



Designing a smartcard interface using an STM32F05xx microcontroller

Introduction

This document describes a firmware and hardware smartcard interface solution based on the STM32F05xx USART peripheral. The main purpose of this firmware and hardware package is to provide resources that facilitate the development of an application using the USART peripheral in smartcard mode, supporting both T=0 and T=1 protocols.

The firmware interface consists of library source files developed so as to support the ISO 7816-3/4 specification. An application example based on STMicroelectronics STM320518-EVAL evaluation board (with some additional hardware) is also provided.

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

[Table 1](#) lists the microcontrollers and development tools concerned by this application note.

Table 1. Applicable products and tools

Type	Applicable products
Microcontrollers	STM32F05xx devices
Development tools	STM320518-EVAL board

Glossary

STM32F05xx devices are:

- STM32F050xx microcontrollers where the Flash memory density can go up to 32 Kbytes.
- STM32F051xx microcontrollers where the Flash memory density can go up to 64 Kbytes.

Contents

1	Smartcard interface description	6
1.1	Introduction	6
1.2	External interface	6
1.3	Protocol	7
1.4	Smartcard clock generator	7
2	Smartcard reader hardware connection	8
3	ISO 7816: protocol overview	10
3.1	Introduction	10
3.2	ISO 7816-2 – pin location	10
4	ISO 7816-3 – Electronic signal and transmission protocol	11
4.1	Card power-up and reset	11
4.2	Data transfer	13
4.3	Answer to reset (ATR)	16
5	ISO 7816-4 – Smartcard commands	18
5.1	T0 protocol	18
5.2	T1 protocol	20
5.3	Application-level protocols	22
5.3.1	The ISO 7816-4 APDU	22
5.3.2	File system API	23
5.3.3	ISO 7816-4 functions	24
5.3.4	Security API	26
6	Smartcard (T=0) interface library: description	28
6.1	File organization	28
6.2	Smartcard interface library functions	28
6.2.1	SC_Handler function	28
6.2.2	SC_PowerCmd	32
6.2.3	SC_Reset	32
6.2.4	SC_ParityErrorHandler	33

6.2.5	SC_PTSConfig	33
6.3	How to send APDU commands to the smartcard	33
6.3.1	SC_GET_A2R	34
6.3.2	SELECT_FILE	34
6.3.3	SC_GET_RESPONSE	34
6.3.4	SC_READ_BINARY	35
6.3.5	SC_CREATE_FILE	35
6.3.6	SC_UPDATE_BINARY	36
6.3.7	SC_VERIFY	36
6.4	Parity error management	37
6.4.1	Data sent from card to reader	37
6.4.2	Data sent from reader to card	37
7	Smartcard (T=0) interface example	38
7.1	Firmware description	39
7.1.1	Smartcard startup: answer to reset (A2R)	40
7.1.2	Reading a file at a specified path	40
7.1.3	Enabling/disabling the PIN1 (CHV1) code	42
7.1.4	Verifying the PIN1 (CHV1) code	42
8	Smartcard (T=1) interface library: description	43
8.1	File organization	43
8.2	Smartcard interface library functions	43
8.2.1	T1_Protocol_Init function	44
8.2.2	T1_SetParameter function	44
8.2.3	T1_Negotiate_IFSD function	44
8.2.4	T1_APDU function	45
9	Smartcard (T=1) interface example	46
9.1	Firmware description	46
10	Conclusion	48
11	Revision history	49

List of tables

Table 1.	Applicable products and tools	1
Table 2.	Smartcard pins	6
Table 3.	STM32F05xx and smartcard connection	8
Table 4.	Clock rate conversion factor F	14
Table 5.	Bit rate adjustment factor D	15
Table 6.	Maximum programming current factor I	15
Table 7.	Answer-to-reset structure	17
Table 8.	CLA instruction set definitions	19
Table 9.	ISO 7816-4 INS codes	19
Table 10.	Block frame	20
Table 11.	T0 file library description	28
Table 12.	Smartcard library functions	28
Table 13.	SC_Handler	28
Table 14.	SCState	29
Table 15.	SC_PowerCmd	32
Table 16.	SC_Reset	32
Table 17.	SC_ParityErrorHandler	33
Table 18.	SC_PTSCfg	33
Table 19.	T1 file library description	43
Table 20.	Smartcard T =1 library functions	43
Table 21.	T1_Protocol_Init	44
Table 22.	T1_SetParameter	44
Table 23.	T1_SetParameter	44
Table 24.	T1_APDU	45
Table 25.	Document revision history	49

List of figures

Figure 1.	ISO 7816-3 asynchronous protocol	7
Figure 2.	Smartcard interface hardware connection	9
Figure 3.	Contact definitions for smartcards	10
Figure 4.	Reader and card FSM	11
Figure 5.	Answer to reset.	12
Figure 6.	Character waiting time	21
Figure 7.	Block waiting time	21
Figure 8.	Application communication architecture	22
Figure 9.	Command APDU structure	22
Figure 10.	Response APDU structure	23
Figure 11.	Smartcard file system architecture ⁽¹⁾	24
Figure 12.	State machine for smartcard operation.	30
Figure 13.	Smartcard software example flowchart.	39
Figure 14.	Smartcard example: file system description	40
Figure 15.	Get Response from a file at a specified path (example).	41
Figure 16.	Smartcard software (T1 example) flowchart.	47

1 Smartcard interface description

1.1 Introduction

The smartcard interface is developed using the USART smartcard mode. For the description of the USART registers, please refer to the STM32F05xx reference manual (RM0091). The USART smartcard mode supports asynchronous protocol smartcards as defined in the ISO 7816-3 (Class A) standard. Refer to this standard for more details.

With the smartcard mode enabled, the USART 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 different operating voltages for the card:

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

1.2 External interface

Table 2. Smartcard pins

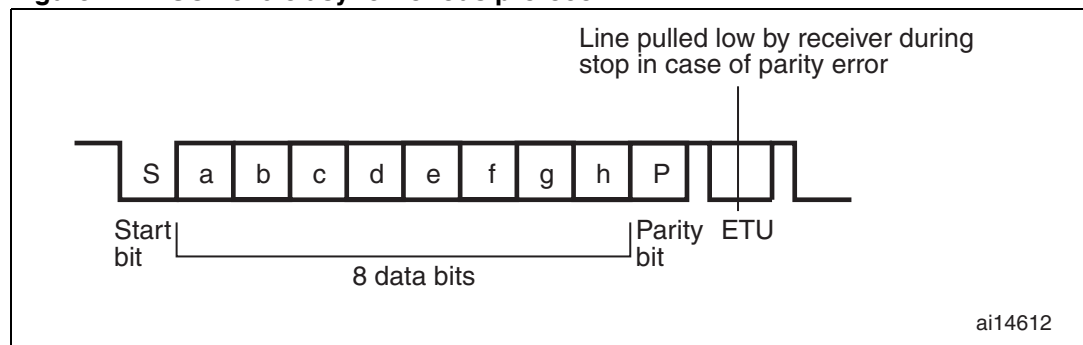
STM32F05xx pin	Smartcard pin	Function
USART CK	CLK	Smartcard clock
USART_TX	IO	IO serial data: open drain
Any GPIO	RST	Reset to card
Any GPIO	V _{CC}	Supply voltage
Any GPIO	V _{PP}	Programming voltage

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 the alternate function open-drain mode, connects the USART_TX data signal to the Smartcard_IO pin with the correct driver type. It also connects the clock generator to the Smartcard_CLK pin, configured in alternate function 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 USART transmitter output and receiver input are internally connected through the Rx_SW line. For the transmission of data from the STM32F05xx to the smartcard, the USART 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 USART. 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

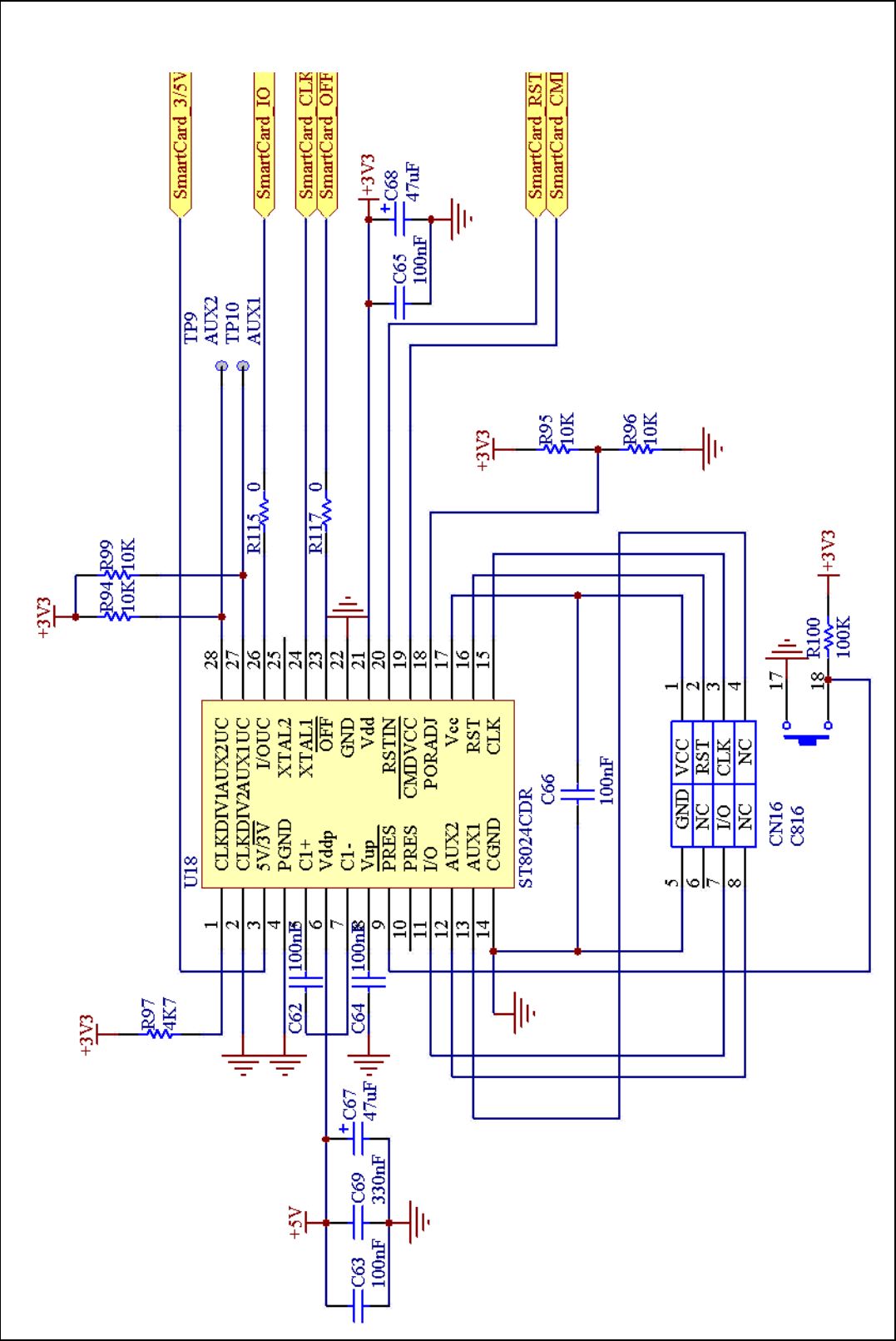
Please remember that STM320518-EVAL board has no smartcard reader. To run this example, an external smartcard reader was used, as described in [Table 3](#).

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 STM32F05xx with few external components to perform all supply protection and control functions.

Table 3. STM32F05xx and smartcard connection

External smartcard pins	STM320518-EVAL	Function
CLK	USART1_ CK: PA08	Smartcard clock: alternate function push-pull
IO	USART1_TX: PA09	IO serial data: alternate function open drain
RST	PB.15	Reset to card: output push-pull
V _{CC}	PC.13	Supply voltage: output push-pull
OFF	PA.11	Smartcard detect: input floating
3/5V	PA.12	3 V or 5 V: output push-pull

Figure 2. Smartcard interface hardware connection



3 ISO 7816: protocol overview

3.1 Introduction

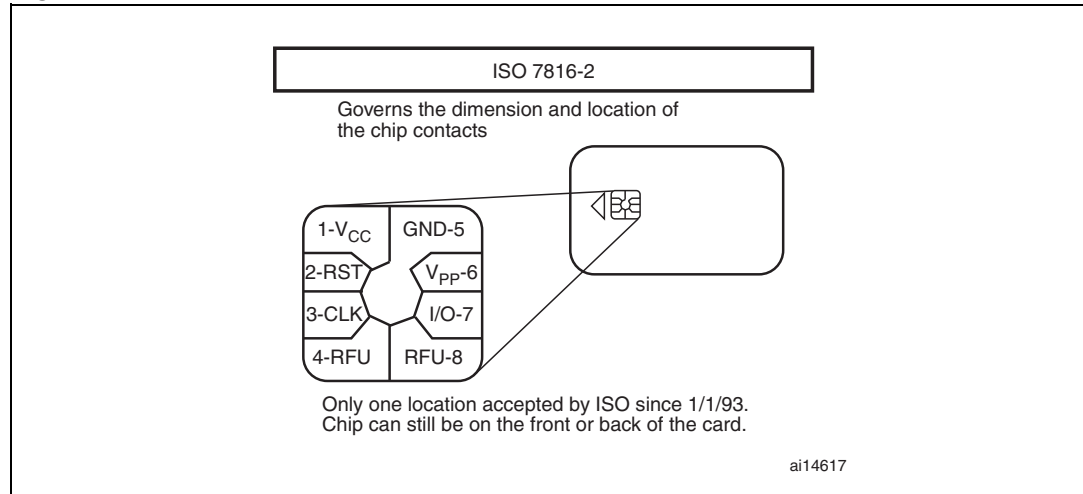
"ISO 7816: Identification cards -- Integrated circuit(s) cards with contacts" provides the basis to transition the relatively simple identification card from a token that can be compromised through forgery, theft, or loss into a tamper-resistant and "intelligent" integrated circuit card (ICC), more popularly 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. 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

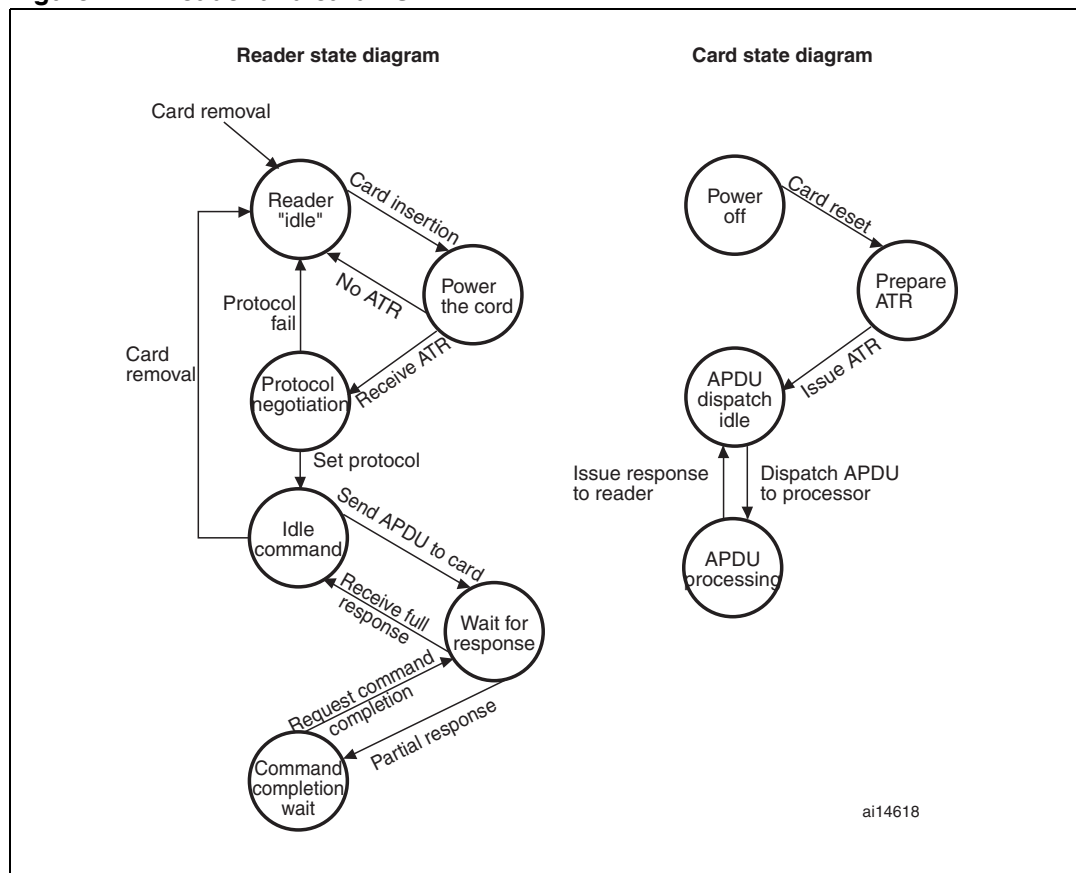


4 ISO 7816-3 – Electronic signal and transmission protocol

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 proceeds according to various state transitions, as 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.

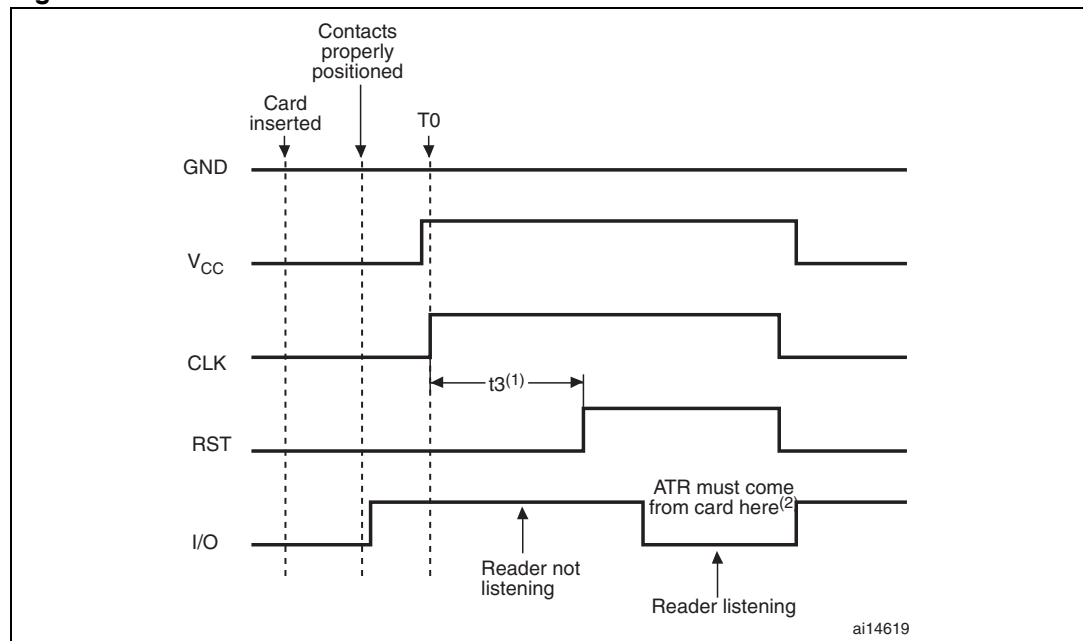
4.1 Card power-up and reset

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. 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. $t_3 = 40\,000$ 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 HLHHLLLLLH 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: 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 $ETU_0 = 372 / (CLK \text{ frequency})$ where the CLK frequency is always between 1 MHz and 5 MHz. The frequency is almost always selected so that the initial data transfer rate is 9,600 bits per second.

This initial ETU, used during an answer to reset, is replaced by the work ETU during the subsequent transmission. F is the clock rate conversion factor and D is the bit rate adjustment factor 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/f_i s
 - work ETU = (1/D)*(F/f_s) s

f_s minimum value must be 1 MHz.

f_s maximum value is given in [Table 4](#).

I and P define the active state on VPP.

- Maximum programming current: I_{pp} = 1 mA
- Programming voltage: V_{pp} = 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

FI	0000	0001	0010	0011	0100	0101	0110	0111
F	Internal clk	372	558	774	1116	1488	1860	RFU
Freq max	-	5	6	8	12	16	20	-

FI	1000	1001	1010	1011	1100	1101	1110	1111
F	RFU	512	768	1024	1536	2048	RFU	RFU
Freq max	-	5	7.5	10	15	20	-	-

RFU: Reserved for Future Use

Table 5. Bit rate adjustment factor D

DI	0000	0001	0010	0011	0100	0101	0110	0111
D	RFU	1	2	4	8	16	RFU	RFU

DI	1000	1001	1010	1011	1100	1101	1110	1111
D	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. Other values of PI2 are reserved for future use.

Table 6. Maximum programming current factor I

II	00	01	10	11
I	25	50	100	RFU

RFU: Reserved for Future Use

Extra guardtime N

N codes directly the extra guard time, 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
- T_{Ai} T_{Bi} T_{CI} T_{Di} - 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 reader, 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 CLA value. [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

P1 and P2 parameters 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 TDPU command sent from the reader, a TPDU response 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 TPDU command. 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 T1 protocol

The T=1 protocol is an asynchronous half-duplex block transmission protocol, meaning that one block is the smallest data unit that can be transmitted between the card and the terminal.

This block of data may contain an Application Protocol Data (APDU) defined for a specific application. Moving the information as a single block calls for error-free transmission, and this error detection and correction is much more complex for the T=1 protocol than for the T=0 protocol.

Error detection is managed with LRC (Longitudinal Redundancy Check) or with CRC (Cyclic Redundancy Check).

The block frame consists of three fields (prologue field - information field - epilogue field) as described in [Table 10](#).

Table 10. Block frame

Prologue field			Information field	Epilogue field
Node Address	Protocol Control Byte	Length	Optional	Error Detection LRC or CRC
NAD	PCB	LEN	INF	EDC
1 Byte	1 Byte	1 Byte	0-254 Bytes	1/2 Bytes

The **prologue field** consists of three bytes:

- NAD, the node address
- PCB, protocol control byte
- LEN, the data length

The NAD byte uses bits 3 - 1 to identify the source address and bits 7 - 5 to identify the destination address. Bits 4 and 8 are used for Vpp control (refer to ISO_IEC_7816-3 for more details).

The PCB byte allows the identification of three types of block frame:

- An information block (I - block)
- A receive ready block (R - block)
- A supervisory block (S - block)

The information block is the frame which is used to transmit application commands and data between the card and the reader. The receive-ready block is used as an acknowledgment

when the protocol is sending data as a sequence of chained blocks. The supervising block is used to establish control parameters and to effect a resynchronization or abort status as the result of some error condition.

The LEN byte indicates the number of bytes (if any) in the information field of the frame. Its allowed range of values is 0x00 - 0xFE. This allows a maximum information field of 254 bytes.

The **information field** is used to convey the application commands and data.

The **epilogue field** contains the block error detection code which may be either an LRC (longitudinal redundancy check) or a CRC (cyclic redundancy check). The LRC is 1 byte whilst the CRC occupies 2 bytes.

The T=1 protocol uses two waiting time parameters:

- Character Waiting Time (CWT)
- Block Waiting Time (BWT)

The character waiting time ([Figure 6](#)) is defined as the maximum time between successive characters in a block, whilst the block waiting time ([Figure 7](#)) is defined as the maximum delay between the leading edge of the last character of the block received by the card and the leading edge of the first character of the next block transmitted by the card.

Figure 6. Character waiting time

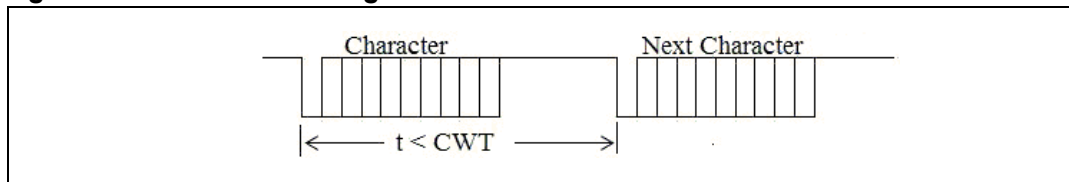
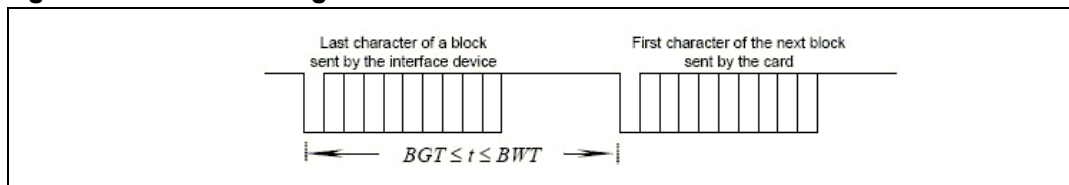


Figure 7. Block waiting time



There is also a Block guard time (BGT) which is defined as the minimum time between the leading edge of the last character of one block and the leading edge of the first character in the new block to be sent in the alternative direction.

The CWT and BWT are calculated using the CWI and BWI data elements in the ATR using the following formulas:

CWT & BWT formulas:

$$CWT = (11 + 2^{CWI})ETU$$

$$BWT = 11ETU + 2^{BWI} \times 960 \times \frac{372}{f} \text{ s}$$

Where f is the clock frequency.

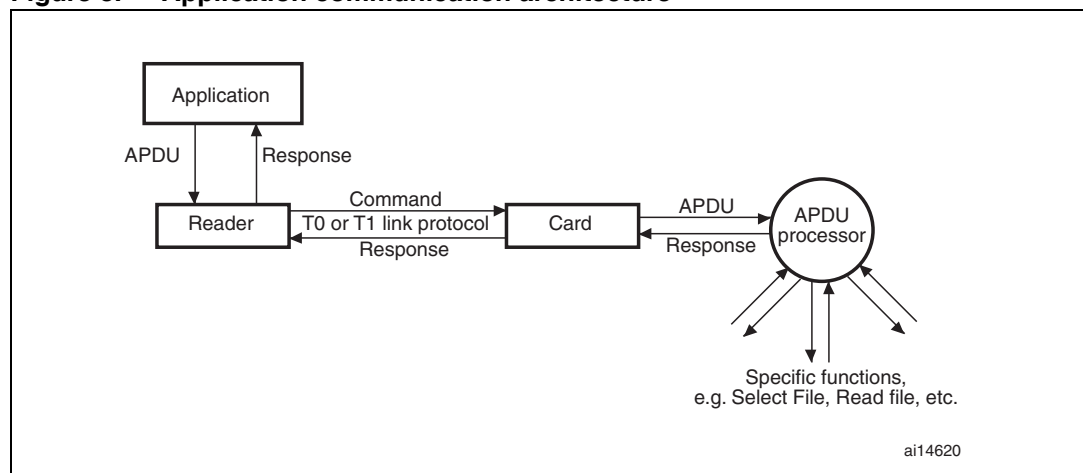
5.3 Application-level protocols

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, the application software on the reader side can access files in the file system.
- Security functions: these can be used to limit access to the application software or to files on the card.

The T0/T1 protocols are 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 8. Application communication architecture

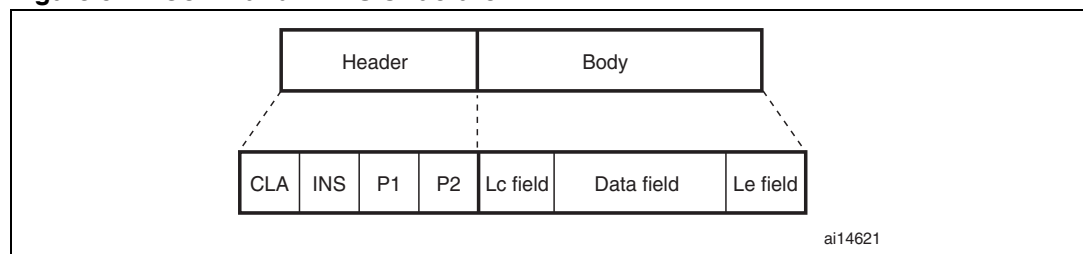


The APDU structure defined by ISO 7816-4 is very similar to the TPDU structure used in the T0 protocol. In fact, when an APDU is transported by the T0 protocol, the elements of the APDU directly overlay the elements of the TPDU.

5.3.1 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 9. Command APDU structure



The command APDU consists of a **header** and a **body** (this can be seen in [Figure 9](#) above).

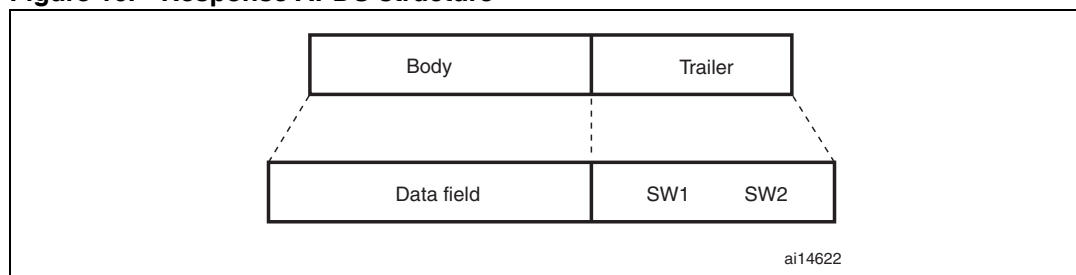
The header includes CLA, INS, P1 and P2 fields. As in the T0 protocol, **CLA** and **INS** specify an application class and instruction. **P1** and **P2** are used to qualify specific instructions and are given specific definitions by each [CLA, INS] instruction.

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:

1. No data is transferred to or from the card, so the APDU only contains the header.
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.
3. Data is transferred to the card, but none is returned from it. The body of the APDU includes the Lc and data fields.
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 10. 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.

5.3.2 File system API

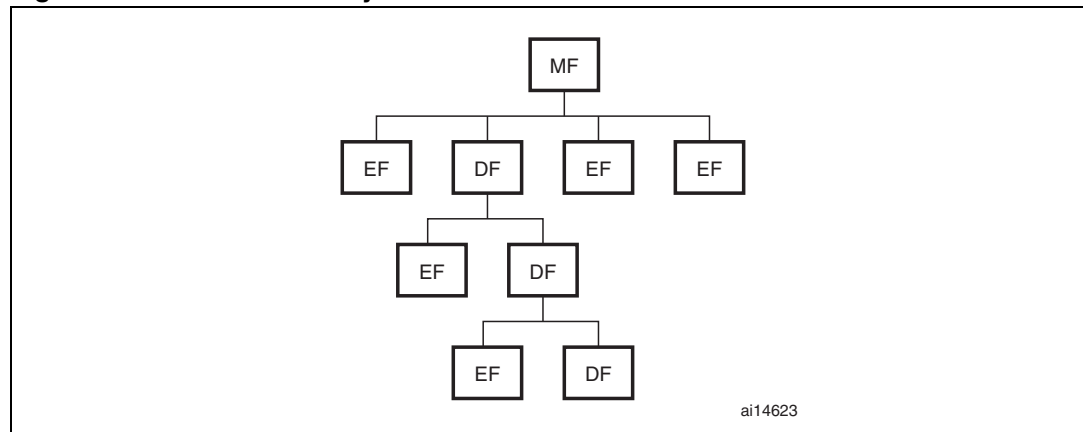
The file system is used on the non-volatile memory or EEPROM. It is defined as a simple hierarchical structure (similar to conventional file systems). The file system may contain three types of files (identified by a 2-byte identifier):

- 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 11](#).

Figure 11. 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.

5.3.3 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 multi-threaded, 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 (set selected bits, within a specified byte, to a value of 1), 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: 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.

5.3.4 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 type 4 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 (T=0) interface library: description

The user may access a smartcard (T=0) 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 11](#) presents the smartcard library modules:

Table 11. T0 file library description

File	Description
smartcard.h, smartcard.c	<ul style="list-style-type: none"> – Smartcard definitions, types definitions and function prototypes – T0 protocol management – Physical layer

6.2 Smartcard interface library functions

[Table 12](#) lists the various functions of the smartcard library.

Table 12. 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_PTSCfg	Configures the IO speed (BaudRate) communication.

6.2.1 SC_Handler function

It is described in [Table 13](#).

Table 13. SC_Handler

Function name	SC_Handler
Function prototype	<code>void SC_Handler(SC_State *SCState, SC_ADPU_Commands *SC_ADPU, SC_ADPU_Response *SC_Response)</code>
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.

Table 13. SC_Handler (continued)

Function name	SC_Handler
Input parameter3	SC_Response: pointer to an SC_ADPU_Response structure which will be initialized.
Output parameter	None
Return parameter	None
Required preconditions	None
Called functions	None

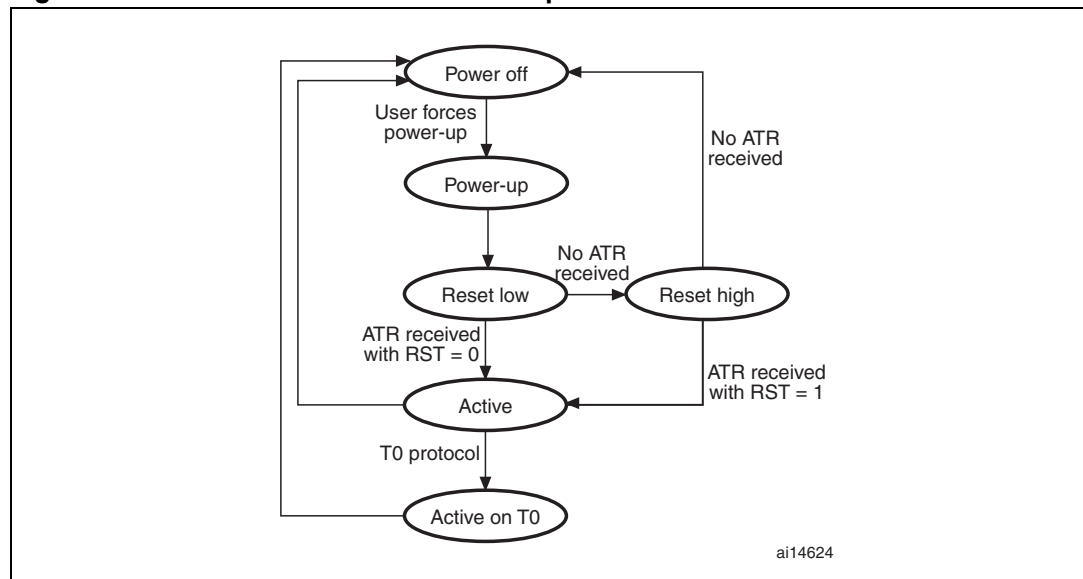
SCState

SCState informs the user about the smartcard state and allows the user to power off the smartcard. It can assume one of the values defined in [Table 14](#) below.

Table 14. SCState

SCState	Meaning
SC_POWER_OFF	No power is provided to the smartcard ($V_{CC} = 0$). The STM32F05xx 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 ($RST = 0$). $V_{CC} = 5\text{ V}$ 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 protocol used.
SC_ACTIVE_ON_T0	If the protocol used is T0, the reader goes in SC_ACTIVE_ON_T0 state and commands can then be sent to the smartcard.

Figure 12. State machine for smartcard operation



SC_ADPU_Commands

The SC_ADPU_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_Response;
```

- **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_Response);
```

6.2.2 SC_PowerCmd

It is described in [Table 15](#).

Table 15. SC_PowerCmd

Function name	SC_PowerCmd
Function prototype	<code>void SC_PowerCmd(FunctionalState NewState);</code>
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

It is described in [Table 16](#).

Table 16. SC_Reset

Function name	SC_Reset
Function prototype	<code>void SC_Reset(BitAction ResetState);</code>
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

It is described in [Table 17](#).

Table 17. SC_ParityErrorHandler

Function name	SC_ParityErrorHandler
Function prototype	<code>void SC_ParityErrorHandler(void);</code>
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_PTSCConfig

It is described in [Table 18](#).

Table 18. SC_PTSCConfig

Function name	SC_PTSCConfig
Function prototype	<code>void SC_PTSCConfig(void);</code>
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_PTSCConfig();
```

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_Response);
}
```

- **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_Response);
```

- **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_Response.SW2;
```

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

- **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_Response);
```

- **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_Response);
```

- **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_Response);
```

- **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_Response->Data:** It contains the smartcard data to write.
- **SC_Response->SW1** and **SC_Response->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_Response);
```

- **CHV1:** It contains the 8-byte CHV1 code.
- **SCState:** It stores the current smartcard state.
- **SC_Response->SW1** and **SC_Response->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

STM32F05xx 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

Vice versa if the smartcard pulls down the I/O line to signal that a parity error occurred, the STM32F05xx is able to detect a frame error via hardware. The smartcard library uses the `SC_ParityErrorHandler()` function to check whether a parity error has occurred and to manage the error, if any.

Each time the `SC_ParityErrorHandler` function is called, it resends the byte where the error was detected.

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 related IRQ event invokes the `SC_ParityErrorHandler()` function that resends the last data.

7 Smartcard (T=0) interface example

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

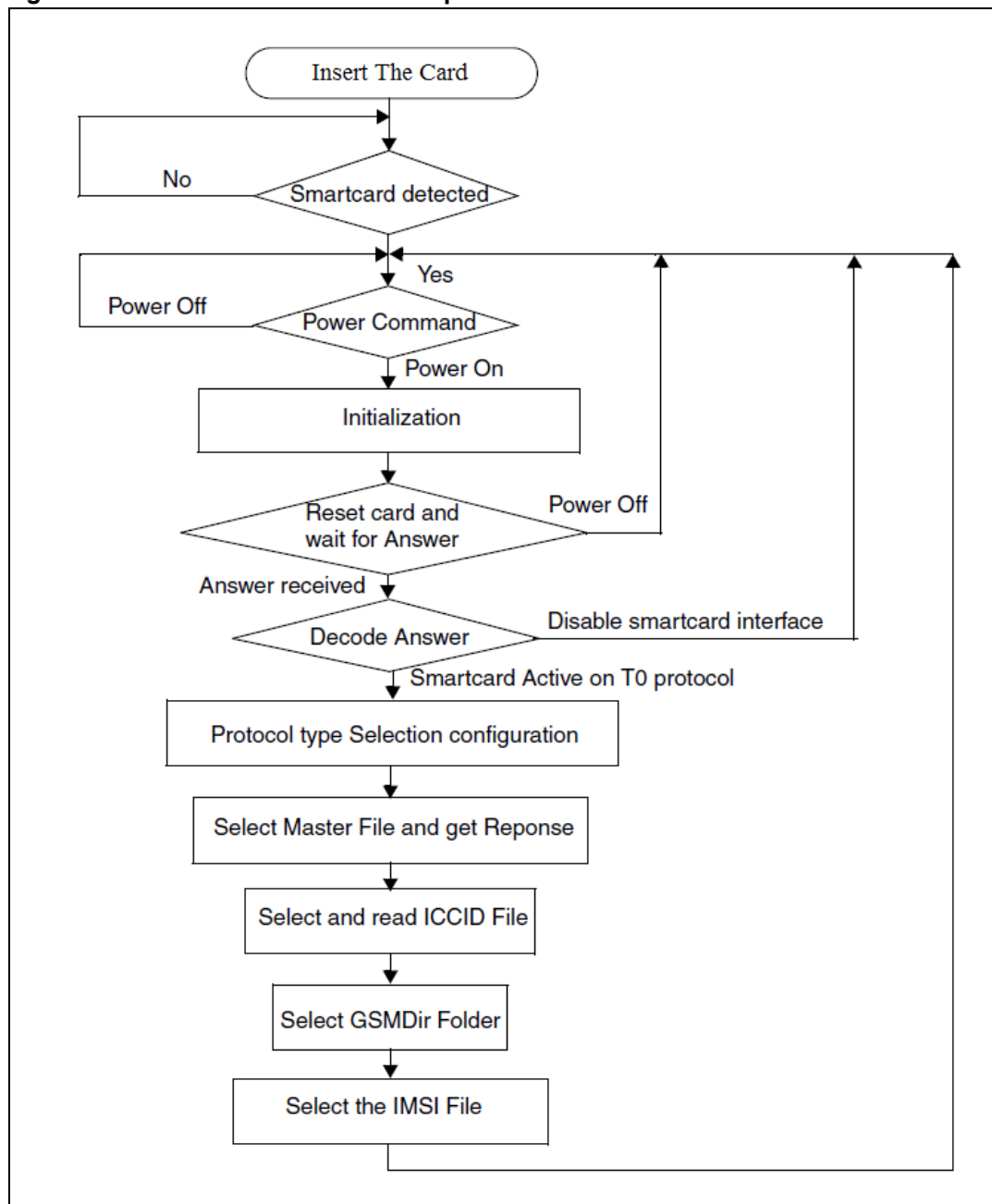
The example provides simple operations with an ISO 7816-3/4-compatible GSM11.11 smartcard, such as file system exploration, pin1 enable/disable, read/write operation on files and pin verify on protected files.

This example runs on the STM320518-EVAL STMicroelectronics evaluation board and you can easily tailor them to any other hardware.

Note: Please remember that STM320518-EVAL board has no smartcard reader. To run this example, an external smartcard reader was used, as described in [Table 3](#).

7.1 Firmware description

Figure 13. Smartcard software example flowchart

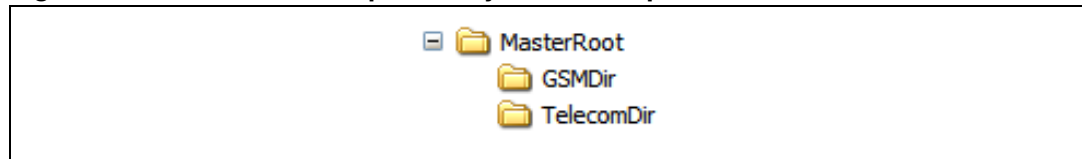


Three directories have been defined for the GSM smartcard directory tree:

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

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

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

Figure 14. 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
- PIN1 is enabled/disabled

7.1.1 Smartcard startup: answer to reset (A2R)

When the reader wants to access a card, the first action to perform 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_Response);
}
  
```

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_PTSCfg()* 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, Baud rate = 112500 baud.

7.1.2 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.

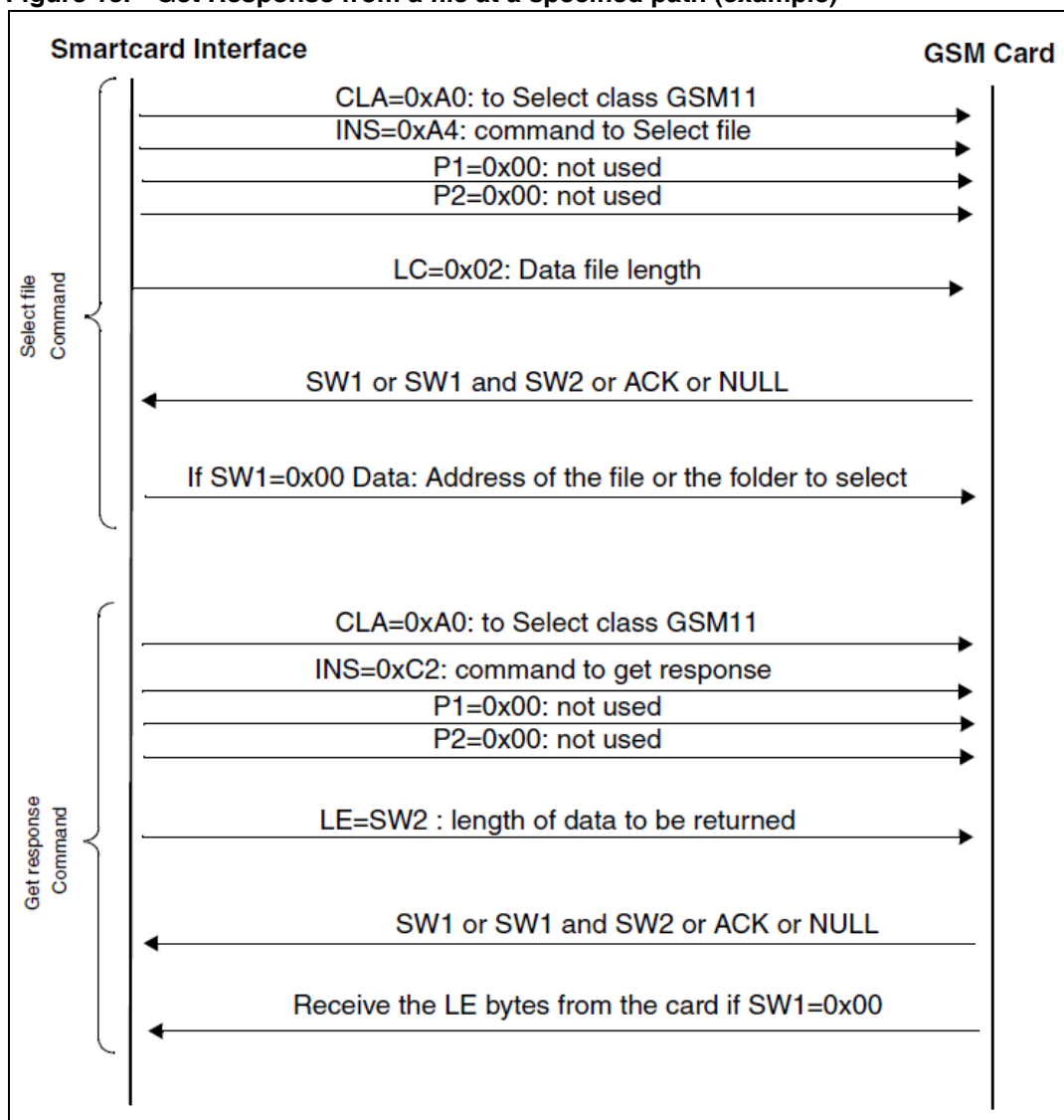
To get file characteristics:

- 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; to run correctly the READ_BINARY commands, the following parameters are used:

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

Figure 15. Get Response from a file at a specified path (example)



7.1.3 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, PIN1 will be disabled to give access to all files that have 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 bit 8 of the 14 received bytes. If bit 8 is 0, PIN1 is enabled; else, PIN1 is disabled.

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

7.1.4 Verifying the PIN1 (CHV1) code

Some files have 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 contains the file to be accessed.
- Use the Verify APDU command by presenting the CHV1 code.
- Select the file and execute the selected operation.

8 Smartcard (T=1) interface library: description

Smartcard T1 library for STM32F05xx is a USART driver allowing users to communicate with smartcards according to the ISO 7816-3 standard.

8.1 File organization

[Table 19](#) presents the smartcard T=1 library modules.

Table 19. T1 file library description

File	Description
t1_hal.h, t1_hal.c	– Smart Card firmware functions – Physical layer
t1_protocol.h, t1_protocol.c	T=1 protocol functions
t1_protocol_param.h, t1_protocol_param.c	T=1 parameters configuration functions
pps.h, pps.c	PPS functions
atr.h, atr.c	ATR functions

8.2 Smartcard interface library functions

The smartcard T=1 library contains the following functions to communicate with smartcards supporting T=1 protocol ([Table 20](#)).

Table 20. Smartcard T =1 library functions

Function name	Description
T1_Protocol_Init	Initializes T=1 protocol with default values.
T1_SetParameter	Sets T=1 protocol parameters.
T1_Negotiate_IFSD	Sends IFS request to indicate a new IFSD that can support (reader side).
T1_APDU	Sends APDU command and receives APDU responses through T=1 protocol.

8.2.1 T1_Protocol_Init function

It is described in [Table 21](#).

Table 21. T1_Protocol_Init

Function name	T1_Protocol_Init
Function prototype	void T1_Protocol_Init (t1_TypeDef * t1, uint32_t sc_freq)
Description	Initializes the structure of the T=1 protocol with default values.
Parameter 1	t1: pointer to t1 structure of T=1 protocol
Parameter 2	sc_freq: smartcard clock frequency
Return parameter	None
Required preconditions	None

8.2.2 T1_SetParameter function

It is described in [Table 22](#).

Table 22. T1_SetParameter

Function name	T1_SetParameter
Function prototype	int32_t T1_SetParameter (t1_TypeDef * t1, uint8_t param_type, uint32_t value)
Description	Sets T=1 protocol parameters into t1 structure.
Parameter 1	t1: pointer to t1 structure of T=1 protocol
Parameter 2	param_type: the parameter to be settled
Parameter 3	value: the new value of the parameter
Return parameter	The status: supported or unsupported parameter
Required preconditions	None

8.2.3 T1_Negotiate_IFSD function

It is described in [Table 23](#).

Table 23. T1_SetParameter

Function name	T1_SetParameter
Function prototype	int32_t T1_Negotiate_IFSD (t1_TypeDef * t1, uint8_t nad, uint8_t ifsd)
Description	Sends an IFS request to indicate a new IFSD that can support (reader side).
Parameter 1	t1: pointer to t1 structure of T=1 protocol
Parameter 2	nad: the value of the node address
Parameter 3	ifsd: the new value of the reader IFS to be negotiated
Return parameter	the status of the IFSD request communication
Required preconditions	T1 protocol is already initialized.

8.2.4 T1_APDU function

It is described in [Table 24](#).

Table 24. T1_APDU

Function name	T1_APDU
Function prototype	int32_t T1_APDU (t1_TypeDef * t1, uint8_t nad, void *apdu_c, uint32_t apdu_c_len, void *apdu_r, uint32_t apdu_r_len)
Description	Sends APDU command and receives APDU response through T=1 protocol.
Parameter 1	t1: pointer to t1 structure of T=1 protocol
Parameter 2	nad: nad value (Node Address)
Parameter 3	apdu_c: pointer to ADPU command buffer
Parameter 4	apdu_c_len: the length of the command ADPU buffer
Parameter 5	apdu_r: pointer to ADPU command buffer
Parameter 6	apdu_r_len: pointer to ADPU command buffer
Return parameter	the status of the APDU transaction
Required preconditions	T1 protocol is already initialized.

9 Smartcard (T=1) interface example

An example is provided in conjunction with the smartcard library in order to facilitate the development of smartcard (T=1) application using the USART peripheral with the STM32F05xx microcontrollers.

The example describes how to use the smartcard T=1 protocol driver and to communicate with a Java Card. It consists of sending some APDU commands such as Select File, Read File and Write File.

This example runs on the STM320518-EVAL STMicroelectronics evaluation board and you can easily tailor them to any other hardware.

Note: Please remember that STM320518-EVAL board has no smartcard reader. To run this example, an external smartcard reader was used, as described in [Table 3](#).

9.1 Firmware description

At the first time, the example applies the "Answer To Reset" procedure and then configures the smartcard interface and the T=1 protocol according to the received ATR.

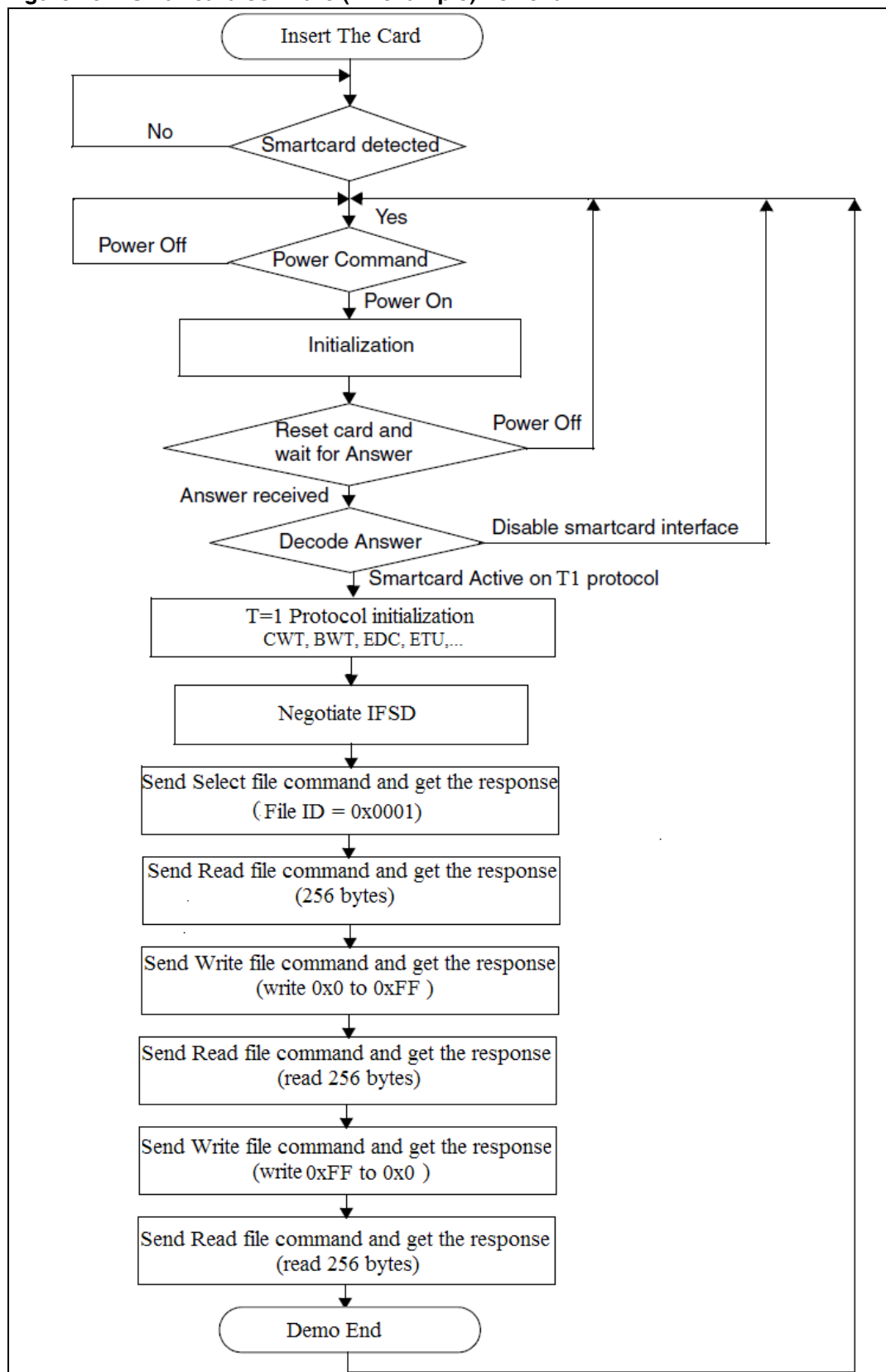
After that, the demo sends an IFSD request indicating that the Reader would extend the length of the information field of the block from 32 to 254.

Then, it starts sending/receiving APDU commands/responses in the following sequence:

1. Select file having ID = 0x0001.
2. Read file: read 256 bytes from the same file (to view initial data saved in the file)
3. Write file: write 0x0 to 0xFF to this file.
4. Read file: read 256 bytes from the file (to verify the data written).
5. Write file: write 0xFF to 0x0 to this file.
6. Read file: read 256 bytes from the file (to verify the data written).
7. Demo END.

Refer to flowchart in [Figure 16](#).

Figure 16. Smartcard software (T1 example) flowchart



10 Conclusion

Thanks to the STM32F05xx USART's smartcard mode that supports the ISO 7816-3/4 specification, the user can develop a smartcard-based application with reduced firmware and hardware resources.

11 Revision history

Table 25. Document revision history

Date	Revision	Changes
03-Aug-2012	1	Initial release.

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