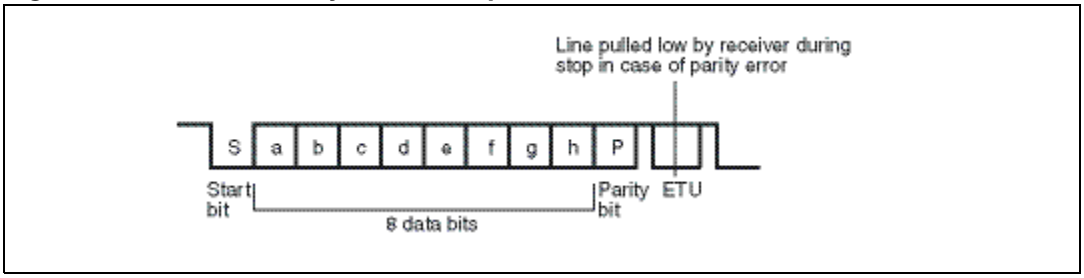
The Smartcard_RST (Smartcard reset), Smartcard_3/5V (3 V or 5 V), Smartcard_CMDVCC (command for V_{CC}), and Smartcard_OFF signals (signal for card detection) are provided by GPIO bits of the I/O ports under software control. Programming the GPIO bits of the port for alternate function open-drain mode connects the UART1_TX data signal to the Smartcard_IO pin with the correct driver type and the clock generator to the Smartcard_CLK pin configured in output push-pull.

1.3 Protocol

The ISO 7816-3 standard defines the bit times for the asynchronous protocol in terms of time units called ETUs (elementary time units), that are related to the clock frequency input

to the card. The length of an ETU is a bit time. The UART1 transmitter output and receiver input are internally connected through the Rx_SW line. For the transmission of data from the STM8S20x to the smartcard, the UART1 must be set up in smartcard mode.

Figure 1. ISO 7816-3 asynchronous protocol



1.4 Smartcard clock generator

The smartcard clock generator provides a clock signal to the connected smartcard. The smartcard uses this clock to derive the baud rate clock for the serial I/O between the smartcard and another UART1. The clock is also used for the CPU in the card, if present.

Operation of the smartcard interface requires that the clock rate to the card is adjusted while the CPU in the card is running code so that the baud rate can be changed or the performance of the card can be increased. The protocols that govern the negotiation of these clock rates and the altering of the clock rate are detailed in the ISO 7816-3 standard.

The clock is used as the CPU clock for the smartcard, therefore updates to the microcontroller clock rate must be synchronized to the smartcard clock, that is the clock high or low pulse widths must not be shorter than either the old or new programmed value.

2 Smartcard reader hardware connection

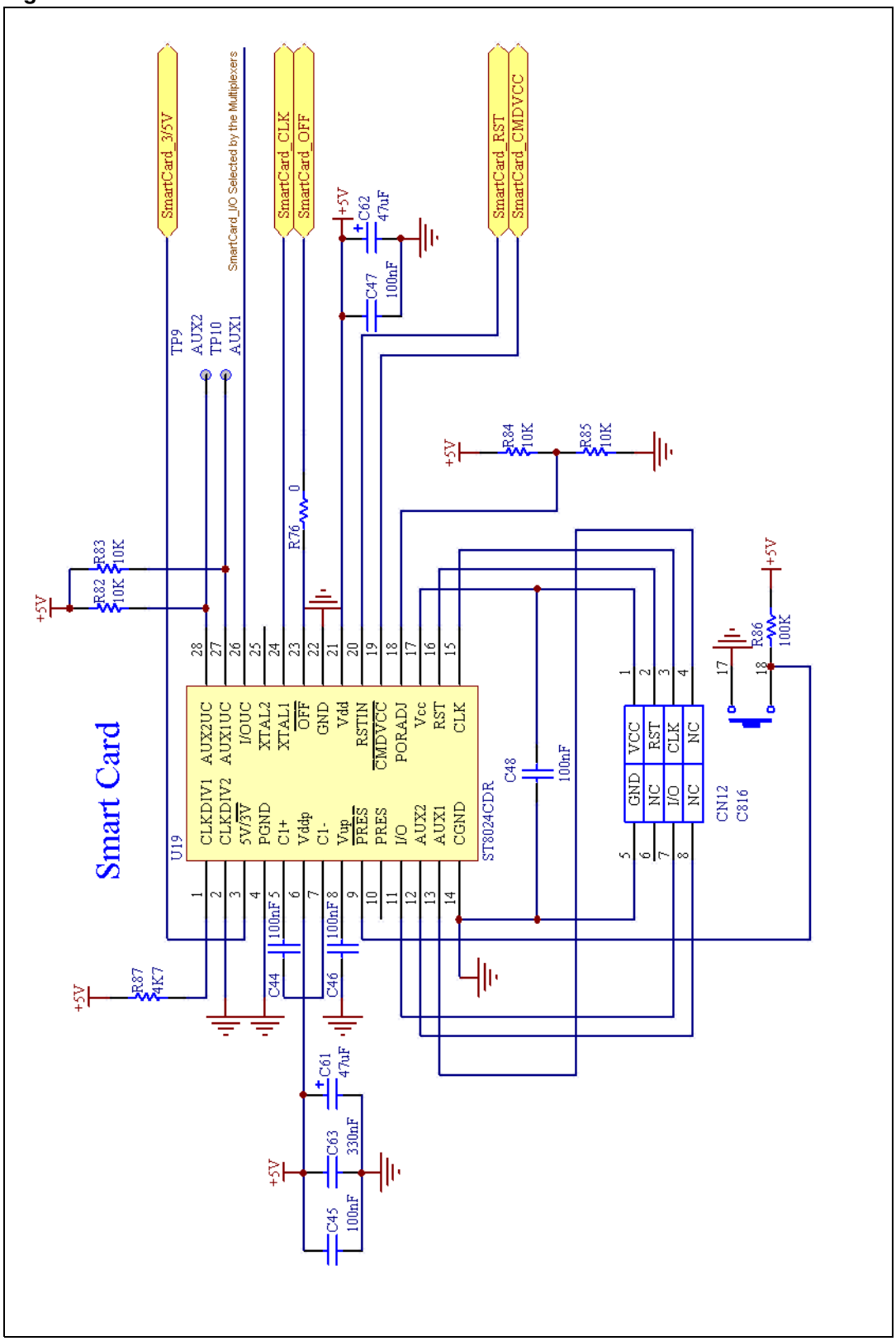
To interface to the smartcard, the ST8024 device was used. The ST8024 is a complete low-cost, analog interface for asynchronous 3 V and 5 V smartcards. It is placed between the smartcard and the STM8S20x with few external components to perform all supply protection and control functions.

The M74HC4052 multiplexer/demultiplexer is configured by software to allow the UART1_TX to the Smartcard_IO

Table 2. STM8S20x and smartcard connection

STM8S20x pins	Smartcard pins	Function
UART1_CK: PA6	C3: CLK	Smartcard clock: output push-pull
UART1_TX: PA5	C7: IO	IO serial data: output open drain
PG5	C2: RST	Reset to card: output push-pull
PG7	C1: V_{CC}	Supply voltage: output push-pull
PE0	OFF	Smartcard detect: input floating
PG4	3/5V	3 V or 5 V: output push-pull

Figure 2. Smartcard interface hardware connection



3 ISO 7816 – protocol overview

3.1 Introduction

"ISO 7816: Identification cards -- Integrated circuit(s) cards with contacts" provides the basis to transition the relatively simple identification card from a token that can be compromised through forgery, theft, or loss into a tamper-resistant and "intelligent" integrated circuit card (ICC), more popularly known as a smartcard. ISO 7816 includes at least six approved parts and has several additional parts under review:

- Part 1: Physical characteristics
- Part 2: Dimensions and location of the contacts
- Part 3: Electrical interface and transmission protocols
- Part 3: Amendment 2-Revision of protocol type selection
- Part 4: Organization, security and commands for interchange
- Part 5: Registration of application providers

3.2 ISO 7816-2 – pin location

ISO 7816-2 specifies an ICC with eight electrical contacts present in a standardized position on the front face of the card. These are referred to as C1 through C8. Some of these contacts are electrically connected to the microprocessor chip embedded within the card; some are not, having been defined to allow for enhancements but unused at the present time. *Figure 3* shows the contact positions.

Figure 3. Contact definitions for smartcards

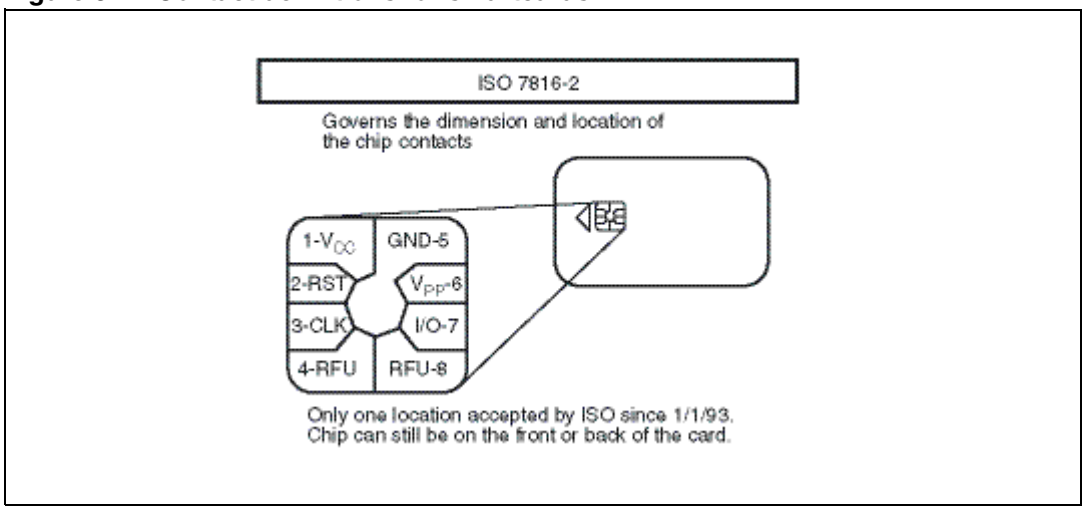


Table 3. Pin assignment

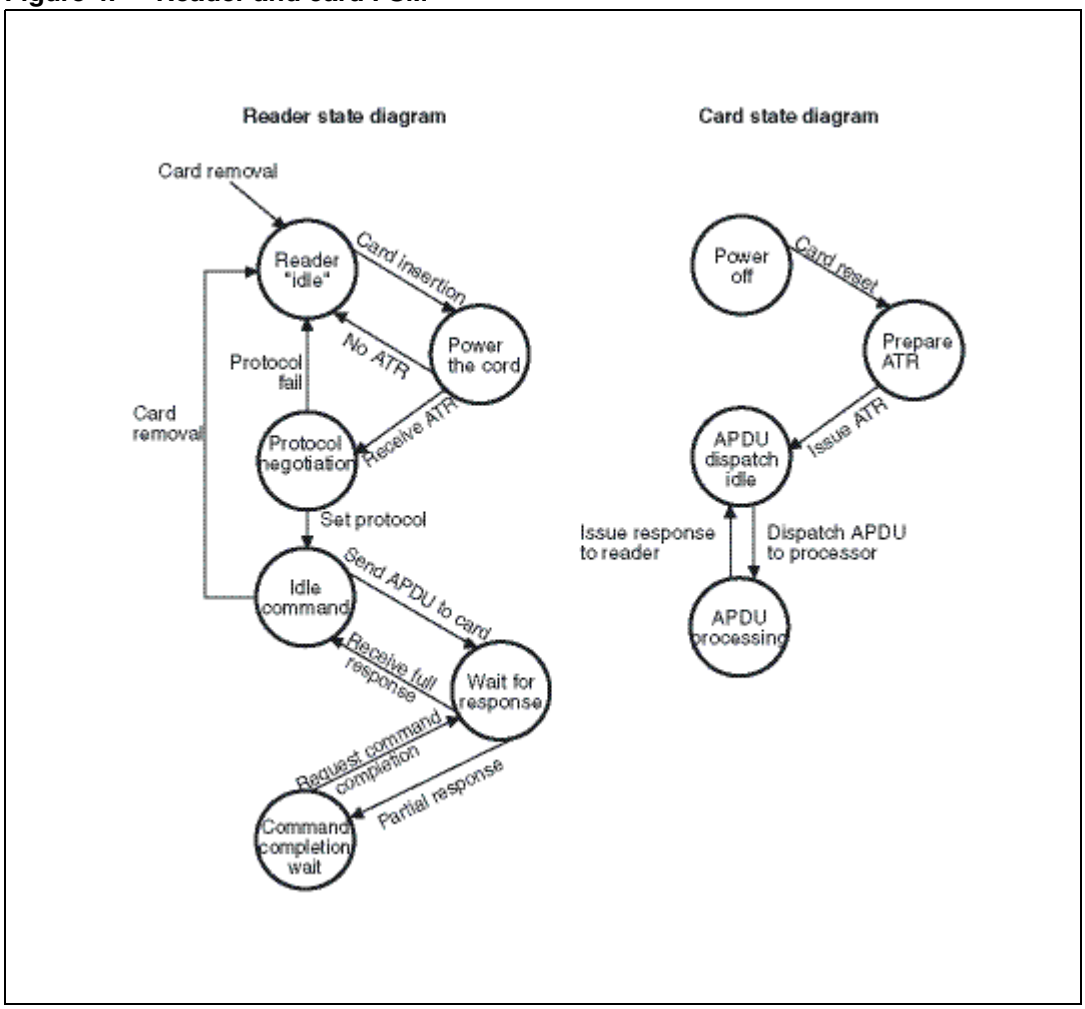
Pins	Functions
C1	V_{CC} = 5 V or 3.3 V
C2	Reset
C3	Clock
C4	RFU
C5	GND
C6	V_{PP}
C7	I/O
C8	RFU

4 ISO 7816-3 – electronic signal and transmission protocol

ISO 7816-3 begins to delve into the specification of the "intelligent" aspects of the smartcard. This standard describes the relationship between the smartcard and the reader as one of "slave" (the smartcard) and "master" (the reader). Communications are established by the reader signaling to the smartcard through the contacts noted previously and are continued by the smartcard responding accordingly.

Communication between the card and reader proceed according to various state transitions illustrated in *Figure 4.*

Figure 4. Reader and card FSM



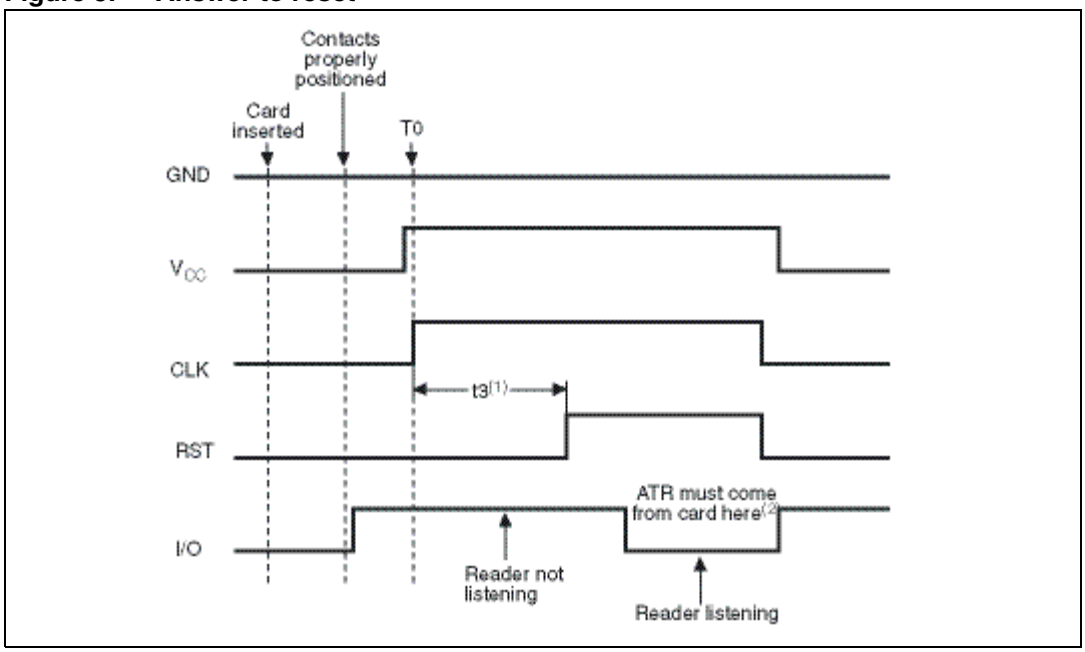
The communication channel is single-threaded; once the reader sends a command to the smartcard, it blocks until a response is received.

4.1 Card power-up and reset

When a card is inserted into a reader, no power is applied to any of the contacts. The chip on the card could be seriously damaged by applying power to the wrong contacts, and this situation could easily occur if a card were inserted across powered contact points. The contacts remain unpowered until an edge detector determines that the card is properly aligned with the contact points to within some acceptable (for the reader) mechanical tolerance.

When the reader detects that the card is properly inserted, power is applied to the card. First, the contacts are brought to a coherent idle state, as shown in *Table 3*. A reset signal is then sent to the card via the RST contact line. The idle state occurs when the power (V_{CC}) contact is brought up to a normal, stable operating voltage of 5 V. An initial power setting of 5 V is always applied first, even though some microprocessor chips being introduced operate at 3 V when in an I/O state. The I/O contact is set to a reception mode on the reader side and a stable clock (CLK) is applied. The reset line is in a low state. It must remain in a low state for at least 40 000 CLK cycles before a valid reset sequence can be started by the reader, raising the reset line to a high state.

Figure 5. Answer to reset



1. t3 = 40 000 clock cycles.
2. ATR must be issued by card between 400 clock cycles and 40 000 clock cycles after RST goes high.

4.2 Data transfer

Data transfer between the reader and the card occurs through the concerted action of two of the contact lines: CLK and I/O. The I/O line conveys a single bit of information per unit of time as defined by the CLK depending on its voltage relative to GND. A 1 bit can be conveyed either through a +5 V value or through a 0 V value. The actual convention used is determined by the card and is conveyed to the reader through the "initial character" of the ATR, which is referenced as TS. To transfer 1 byte of information, 10 bits are actually moved across the I/O line; the first is always a "start bit" and the last is always a parity bit used to convey even parity. Considering that the I/O line can be (in one bit period) either in a high (H) state or a low (L) state, the TS character of the form HLHHLLLLLLH signals that the card wants to use the "inverse convention," meaning that H corresponds to a 0 and L corresponds to a 1. A TS character of the form HLHHLHHHLLH signals that the card wants to use the "direct convention," meaning that H corresponds to a 1 and L corresponds to a 0.

The direct convention and the inverse convention also control the bit ordering with each byte transferred between the card and the reader. In the direct convention, the first bit following the start bit is the low-order bit of the byte. Successively higher-order bits follow in sequence. In the inverse convention, the first bit following the start bit is the high-order bit of the byte. Successively lower-order bits follow in sequence. Parity for each byte transferred should be even; this means that the total number of 1 bits in the byte, including the parity bit, must be an even number.

The I/O line comprises a half-duplex channel; that is, either the card or the reader can transmit data over the same channel, but they both cannot be transmitting at the same time. So as part of the power-up sequence, both the reader and the card enter a receive state in which they are listening to the I/O line. With the start of the reset operation, the reader remains in the receive state while the card must enter a send state in order to send the ATR back to the reader. From this point on, the two ends of the channel alternate between send states and receive states. With a half-duplex channel, there is no reliable way for either end to asynchronously change a state from send to receive or from receive to send. Rather, if this is desired, that end must go into a receive state and allow a timeout of the operation in progress; then a reader end will always try to re-establish a known sequence by re-entering a send state. The CLK and I/O lines can support a wide variety of data transmission speeds. The specific speed is defined by the card and is conveyed back to the reader through an optional character in the ATR. The transmission speed is set through the establishment of one bit time on the I/O line, which means that an interval is established at which the I/O line may be sampled in order to read a bit and then each successive bit. This time is defined as an elementary time unit (ETU) and is established through a linear relationship between several factors. Note that the TS character is returned before any definition of the ETU can be made. This is possible because the ETU during the ATR sequence is always specified to be ETU0=372/(CLK frequency) where the CLK frequency is always between 1 MHz and 5 MHz; in fact, the frequency is almost always selected such that the initial data transfer rate is 9,600 bits per second.

This initial etu is used during answer to reset and is replaced by the work etu during subsequent transmission. F is the clock rate conversion factor and D is the bit rate adjustment factor used to determine the work etu in subsequent transmissions.

For internal clock cards:

initial etu = 1/9600 s

work etu = (1/D)*(1/9600) s

For external clock cards:

initial etu = 372/fi s

work etu = (1/D)*(F/fs) s

The minimum value of fs must be 1 MHz.

The maximum value of fs is given in *Table 4*.

I and P define the active state on VPP.

- Maximum programming current: Ipp = 1 mA
- Programming voltage : Vpp = P.V

N is an extra guardtime requested by the card. Before receiving the next character, the card requires a delay of at least (12+N) etu from the leading edge of the previous character. No extra guardtime is used to send characters from the card to the interface device.

The default values of these parameters are:

F = 372; D = 1; I = 50; P = 5; N = 0

Integer values represent the number of global interface bytes

The global interface bytes, TA1, TB1, TC1, TB2 contain integer values FI,DI, II, PI1, N and PI2 which either directly contain or are used to compute the values of the parameters F, D, I, P, N presented above.

TA1 codes FI over the most significant half byte (b8 to b5) and DI over the least significant half byte (b4 to b1).

TB1 codes II over bits b7 and b6, and PI1 over the 5 least significant bits b5 to b1. The most significant bit b8 has a value of 0.

Note: The interface device may ignore bit b8 of TB1.

TC1 codes N over the eight bits (b8 to b1).

TB2 codes PI2 over the eight bits (b8 to b1).

Table 4. Clock rate conversion factor F

Parameter	Values															
FI	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
F	Internal clk	372	558	774	1116	1488	1860	RFU	RFU	512	768	1024	1536	2048	RFU	RFU
Freq max	-	5	6	8	12	16	20	-	-	5	7.5	10	15	20	-	-

RFU : Reserved for Future Use

Table 5. Bit rate adjustment factor D

Parameter	Values															
DI	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
D	RFU	1	2	4	8	16	RFU	RFU	RFU	RFU	1/2	1/4	1/8	1/16	1/32	RFU

RFU : Reserved for Future Use

Programming voltage factor P

PI1 from 5 to 25 gives the value of P in volts. PI1=0 indicates that VPP is connected in the card which generates an internal programming voltage from VCC. Other values of PI1 are reserved for future use.

When PI2 is present, the indication of PI1 should be ignored. PI2 from 50 to 250 gives the value of P in 0.1 V units. Other values of PI2 are reserved for future use.

Table 6. Maximum programming current factor I

Parameter	Values			
II	00	01	10	11
I	25	50	100	RFU

RFU : Reserved for Future Use

Extra guardtime N

N codes the extra guard time directly, from 0 to 254 etu. N=255 indicates that the minimum delay between the start edges of two consecutive characters is reduced to 11 etu.

4.3 Answer to reset (ATR)

Once an RST signal is sent from the reader to the card, the card must respond with the first character of the ATR within 40 000 CLK cycles. The card might not respond with an ATR for a number of reasons, the most prevalent being that the card is inserted incorrectly into the reader (probably upside down). In some instances, the card may not be functioning because it has been damaged or broken. Whatever the case, if the ATR is not returned within the prescribed time, the reader should begin a sequence to power down the card. During this sequence, the reader sets the RST, CLK, and I/O lines low and drops voltage on the V_{CC} line to nominal 0 (that is, less than 0.4 V).

The ATR is a string of characters returned from the card to the reader following the successful completion of the power-up sequence. As defined in ISO/IEC 7816-3, the ATR consists of 33 or fewer characters comprising the following elements:

- TS - a mandatory initial character
- T0 - a mandatory format character
- TAi TBi TCi TDi - optional interface characters
- T1, T2,TK - optional historical characters
- TCK - a conditional check character

The historical characters can be defined at the discretion of the card manufacturer or the card issuer. These characters are typically used to convey some type of designation of the type, model, and use of this specific card. When used in this way, the historical characters provide a mechanism through which systems can automatically detect the use of an inserted card (within that system) and can initiate other actions (or software) accordingly. The check character provides a mechanism through which the integrity of the ATR can be measured; that is, whether a transmission error has occurred in sending the characters from the card to the reader.

The structure of the ATR is illustrated in *Table 7*. As discussed previously, the initial TS character is used to establish the bit-signaling and bit-ordering conventions between the reader and the card. The T0 character is used to signal the presence or absence of subsequent interface characters or historical characters. The interface characters are used to tailor the characteristics of the I/O channel, including the specific protocol used by the card and reader during subsequent exchange of commands (from the reader to the card) and responses (from the card to the reader). The historical characters, if present, are used to convey card-manufacturer-specific information from the card to the read, and hence to the application system being served by the reader. There is really no established standard for the information presented in the historical bits.

The total length of the ATR sequence is limited to 33 bytes and must adhere to the following format:

Table 7. Answer-to-reset structure

	Character ID	Definition
Initial character section	TS	Mandatory initial character
Format character section	T0	Indicator for presence of interface characters
Interface character section	TA1	Global, codes F1 and D1
	TB1	Global, codes 11 and PI1
	TC1	Global, code N
	TD1	Codes Y2 and T
	TA2	Specific
	TB2	Global, code PI2
	TC2	Specific
	TD2	Codes Y3 and T
	TA3	TAi, TBi and TCi are specific
	..TDi	Codes Yi+1 and T
	T1	Card specific information
Historical character section	...TKi	(Maximum of 15 characters)
Check character section	TCK	Optional check character

5 ISO 7816-4 – smartcard commands

The previous chapter discussed the answer-to-reset (ATR) mechanism, which establishes a basic communication channel between the smartcard and the reader. This channel is a half-duplex physical channel. This chapter investigates the use of more complex protocols on top of this physical channel.

A link-level communication protocol resides directly on top of the physical channel, providing error-free communication between the reader and the smartcard. Once this link-level protocol is established, application-level protocols can be defined. ISO 7816-4 defines two such application-level protocols:

- File system API providing a set of functions to manipulate files (for example read, write, select, etc.).
- Security service API allowing the smartcard and the reader to mutually authenticate themselves and also to encrypt data to be exchanged between the card and the reader.

ISO 7816-4 defines a protocol message structure to support the application protocol APIs. This message structure consists of application protocol data units (APDUs) which are exchanged between the reader application and the smartcard application by the link-level protocol. This chapter will provide an overview of the file access and security APIs.

5.1 T0 protocol

The T0 protocol is a byte-oriented protocol where a character is transmitted across the channel between the reader and the card. In addition, error handling is performed on each byte by looking at the parity bit. If the actual parity bit does not correspond to the parity of the transmitted data, then an error must have occurred. In the T0 protocol, the receiving side signals that it requires the byte to be retransmitted in the case of detecting a parity error. This is done by holding the I/O line low (normally the I/O line is set high preceding the transfer of a byte). When the transmitting side detects this, it resends the byte that was not received correctly.

The reader and the smartcard exchange data structures known as transmission protocol data units (TPDUs). It consists of two distinct structures:

- a command that is sent from the reader to the card
- a response that is sent from the card to the reader

The command header includes the following five fields each of one byte in length:

- CLA: class designation of the command set to establish a collection of instructions
- INS: specifies a specific instruction from within the set of instructions
- P1: used to specify the addressing used by the [CLA, INS] instruction
- P2: also used to specify the addressing used by the [CLA, INS] instruction
- P3: specifies the number of data bytes transferred to or from the card as part of the [CLA, INS] instruction execution.

Each value of CLA defines an application-specific set of instructions. *Table 8.* below lists values for some sets of instructions.

Table 8. CLA instruction set definitions

CLA byte	Instruction set
0x	ISO 7816-4 instructions (files and security)
10 to 7F	Reserved for future use
8x or 9x	ISO 7816-4 instructions
Ax	Application/vendor specific instructions
B0 to CF	ISO 7816-4 instructions
D0 to FE	Application/vendor specific instructions
FF	Reserved for protocol type selection

The INS byte is used to identify a specific instruction within a class of instructions identified by the value of CLA. *Table 9.* lists the instructions in the ISO 7816-4 standard used to access file system and security functions.

Table 9. ISO 7816-4 INS codes

INS value	Command name	INS value	Command name
0E	Erase Binary	C0	Get Response
20	Verify	C2	Envelope
70	Manage Channel	CA	Get Data
82	External Authenticate	D0	Write Binary
84	Get Challenge	D2	Write Record
88	Internal Authenticate	D6	Update Binary
A4	Select File	DA	Put Data
B0	Read Binary	DC	Update Record
B2	Read Record(s)	E2	Append Record

The parameters P1 and P2 are defined at the link level but are actually dependent on the specific instruction (application level). They provide control or addressing parameters for the various application-specific instructions. For example, in the Select File instruction, P1 is used to indicate how the file will be referred to (by identifier, name, path etc.) and P2 offers further refinement as to which file is to be selected. P3 defines the number of bytes to be transmitted during the execution of the INS specified instruction. The convention used to indicate movement of data is card-centric that is, outgoing refers to data moving from the card to the reader and incoming refers to data moving from the reader to the card.

For each command TDPU sent from the reader, a response TPDU is sent by the card. The response includes three mandatory fields and one optional field (all one byte in length):

- ACK: indicates that the card has received the [CLA, INS] command
- NULL: used for flow control on the I/O channel by the card. It signals (to the reader) that the card is still processing the command and so the reader must wait before sending another command
- SW1: status response of the current command
- SW2: (optional) also conveys a status response to the reader

The ACK byte is a repeat of the INS byte from the command TPDU. If the response does not reach the reader within a specified time, the reader may initiate an RST sequence to restart the protocol between the reader and the card. This can be prevented if the reader receives at least one NULL byte from the card. SW1 informs the reader of the result of the requested instruction. The values allowed for SW1 are defined as part of the application protocol. Some instructions require the card to send data to the reader. In this case SW2 is returned to the reader, triggering the reader to execute a GetResponse command. The card will then return the data bytes generated by the execution of the previous command.

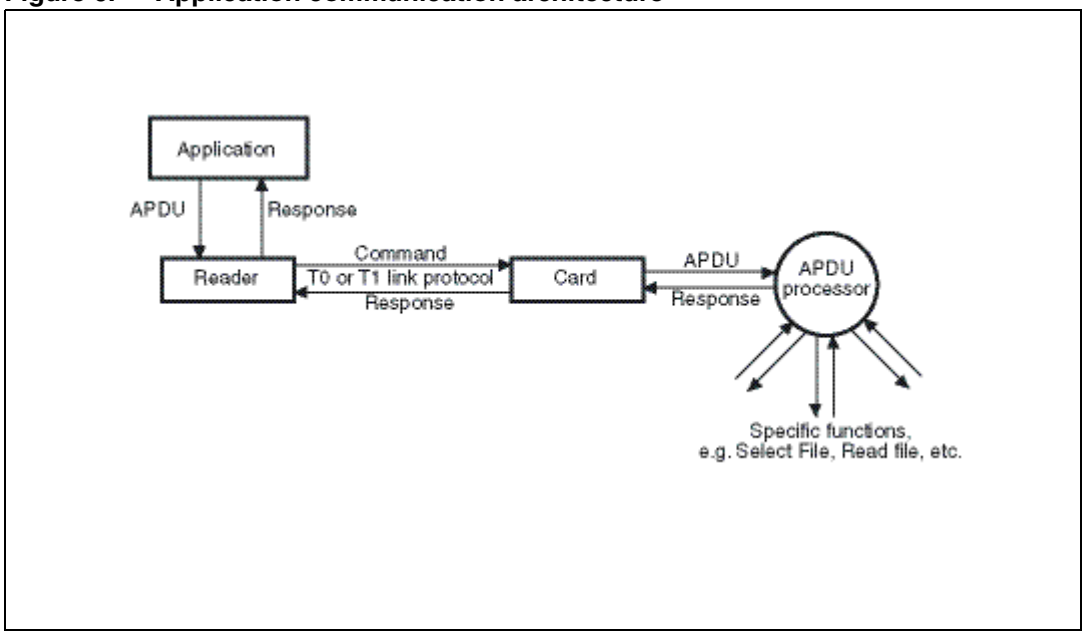
5.2 Application-level protocols

The ISO 7816-4 standard addresses two areas of functionality for application software:

- File system: a set of functions is provided in the form of an API. By using this API application software on the reader side can access files in the file system.
- Security functions: these can be used to limit access to application software or to files on the card.

The T0 protocol is used to support application-level protocols between the smartcard application and the reader application. These application protocols exchange data structures called application protocol data units (APDUs). The following diagram illustrates this architecture:

Figure 6. Application communication architecture

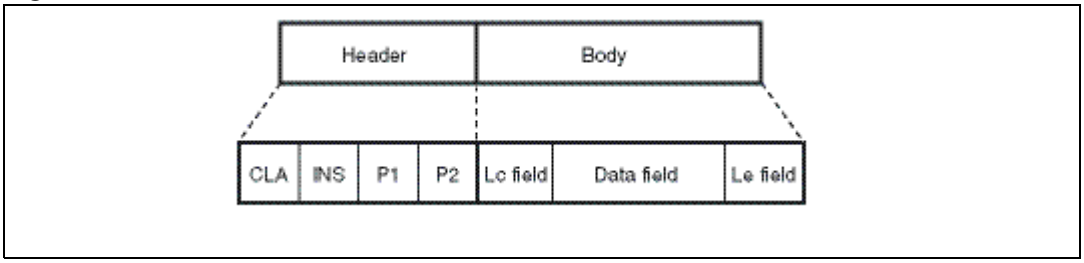


The APDU structure defined by ISO 7816-4 is very similar to the TPDU structure used in the T0 protocol. In fact, when an APDU is transported by the T0 protocol, the elements of the APDU directly overlay the elements of the TPDU.

5.2.1 The ISO 7816-4 APDU

There are two types of messages used to support the ISO 7816-4 application protocols: the command APDU (sent from the reader to the card) and the response APDU (sent from the card to the reader).

Figure 7. Command APDU structure

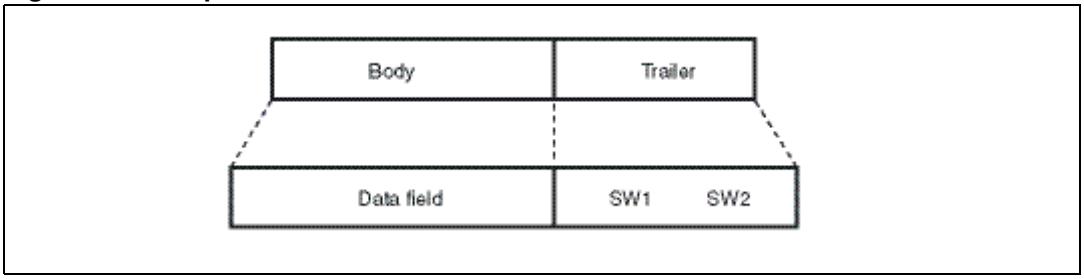


The command APDU consists of a header and a body (this can be seen in the diagram above). The header includes CLA, INS, P1 and P2 fields. As in the T0 protocol, CLA and INS specify an application class and instruction. P1 and P2 are used to qualify specific instructions and are given specific definitions by each [CLA, INS] instruction. The body of the APDU can vary in size and is used to transmit data to the card's APDU processor as part of a command or to convey a response from the card to the reader. The Lc field specifies the number of bytes to be transmitted to the card as part of the instruction, that is, the length of the data field. The data field contains information that must be sent to the card to allow its APDU processor to execute the command specified in the APDU. The Le field specifies the number of bytes that will be returned to the reader in the response APDU.

The body of the APDU can take on four different forms:

- Case 1: No data is transferred to or from the card, so the APDU only contains the header.
- Case 2: No data is transferred to the card, but data is returned from the card. The body of the APDU only contains a non-null Le field.
- Case 3: Data is transferred to the card, but none is returned from it. The body of the APDU includes the Lc and data fields.
- Case 4: Data is transferred to the card and is also returned from the card as a result of the command. The body of the APDU includes the Lc, data and Le fields.

Figure 8. Response APDU structure



The response APDU has a much simpler structure than that of the command APDU. It consists of a body and a trailer. The body is either null or it includes a data field - depending on the specific command. The length of the data field is determined by the Le field in the corresponding command APDU. The trailer consists of up to two fields of status information called SW1 and SW2. These fields return a status code in which one byte is used to specify

an error category and the other is used to specify a command-specific status or error indication.

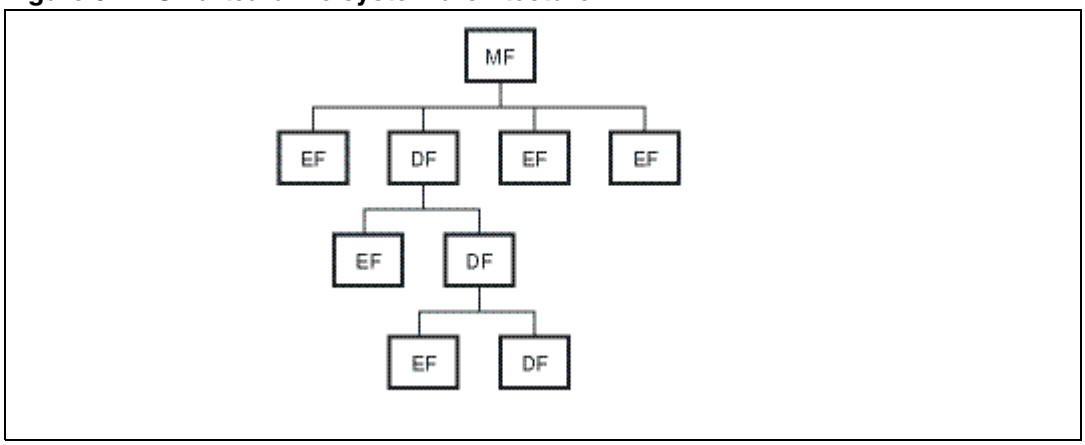
5.2.2 File system API

The file system is used on the non-volatile memory or EEPROM. It is defined as a simple hierarchical structure (similar to conventional file systems). The file system may contain three types of files (identified by a 2-byte identifier):

- Master file (MF)
- Dedicated file (DF)
- Elementary file (EF)

There is one master file found on each smartcard and it is the root of the file system. A master file may contain dedicated files or elementary files. The file identifier reserved for the master file is 3F00. The directory file is essentially a container (or directory) for elementary files - a DF may contain zero or more EFs. Dedicated files partition the smartcard into an ordered structure of elementary files. A dedicated file must be given a unique file identifier within the dedicated file or master file that contains it - allowing for a unique path for each file. A dedicated file can also be referenced by name (1-16 bytes long). The naming convention can be found in ISO 7816-5. An elementary file is a leaf node in the hierarchy and contains the actual data. An elementary file can be identified by a 5-bit identifier within a dedicated file. This file system hierarchy is illustrated in *Figure 9.*

Figure 9. Smartcard file system architecture(1)



1. MF = master file, DF = dedicated file, EF = elementary file.

There are four types of elementary files:

- Transparent file
- Linear, fixed-length record file
- Linear, variable-length record file
- Cyclic, fixed-length record file

A transparent file is essentially a string of bytes, that is an unstructured binary file. Consequently a byte offset from the start of the file is required when data is to be read or written to this type of file. In addition, a command to read or write to a transparent file will contain the length of the byte string to be read or written to the file.

Fixed- and variable-length files contain records that are identified by a sequence number. In a fixed-length record file, all the records contain the same number of bytes. In contrast, a

variable-length record file contains records that may vary in length. As a result, variable-length record files have a higher overhead in read/write access times as well as a higher administrative overhead required by the file system.

A cyclic file allows applications to access records in a consistent and transparent manner. It can be thought of as a ring of files. Write operations are performed on the next physical record in the ring.

5.2.3 ISO 7816-4 functions

The few functions that are defined in ISO 7816-4 for selecting, reading and writing to files will be briefly discussed below.

Select File

This command establishes a logical pointer to a particular file in the smartcard's file system. This pointer is required for any file manipulation operation. Access to the smartcard's file system is not multithreaded, however it is possible to have several file pointers defined at any point in time. This is accomplished by the Manage Channel command, which establishes multiple logical channels between the reader side application and the card. This allows different files on the card to be in various states of access by the reader application at the same time. The identification of the file can be provided in the following ways:

- file identifier (2-byte value)
- DF name (string of bytes)
- path (concatenation of file identifiers)
- short ID

Note that not all smartcards support all four naming mechanisms.

Read Binary

This command is used by the application on the reader side to retrieve a part of an EF on the card. However, the EF must be a transparent file (not record-oriented). If the Read Binary command is attempted on a record-oriented EF, the command will abort with an error indicator being returned from the card.

The Read Binary command takes two parameters: an offset pointer from the start of the file to the initial byte to be read, and the number of bytes to be read and returned to the reader.

Write Binary

This command is used to insert data into a transparent EF on the card. This command can be used to set a series of bytes in the EF (that is set selected bits within a specified byte to a value of1), clear a series of bytes or perform a write of a series of bytes in the EF.

Update Binary

A reader-side application can utilize this command to directly erase and store a contiguous sequence of bytes in a transparent EF on the card. It effectively functions as a write command that is a string of bytes provided in the command are written into the EF on the card. The input parameters consist of an offset pointer from the start of the file as well as the number of bytes to be written.

Erase Binary

The Erase Binary command is used to clear bytes within a transparent EF on a card. Similarly to the previous commands, the input parameters comprise an offset from the start of the EF to the segment of bytes to be erased as well as the number of bytes to be erased.

Read Record

This command is used to read and return the contents of one or more records in an EF on a card. Unlike the previous command, the EF for the Read Record command must be a record-oriented file. If it is applied to a transparent EF, the command will abort and an error will be returned to the reader.

The following may be returned from this command, depending on the input parameters:

- A specified record
- All the records from the beginning of the file to a specific record
- All the records from a specific record to the end of the file

Write Record

This command is used to write a record into a record-oriented EF. As with the Write Binary command, this command can be used to write a record into an EF, set or clear specific bits within a specific record in an EF.

Append Record

The Append Record command is used to add a record to the end of a linear, record-oriented EF or to write the first record to a cyclic, record-oriented EF on a card.

Update Record

This command writes a specific record into a record-oriented EF on a card. As with the Update Binary command, the old record is erased and the new one is written into the EF.

Get Data

This command reads and returns the contents of a data object stored within the file system on the card. The Get Data command is card-specific as the definition of a data object varies between different cards.

Put Data

This command (as the name suggests) puts information into a data object on the card. As with the previous command, this is a card-specific command.

5.2.4 Security API

Each component of the file system on a smartcard has an associated list of access properties. The access properties ensure that only authorized parties are allowed to access the particular component of the file system. The authentication can be simple, such as requiring the reader to provide a predefined personal identification number (PIN). Alternatively, it may be more complicated, such as requiring the reader to prove that it possesses some shared secret with the card (for example a key) by encrypting or decrypting a string of bytes provided by the card.

A few of the functions provided by the security API are briefly discussed below.

Verify

This command is sent by the application on the reader side to the security system on the card. Its purpose is to convince the card that the reader knows a password maintained by the card in order to restrict access to sensitive information stored on the card. The password-type information may be associated with a specific file or to some or all of the file hierarchy. If the Verify command fails i.e. the reader provides an incorrect password, an error is returned to the reader.

Internal Authenticate

This command allows the card to authenticate itself to the reader by proving that it possesses a secret key shared with the reader. The reader application software first generates a random number and encrypts it with some algorithm known to both card and reader. This constitutes a challenge to the card. The card then decrypts this challenge with the secret key (that is stored on the card) and sends the resulting data back to the reader. If the data received by the reader matches the random number that it generated then the reader application software is assured of the identity of the card.

External Authenticate

This command is used in conjunction with the Get Challenge command to enable the reader application software to authenticate itself to the card. The reader receives challenge data (a random number) from the card and encrypts it with a secret key. This is then sent to the card using the External Authenticate command. The card decrypts the data and compares it to the random number that it generated in the previous Get Challenge command. If there is a match, then the card is assured of the identity of the reader application.

Get Challenge

This command is sent by the reader to the card. Its purpose is to provide the reader application with a random number generated by the smartcard. As previously described, this number is used in the External Authenticate command.

Manage Channel

The Manage Channel command is used by the reader application to open and close the logical communication channels between it and the card. Initially the card opens a basic communication channel by establishing an application-level protocol with the reader application through the completion of an ATR sequence. This channel is then used to open or close additional logical channels through the Manage Channel command.

Envelope

This command supports the use of secure messaging using the T0 protocol. It enables an APDU to be encrypted and then incorporated into the Envelope command's data section (of its APDU). The APDU processor on the card can then extract and execute the command.

Get Response

As with the previous command, the Get Response command allows the use of the T0 protocol for transferring APDUs. The Case 4 type of APDU cannot be supported by the T0 protocol i.e. it is not possible to send a block of data to the card and then receive a block of data in return. So when using the T0 protocol, the initial command results in a response which indicates that more data is waiting to be sent by the card. The Get Response command is then used to retrieve this data.

6 Smartcard interface library: description

The user may access a smartcard using directly the application layer. It allows to send/receive ADPU commands to/from the smartcard using the following user interface:

6.1 File organization

Table 10 presents the smartcard library modules:

Table 10. File library description

File	Description
smartcard.h, smartcard.c	– Smartcard definitions, types definitions and function prototypes – T0 protocol management – Physical layer

6.2 Smartcard interface library functions

Table 13 lists the various functions of the smartcard library.

Table 11. Smartcard library functions

Function name	Description
SC_Handler	Handles all smartcard states and serves to send and receive all communication data between smartcard and reader.
SC_PowerCmd	Enables or disables the power to the smartcard.
SC_Reset	Sets or clears the smartcard reset pin.
SC_ParityErrorHandler	Resends the byte that failed to be received (by the smartcard) correctly.
SC_PTSConfig	Configures the IO speed (BaudRate) communication.

6.2.1 SC_Handler function

Function name	SC_Handler
Function prototype	`void SC_Handler(SC_State *SCState, SC_ADPU_Commands *SC_ADPU, SC_ADPU_Responce *SC_Response)`
Behavior description	Handles all smartcard states and serves to send and receive all communication data between smartcard and reader.
Input parameter1	SCState: pointer to an SC_State enumeration that will contain the smartcard state.
Input parameter2	SC_ADPU: pointer to an SC_ADPU_Commands structure that will be initialized.
Input parameter3	SC_Response: pointer to a SC_ADPU_Responce structure which will be initialized.
Output parameter	None
Return parameter	None
Required preconditions	None
Called functions	None

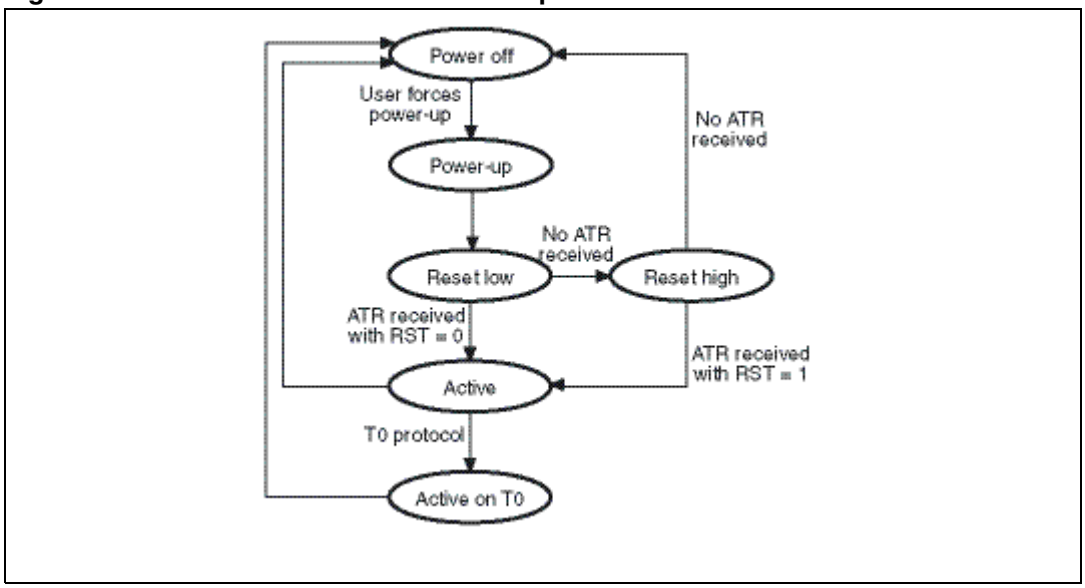
SCState

SCState informs the user about the smartcard state and allows the user to power off the smartcard. It can take one of the values defined in *Table 12* below.

Table 12. SCState

SCState	Meaning
SC_POWER_OFF	No power is provided to the smartcard (V_{CC} = 0); the STM8S20x smartcard interface is disabled. No clock is provided to the smartcard.
SC_POWER_ON	The smartcard peripheral is enabled and initialized; no power is provided to the smartcard; no clock is provided to the smartcard.
SC_RESET_LOW	In this state, the RST smartcard pin (pin 2) is driven low (RST = 0). V_{CC} = 5 V is provided to the smartcard; clock CLK is provided to the smartcard. Answer to reset (ATR) procedure begins. The reader waits for an ATR frame from the smartcard.
SC_RESET_HIGH	If no answer is received, the reader forces the reset pin RST high (RST = 1) and holds it high until it receives an answer to reset.
SC_ACTIVE	If an answer to reset is received, the reader goes in active state and decodes the ATR frame. It returns information about the used protocol.
SC_ACTIVE_ON_T0	If the used protocol is T0, the reader goes in SC_ACTIVE_ON_T0 state and commands can then be sent to the smartcard.

Figure 10. State machine for smartcard operation



SC_ADPU_Commands

The SC_APDU_Commands structure is defined in the *smartcard.h* file:

```
typedef struct
{
  SC_Header Header;
  SC_Body Body;
} SC_ADPU_Commands;
```

- **Header**

  Specifies the APDU command header. It is of the SC_Header type, which is defined in the *smartcard.h* file:

```
typedef struct
{
  u8 CLA;  /* Command class */
  u8 INS;  /* Operation code */
  u8 P1;   /* Selection Mode */
  u8 P2;   /* Selection Option */
} SC_Header;
```

- **CLA**

  Specifies the class designation of the command set to establish a collection of instructions.

- **INS**

  Specifies a specific instruction from within the set of instructions.

- **P1**

  Specifies the addressing used by the [CLA, INS] instruction.

- **P2**

  Specifies the addressing used by the [CLA, INS] instruction.

- **Body**

  Specifies the APDU command body. It is of the SC_Body type, which is defined in the *smartcard.h* file:

```
typedef struct
{
  u8 LC;           /* Data field length */
  u8 Data[LCmax];  /* Command parameters */
  u8 LE;           /* Expected length of data to be returned */
} SC_Body;
```

- **LC**

  Specifies the number of data bytes transferred to the card as part of the [CLA, INS] instruction execution.

- **Data**

  Specifies the pointer to the data buffer transferred to the card.

- **LE**

  Specifies the number of data bytes transferred from the card as part of the [CLA, INS] instruction execution.

- **SC_Response**

  Specifies the APDU command response. It is of SC_ADPU_Response type, defined in the *smartcard.h* file:

```
typedef struct
{
  u8 Data[LCmax];  /* Data returned from the card */
  u8 SW1;          /* Command Processing status */
  u8 SW2;          /* Command Processing qualification */
} SC_ADPU_Responce;
```

- **Data**

  Specifies the pointer to the data buffer which will contain the returned card data.

- **SW1**

  Specifies the first status code byte. This byte stores the error category.

- **SW2**

  Specifies the second status code byte. This byte stores a command-specific status or error indication.

Example:

```
/* Select the Master Root MF */
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_SELECT_FILE;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x02;

for(i = 0; i < SC_ADPU.Body.LC; i++)
{
SC_ADPU.Body.Data[i] = MasterRoot[i];
}
while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = 0;
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

6.2.2 SC_PowerCmd

Function name	SC_PowerCmd
Function prototype	`void SC_PowerCmd(FunctionalState NewState);`
Behavior description	Enables or disables the power to the smartcard.
Input parameter	NewState: new state of the smartcard power supply. This parameter can be: ENABLE or DISABLE.
Output parameter	None
Return parameter	None
Required preconditions	None
Called functions	None

Example:

```
/* Power ON the card */
  SC_PowerCmd(ENABLE);
```

6.2.3 SC_Reset

Function name	SC_Reset
Function prototype	`void SC_Reset(BitAction ResetState);`
Behavior description	Sets or clears the smartcard reset pin.
Input parameter	ResetState: this parameter specifies the state of the smartcard reset pin. BitVal must be one of the BitAction enum values: Bit_RESET: to clear the port pin. Bit_SET: to set the port pin.
Output parameter	None
Return parameter	None
Required preconditions	None
Called functions	None

Example:

```
/* Set the smartcard reset pin */
  SC_Reset(Bit_SET);
```

6.2.4 SC_ParityErrorHandler

Function name	SC_ParityErrorHandler
Function prototype	`void SC_ParityErrorHandler(void);`
Behavior description	Resends the byte that failed to be received correctly (by the smartcard)
Input parameter	None
Output parameter	None
Return parameter	None
Required preconditions	None
Called functions	None

Example:

```
/* Resend the byte to the smartcard */
SC_ParityErrorHandler();
```

6.2.5 SC_PTSConfig

Function name	SC_PTSConfig
Function prototype	`void SC_PTSConfig(void);`
Behavior description	Configures the IO speed (BaudRate) communication.
Input parameter	None
Output parameter	None
Return parameter	None
Required preconditions	Must be called just after the ATR sequence.
Called functions	None

Example:

```
/* Configures the baudrate according to the card TA1 value */
SC_PTSConfig();
```

6.3 How to send APDU commands to the smartcard

A detailed description on how to use the `SC_Handler( )` function to send the ADPU command to the smartcard and retrieve the card response is described below. The user has to update the SC_CLA and the smartcard instruction values according to the smartcard specifications.

6.3.1 SC_GET_A2R

```
SC_ADPU.Header.CLA = 0x00;
SC_ADPU.Header.INS = SC_GET_A2R;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x00;

while(SCState != SC_ACTIVE_ON_T0)
{
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
}
```

- **SCState:** It stores the current smartcard state.
- **SC_ATR_Table:** Pointer to an array (filled in by the `SC_Handler` function) that contains the smartcard ATR frame.

6.3.2 SELECT_FILE

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_SELECT_FILE;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x02;
for(i = 0; i < SC_ADPU.Body.LC; i++)
{
SC_ADPU.Body.Data[i] = FileName[i];
}
while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = 0;
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **FileName:** It contains the 16 bit file identifier.
- **SCState:** It stores the current smartcard state.
- **SC_Response->SW1** and **SC_Response->SW2**: they return the smartcard response to the SC_SELECT_FILE command.

6.3.3 SC_GET_RESPONSE

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_GETRESPONSE;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x00;
i = 0;
while(i < LCmax)
{
```

```
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = SC_Responce.SW2;
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **SCState:** It stores the current smartcard state.
- **SC_Response->SW1** and **SC_Response->SW2:** they return the smartcard response to the SC_GET_RESPONSE command.
- **SC_Response->Data:** It returns the smartcard data response to the SC_GET_RESPONSE command.

6.3.4 SC_READ_BINARY

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_READ_BINARY;
SC_ADPU.Header.P1 = OFFSET_MSB;
SC_ADPU.Header.P2 = OFFSET_LSB;
SC_ADPU.Body.LC = 0x00;

while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = LENGTH;

SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **SCState:** It stores the current smartcard state.
- **OFFSET_MSB:** Most significant byte of offset for reading data.
- **OFFSET_LSB:** Least significant byte of offset for reading data.
- **LENGTH:** It contains size (in byte) of the area to read (valid only for the elementary file).
- **SC_Response->Data:** It returns the smartcard data to read.
- **SC_Response->SW1** and **SC_Response->SW2**: they return the smartcard response to the SC_READ_BINARY command.

6.3.5 SC_CREATE_FILE

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_CREATE_FILE;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x10;

for(i = 0; i < SC_ADPU.Body.LC; i++)
{
SC_ADPU.Body.Data[i] = FileParameters[i];
}
while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = 0;
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **FileParameters:** It contains the 16 bytes file parameters (File ID, FILE Access Conditions...).
- **SCState:** It stores the current smartcard state.
- **SC_Response->SW1** and **SC_Response->SW2**: they return the smartcard response to the SC_CREATE_FILE command.

6.3.6 SC_UPDATE_BINARY

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_UPDATE_BINARY;
SC_ADPU.Header.P1 = OFFSET_MSB;
SC_ADPU.Header.P2 = OFFSET_LSB;
SC_ADPU.Body.LC = LENGTH;

while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = 0x00;

SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **SCState:** It stores the current smartcard state.
- **OFFSET_MSB:** Most significant byte of offset for reading data.
- **OFFSET_LSB:** Least significant byte of offset for reading data.
- **LENGTH:** It contains the size (in byte) of the area to write (valid only for the elementary file).
- **SC_Responce->Data:** It contains the smartcard data to write.
- **SC_Responce->SW1** and **SC_Responce->SW2**: they return the smartcard response to the SC_UPDATE_BINARY command.

6.3.7 SC_VERIFY

```
SC_ADPU.Header.CLA = SC_CLA;
SC_ADPU.Header.INS = SC_VERIFY;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x08;

for(i = 0; i < SC_ADPU.Body.LC; i++)
{
SC_ADPU.Body.Data[i] = CHV1[i];
}
while(i < LCmax)
{
SC_ADPU.Body.Data[i++] = 0;
}
SC_ADPU.Body.LE = 0;
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
```

- **CHV1:** It contains the 8-byte CHV1 code.
- **SCState:** It stores the current smartcard state.
- **SC_Responce->SW1** and **SC_Responce->SW2**: they return the smartcard response to the SC_VERIFY command.

6.4 Parity error management

In the T0 protocol, error handling is performed on each byte by looking at the parity bit. If the actual parity bit does not correspond to the parity of the transmitted data, then an error must have occurred; the receiving side signals that it requires the byte to be retransmitted in the case of detecting a parity error. This is done by holding the I/O line low (normally the I/O line is set high preceding the transfer of a byte). When the transmitting side detects this, it resends the byte that was not received correctly.

6.4.1 Data sent from card to reader

STM8S20x is able to detect a parity error on a received data via hardware, by pulling down the data line during the stop bit.

6.4.2 Data sent from reader to card

The smartcard pulls down the I/O line to signal that a parity error occurred, the STM8S20x is able to detect a frame error via software. The smartcard library uses the `SC_ParityErrorHandler()` function to check whether a parity error has occurred and, to manage the error if any.

After a byte is sent from the microcontroller to the card, the smartcard captures the data sent on the I/O line. If a parity error is detected from the card, the I/O line is pulled down during the stop bits. A frame error event occurs and the SC_ParityErrorHandler() function resends the last data.

7 Smartcard interface example

An example is provided in conjunction with the smartcard library in order to help the user develop its custom application.

The example provides simple operations with an ISO 7816-3/4-compatible GSM11.11 smartcard, such as file system exploration, pin1 enable/disable, read/write operation on files and pin verify on protected files.

This example was developed to run on the STM8/128-EVAL (evaluation board) that provides all needed hardware to interface a smartcard.

7.1 Firmware package description

The STM8S20x smartcard application note firmware package contains both the smartcard library and the example described in this section.

The firmware package contains the following subfolders:

7.1.1 FWLib folder

The **FWlib** folder contains all the subdirectories and files that make up the core of the STM8S20XFWLib (firmware library):

- ***inc*** subfolder contains the firmware library header files
- ***src*** subfolder contains the firmware library source files

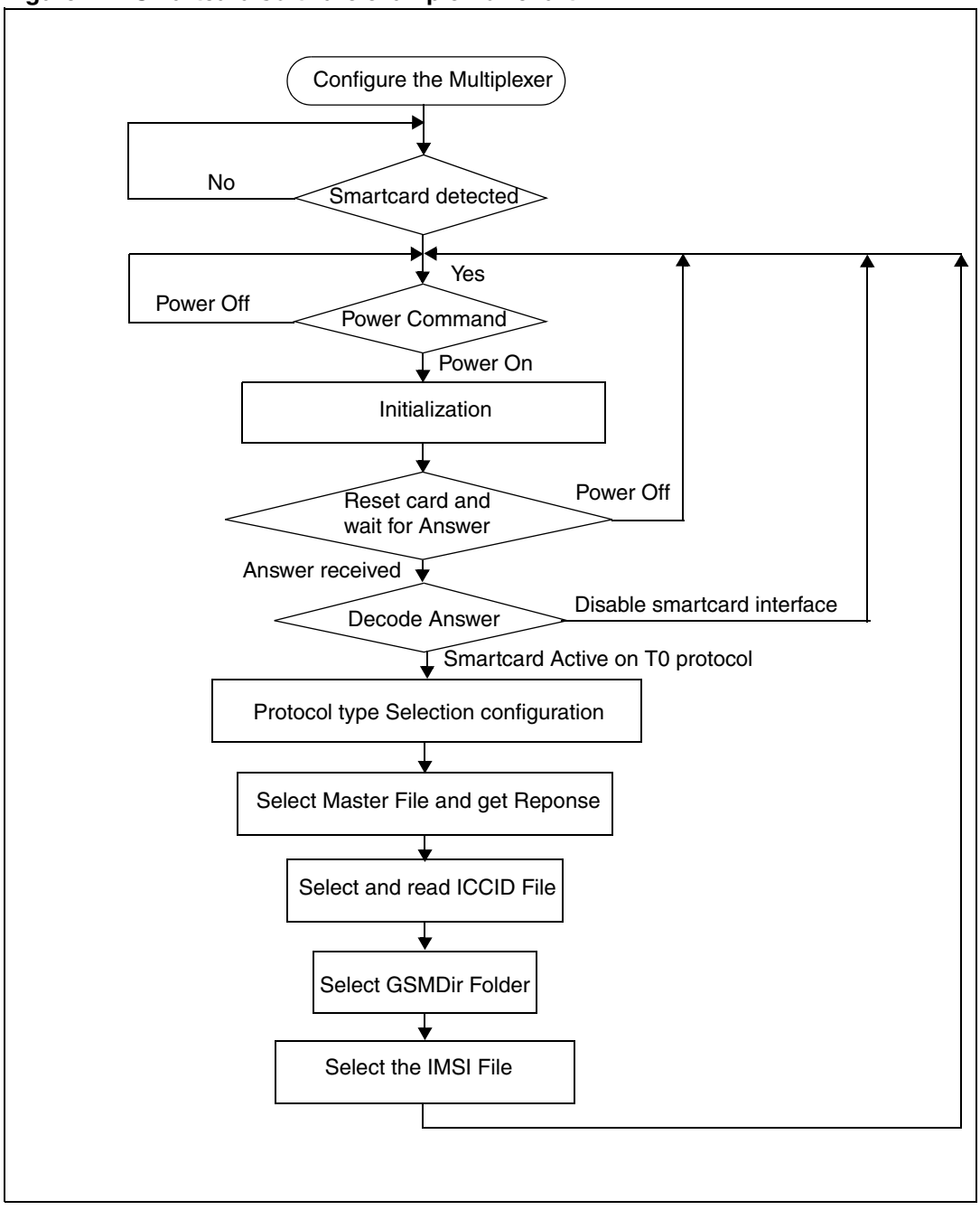
7.1.2 Smartcard_AN folder

The **Smartcard_AN** folder contains all the subdirectories and files that make up the core of the smartcard Interface application example:

- ***include*** subfolder contains the example header files
- ***source*** subfolder contains the example source files
- ***project*** subfolder contains the project that compile the example files:

7.2 Firmware description

Figure 11. Smartcard software example flowchart



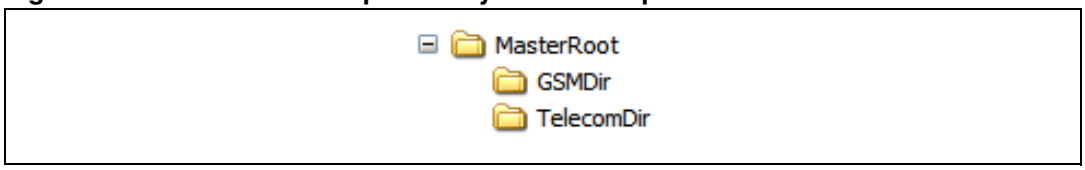
Three directories have been defined for the GSM smartcard directory tree:

MasterRoot[3]={0x3F, 0x00};

GSMDir[3]={0x7F, 0x20};

TelecomDir[3]={0x7F, 0x10};

Figure 12. Smartcard example: file system description



At the end of the example:

- The ICCID file located under the MasterRoot directory is read
- The IMSI file, under GSMDir, that has a secure access through PIN1, is read
- The PIN1 is enabled/disabled

7.2.1 Smartcard startup: answer to reset (A2R)

The first action to perform when the reader wants to access a card is the answer-to-reset procedure. To this aim the SC_Handler is invoked as follows:

```
SC_ADPU.Header.CLA = 0x00;
SC_ADPU.Header.INS = SC_GET_A2R;
SC_ADPU.Header.P1 = 0x00;
SC_ADPU.Header.P2 = 0x00;
SC_ADPU.Body.LC = 0x00;

while(SCState != SC_ACTIVE_ON_T0)
{
SC_Handler(&SCState, &SC_ADPU, &SC_Responce);
}
```

When a card is detected, the A2R sequence is generated, received and decoded. If the recognized protocol is the T0 protocol, the smartcard state of the reader is active (SC_ACTIVE_ON_T0) and the smartcard is available for operations on the file system.

The procedure type selection (PTS) will be applied after the ATR using the *SC_PTSConfig()* function. For the used GSM card, the PTS procedure is as follows:

```
PTSS = 0xFF
PTS0 = 0x10
PTS1 = 0x95
PCK = 0x7A
```

PTS1 = 0x95, F = 9 and D = 5, Fi = 512, Di = 16, BaudRate = 112500 baud.

7.2.2 Reading a file at a specified path

The specified reading path is assumed to be: MasterRoot/GSMDir/IMSI

To reach it, the following actions are performed:

- Select GSMDir using a SelectFile APDU command
- Select IMSI File using a SelectFile APDU command

The user has to get the file characteristics to check its access conditions. The IMSI file has a CHV1(PIN1) read condition, so PIN1 has to be checked before reading it. The verify command must be executed under the directory containing the file to be read, the GSMDir must be selected in the example.

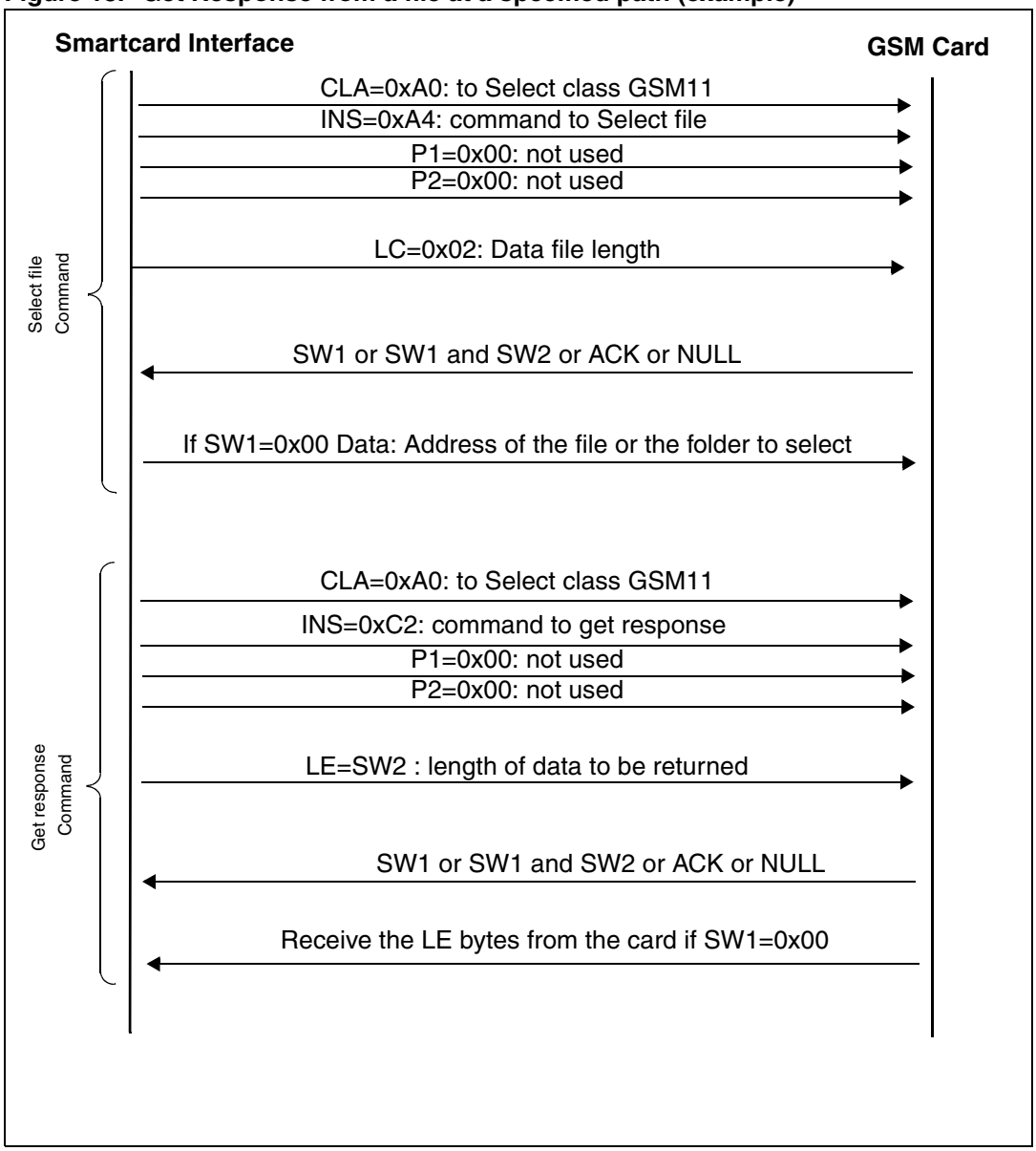
To get file characteristics:

- Select the file the characteristics of which are needed
- Get the data returned after issuing the SelectFile APDU command by sending a GETRESPONSE command

The IMSI file has 9 data bytes, so to run correctly the READ_BINARY commands, the following parameters are used:

- P1 = 0x00
- P2 = 0x00
- LE = 0x09

Figure 13. Get Response from a file at a specified path (example)



7.2.3 Enabling/disabling the PIN1 (CHV1) code

At the beginning of the application, the PIN1 (CHV1) status is checked. This can be done by a GET_RESPONSE command after a successful MasterRoot selection.

In this example, the PIN1 status is checked. If it is enabled, the PIN1 will be disabled to give access to all files that have a secure access conditions.

To check the PIN1 status, the procedure is the following:

- Select the MasterRoot directory using a SelectFile APDU command
- Get the data returned after issuing the MasterRoot SelectFile command by sending a GETRESPONSE command.
- Check the bit8 of the 14 received bytes: if bit8 is 0: PIN1 is enabled else the PIN1 is disabled.

To enable or disable PIN1, the CHV1 code must be sent to the card. The CHV1 code is 8-byte long.

7.2.4 Verifying the PIN1 (CHV1) code

Some files have a restricted access conditions such as IMSI, CHV1 file, CHV2. The access conditions of these files must be met for the user to be allowed to execute the restricted operations (read, update, change CHV1).

To verify the PIN1 (CHV1) condition, the procedure is as follows:

- Go to the directory which contain the file to be accessed
- Use the Verify APDU command by presenting the CHV1 code
- Select the file and execute the selected operation

8 Conclusion

Using the STM8S UART1's smartcard mode that supports the ISO 7816-3/4 specification, you can develop a smartcard-based application with reduced firmware and hardware resources.

9 Revision history

Table 13. Document revision history

Date	Revision	Changes
04-Mar-2008	1	Initial release.
19-Aug-2008	2	Renamed USART to UART1.

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