

KEELOQ™ Token Card Chip

FEATURES

- ISO 7816-3:1989 "Answer to Reset" compatible for synchronous cards
- Industry standard 4406 command set compatible
- Extended commands:
 - Combined WRITE and ERASE-WITH-CARRY function
 - Cryptographic signature of the EEPROM contents and challenge
- 40-bit user programmable area with lock bit
- 64-bit cryptographic key
- 64-bit transport code
- 33352 token units (78888₈)
- Internal protection against token counter value corruption (anti-tearing)

DESCRIPTION

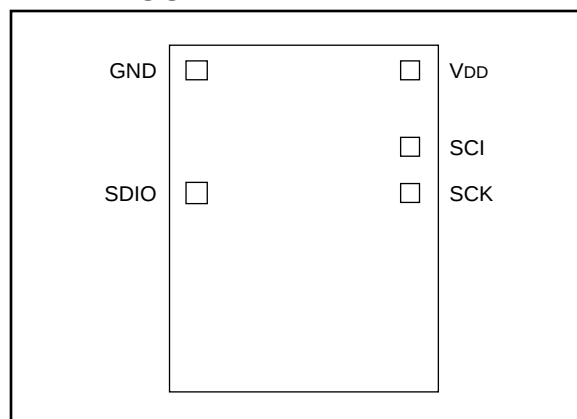
The SCS152 is a third generation token card integrated circuit intended for prepaid applications. Typical applications of the SCS152 include disposable telephone cards, vending machine cards, low value debit cards, access control, and authentication.

The SCS152 incorporates several security features, including an internal signature function and a long transport code. The SCS152 has two modes – issuer mode and user mode. During wafer testing, it is placed in issuer mode for card manufacturing and transportation to the issuer. In issuer mode, the transport code is needed to program the device and, thus, is protected from unauthorized use before personalization by the issuer.

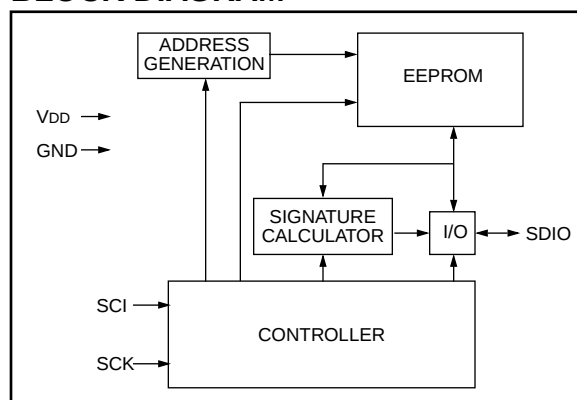
During personalization, a cryptographic key, unique to the card, is programmed into EEPROM. This key can not be read. The system using the card must be able to determine what key was programmed from examining the memory map (i.e., not the token counter) containing the issuer and serial number information.

The signature function computes an 8-bit value based on a system supplied value (challenge) and the visible memory map. Because of the nature of the signature function and the fact that the key is not known outside the system, it is practically impossible to predict the value which the signature will compute.

DIE LAYOUT



BLOCK DIAGRAM



A correct signature indicates that the memory contents have not been altered. It can therefore be used to check the serial number, or that changes to the token counter have actually occurred.

Programming the token counter uses a special circuit to ensure that the programming will either be complete or will not happen at all, if the external supply is suddenly removed.* This is called **Fail Safe Programming™**, and, when used in conjunction with the extended write and erase command, removes the need for special 'tear-out' protection to be performed by the reader.

Note: The fail safe feature only works in the token counter area.

1.0 PIN DEFINITIONS

ISO	Pin Name	I/O Type	Description
C1	VDD	Power	Power connection
C2	SCI	INPUT	Command input to the device controller
C3	SCK	INPUT	Command execution clock input
C5	GND	Power	Power connection
C7	SDIO	Bidir (O.D.)	Open drain serial data I/O line

2.0 DEVICE OPERATION

During the life of the SCS152, it goes through the following stages:

- Manufacture and wafer probing
- Waffle pack and transportation
- Personalization and final application.

Various fields in the memory map must be initialized. These include the first 24 bits in the memory map, the transport code, and the mode bits. The first 24 bits in the memory map typically identifies the device in its final application. The device has two principle modes: issuer mode and user mode. In issuer mode, all access to the device (except one field) is blocked before a correct transport code has been presented to the device. Thus, the transport code protects the device against theft, before it is personalized.

During personalization, all fields, except (Chip Identification Data (CID)), are initialized for the intended application: the device serial number is programmed, the token counter is set to its proper value, the user data field is initialized, and the transport code is erased and replaced with a cryptographic key.

After power has been applied to the device, the I/O pin is driven low. Once the reset period (T_{POR}) has expired, the SCS152 is ready to accept commands. These commands typically read the memory content serially. The first bit at address 0 is initially driven on the I/O line. Each read clock pulse increments the internal address counter and reads the resulting bit from EEPROM. This serial data stream is composed of various fields presented in Table 2-1.

TABLE 2-1: EXTERNAL REPRESENTATION OF THE INTERNAL MEMORY MAP

Field Name	Address	Size	Description
CID	0...23	24	Chip identification data
SER	24...63	40	Serial number
ISS	64	1	Issuer mode status
D4	65...71	7	Digit 4
D3	72...79	8	Digit 3
D2	80...87	8	Digit 2
D1	88...95	8	Digit 1
D0	96...103	8	Digit 0
CFG	104...107	4	Configuration data
USER0	108...147	40	User area
UKEY0	148...211	64	Key area 0 which also acts as the transport code in issuer mode
	212...275	64	Undefined

2.1 CID Field

The device CID field contains a device identification code, which is programmed during wafer probe and cannot be changed later. These bits typically identify the type of the device to the system in the application.

2.2 SER Field

The SER field contains the device serial number which identifies the individual device. It is programmed while the device is in issuer mode during the personalization stage.

2.3 ISS Field

The ISS field indicates whether the device is in issuer mode as determined by the CFG field. This is purely an external view of the CFG field and exists as such for compatibility reasons.

2.4 Digit Fields

2.4.1 DIGIT FIELD VALUE

Each digit field, D4 to D0, represents a number equal to the number of '1' bits in the field. Table 2-2 shows the value of the digit field for each legal digit value.

TABLE 2-2: DIGIT FIELD VALUES

Digit Value	Field Value
0	0000 0000
1	1000 0000
2	1100 0000
3	1110 0000
4	1111 0000
5	1111 1000
6	1111 1100
7	1111 1110
8	1111 1111

Note: The bits are shown, right to left, in the order in which they are read out.

2.4.2 TOKEN COUNTER VALUE

Note: The value digit D4 is shown in the formulas as $|D4|$ indicating the number of 1 bits in the digit D4 field. Similarly $|D3|$ indicates the number of 1 bits in the digit D3 field, and so on.

The following formula shows how the digit fields combine to form the token counter value:

$$Tokens = |D4| \times 4096 + |D3| \times 512 + |D2| \times 64 + |D1| \times 8 + |D0|$$

This is, in fact, an octal representation of a value and can be written as:

$$Tokens = |D4| \times 8^4 + |D3| \times 8^3 + |D2| \times 8^2 + |D1| \times 8^1 + |D0| \times 8^0$$

Suppose the 5-digit field contain the values: (D4=3), (D3=0), (D2=7), (D1=1), (D0=3). The token counter value is then 30713₈ in octal or in decimal:

$$Tokens = 3 \times 4096 + 0 \times 512 + 7 \times 64 + 1 \times 8 + 3 = 12747_{10}$$

A digit needs to be set to eight to handle the borrow from the next higher stage. This also implies that each counter value does not have a unique representation. For example, 00500₈ = 5 × 64 = 320₁₀ or 00480₈ or 00478₈.

2.5 CFG Field

The CFG field is further divided into four subfields:

Name	Address	Description
PC0	104	First bit of the issuer mode/user mode indicator
PC1	105	Second bit of the issuer mode/user mode indicator
N.U.	106	Unused
LOCK0	107	Unlocked status of USER0 area in user mode: '0' means locked

With 'PC0 = 0' and 'PC1 = 1', the device is in issuer mode; with 'PC0 = 1' and 'PC1 = 0', the device is in user mode. Some commands can only be used in issuer mode.

2.6 USER0 Field

The user area can be reprogrammed to any state by the user in user mode. It also can be locked using the LOCK0 bit. In issuer mode, this field typically contains the packaging status of the device. In user mode, this field can be used for application dependent data.

2.7 UKEY0 Field

In issuer mode, this field contains the transport code; in user mode, the UKEY0 field contains the key used in the signature function. The transport code is programmed during wafer probe and is completely reprogrammed during personalization to the value of the key.

3.0 COMMAND INTERFACE

The SCS152 accepts the following basic commands: RESET, RDBIT/PUTBIT, BITPROG and ERASE. The extended commands are DECR-ERASE and initiate signature function.

The device interprets five different SCI/SCK sequences for all its commands:

- An overlap of SCI and SCK for RESET
- A single pulse on SCK for RDBIT or PUTBIT
- A single pulse on SCI followed by a pulse on SCK for BITPROG
- A repeat of c) for ERASE
- A double pulse on SCI followed by a pulse on SCK for extended commands

Normally, any one of these sequences can be followed by another; however, once the signature function has been started, a fixed sequence of commands must follow.

The extended functions are accessed by double pulse on SCI in the correct address range. Depending on the current address, the same sequence of events on SCI and SCK will perform different functions.

TABLE 3-1: EXTENDED FUNCTIONS

Field	Extended Function Accessed by Double SCI Pulse
CID	Test modes
SER	BITPROG
D4...D0	DECR-ERASE
CFG	Test modes
USER0	BITPROG
UKEY0	Address 163: test mode Address 259: Initiate signature operation Other addresses perform BITPROG

3.1 Access Conditions

TABLE 3-2: ACCESS CONDITIONS IN ISSUER MODE

Field	RDBIT	BITPROG	ERASE	Extended Commands
CID	Y	F and TC	N	test modes
SER	Y	TC	N	BITPROG
O4...O1	Y	TC and Z	TC and B	DECR-ERASE: TC and Z
O0	Y	TC and Z	N	N
CFG	Y	TC	N	test modes
USER0	Y	Y	Y	BITPROG
UKEY0	'1'	TC	TC	BITPROG test modes SIGN: Y

TABLE 3-3: ACCESS CONDITIONS IN USER MODE

Field	RDBIT	BITPROG	ERASE	Extended Commands
CID	Y	N	N	test modes
SER	Y	N	N	BITPROG
O4...O1	Y	Z	B	DECR-ERASE: Z
O0	Y	Z	N	N
CFG	Y	Y	N	test modes
USER0	Y	L	L	BITPROG
UKEY0	'1'	N	N	BITPROG test modes SIGN: Y

The condition codes are:

- Y Command always allowed
- N No access allowed and it is converted into a RDBIT command
- TC Transport code must be submitted before the operation is allowed
- '1' Output always logic high in this field
- F Command allowed if the fuse is not blown
- Z The digit code is nonzero
- B Command allowed if previous operation was BITPROG and was successfully
- L Command allowed if LOCK0 bit in the CFG field is '1'
- BITPROG The BITPROG condition is checked and executed

Note 1: If the access condition does not allow a command that modifies the EEPROM (i.e., BITPROG, ERASE or DECR-ERASE), it will be converted into a RDBIT command.

2: The commands that can potentially change the EEPROM (even if it is converted into a RDBIT command) do not increment the I/O address counter.

3: Any command that modifies the EEPROM checks the internal high voltage sensor during the programming and goes into the standby state if the sensor indicates the internal high voltage was not high enough. Power must be removed to clear this condition.

4: If the device is not in issuer mode and not in user mode, only BITPROG access is allowed to the CFG field.

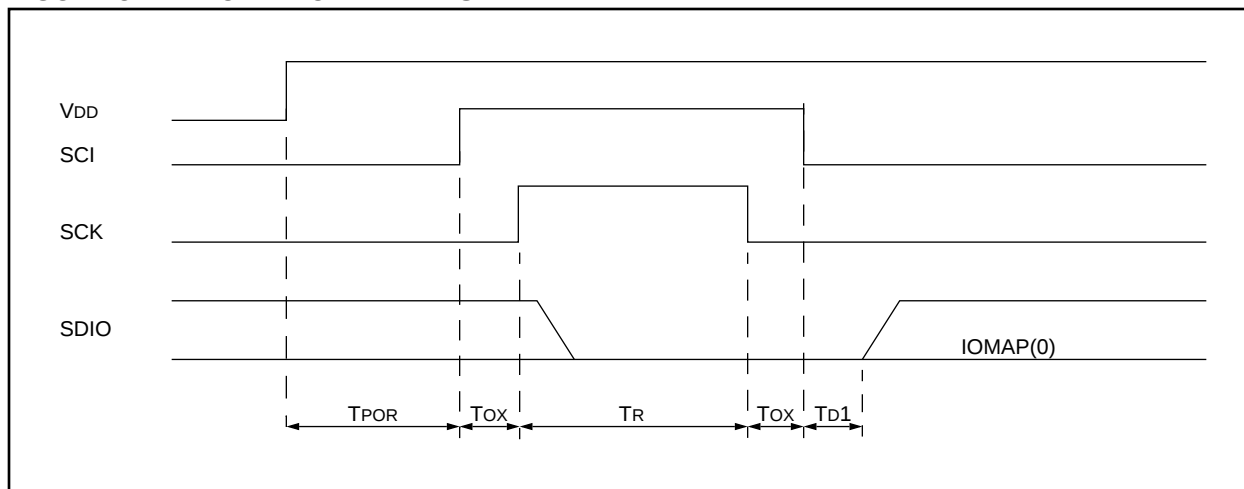
3.2 RESET

The RESET command sets the internal state of the device as follows:

1. The internal address counter is set to '0'.
2. The internal test modes are cleared.
3. The result of the last compared transport code is cleared.

Figure 3-1 shows the RESET command following the application of power.

FIGURE 3-1: POWER ON AND RESET



3.3 RDBIT/PUTBIT

The RDBIT command increments the internal address counter on the leading edge of the SCK pulse and reads the resulting bit in EEPROM. This SDIO line is updated on the falling edge of the SCK pulse. If the new address is in the UKEY0 area, the SDIO line will be tri-stated immediately in preparation of transport code entry, even if the device is in user mode. Figure 3-2 shows two consecutive RDBIT commands.

The PUTBIT command mirrors a RDBIT command, but data is transmitted to the chip instead of transmitting data from the chip. It also increments the internal address counter. PUTBIT is used to enter the transport code in issuer mode and the challenge bits, during signature computation. Figure 3-3 shows data entry, typically during transport code entry.

FIGURE 3-2: RDBIT

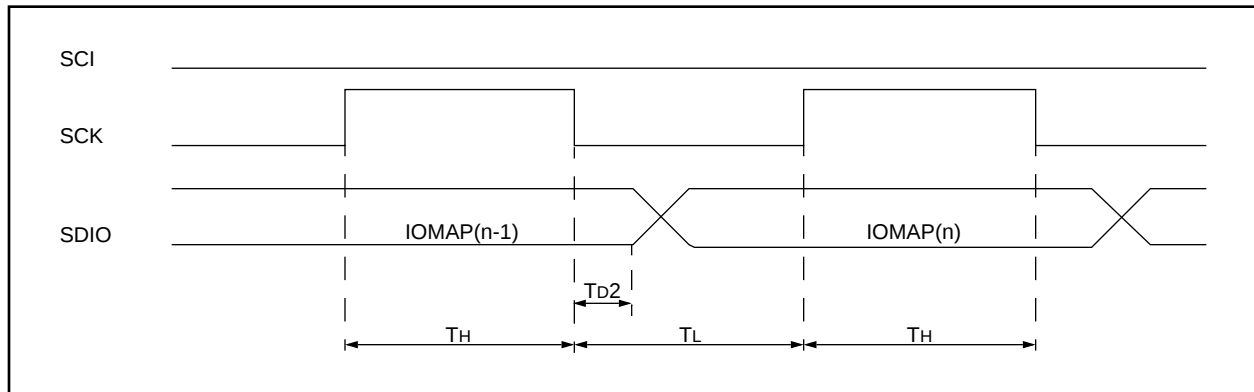
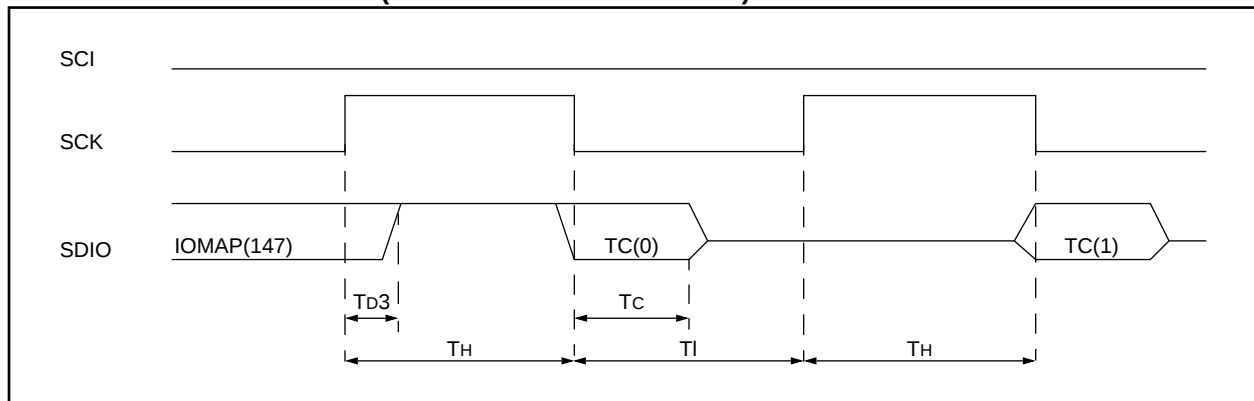


FIGURE 3-3: DATA ENTRY (TRANSPORT CODE DETAIL)



3.4 BITPROG

The BITPROG command modifies one bit in the EEPROM. In the digit area, this command decrements the current digit or in the CFG field it programs the bits to AD(0) xor FUSE-BLOWN state: PC0 is erased to a '1'; PC1 is written to a '0'; LOCK0 is written to a '0', when the fuse is in blown state. Everywhere else in the memory map, the current bit is written to a '0'. Figure 3-4 diagrams the BITPROG command.

This command is signaled by pulsing SCI high. If the operation is allowed, the SDIO line goes high. The actual EEPROM modification is initiated by pulsing SCK high. When the programming operation has been completed, and SCK is low, the output goes low, indicating that the command has completed.

TABLE 3-4: BITPROG FUNCTIONS

Field	Description
CID	Writes current bit to '0'
SER	Writes current bit to '0'
D4...D0	Decrements the current digit
CFG	Program the current bit to the value of (AD(0) xor FUSE-BLOWN)
USER0	Writes current bit to '0'
UKEY0	Writes current bit to '0'

3.5 ERASE

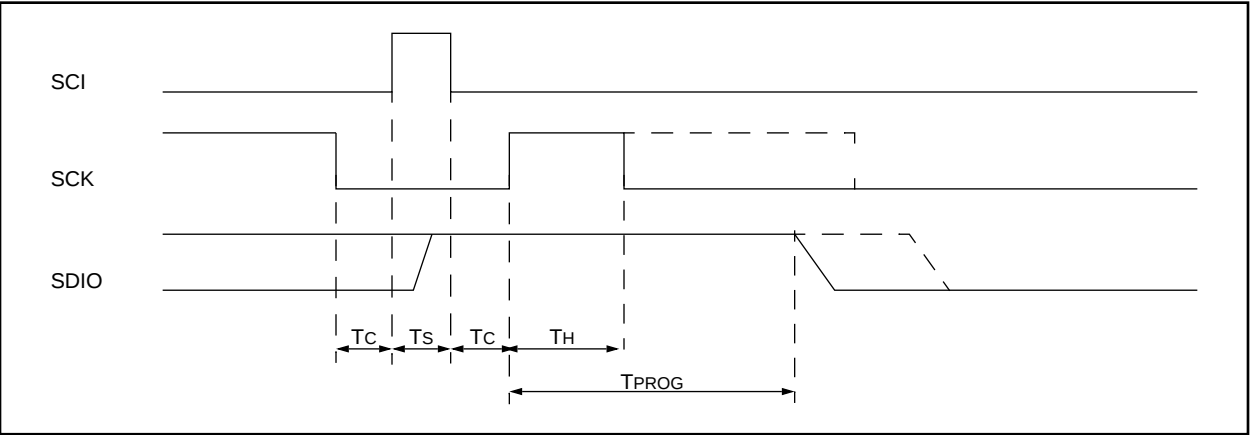
The waveforms for ERASE are the same as BITPROG; the command is implicitly coded by the repetition of the sequence of events.

The ERASE command executes different functions, depending on the current address as shown in Table 3-5:

TABLE 3-5: ERASE FUNCTIONS

Field	Description
CID	—
SER	—
O4...O1	Sets the next digit to the maximum digit value
CFG	—
USER0	0x6C...0x73: Erases current nibble to all '1' state 0x74...0x93: Erases the current byte to all '1' state
UKEY0	Erases the current byte to all '1' state

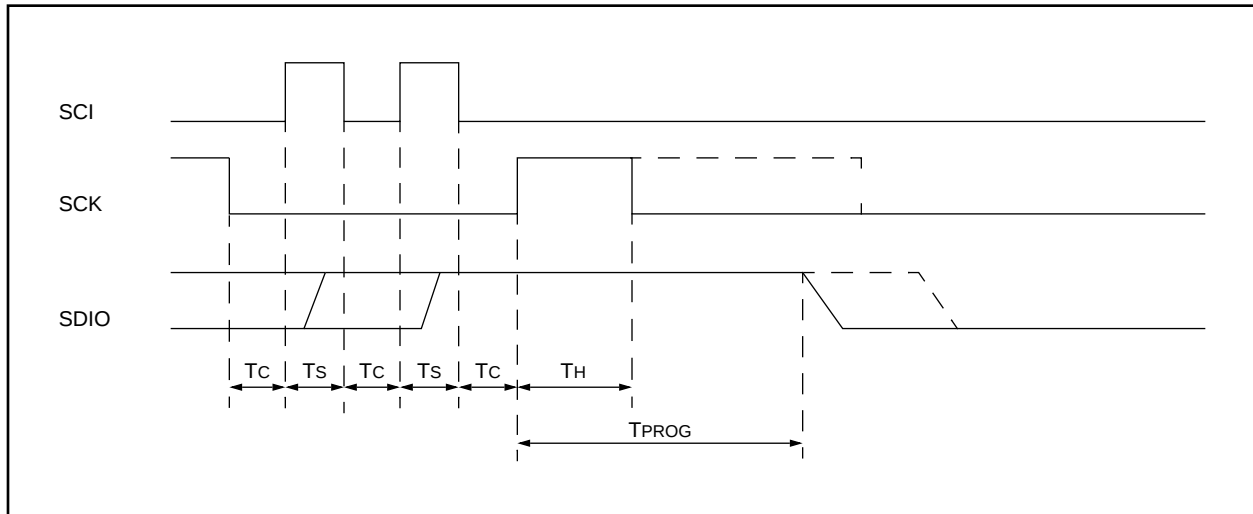
FIGURE 3-4: BITPROG



3.6 DECR-ERASE

The DECR-ERASE command combines BITPROG and ERASE in the digit area into one operation. It is only allowed if both of these operations are allowed at the current address. Figure 3-5 shows the typical waveforms for the DECR-ERASE command.

FIGURE 3-5: EXTENDED FUNCTIONS MODIFYING EEPROM



4.0 SIGNATURE FUNCTION

The signature function combines a system-supplied value with the contents of the memory map to form an 8-bit value. Because UKEY0 is not known and the way in which these values are combined, it is very difficult to duplicate.

The signature function can, therefore, be used for a variety of security related functions, including user/card authentication and protecting against communication tampering.

4.1 Signature Procedure

The following procedure controls the device to compute a signature of the EEPROM contents:

1. Issue a RESET command.
2. Issue 259 RDBIT commands.
3. Pulse SCI high twice.
4. Issue 16 PUTBIT commands to enter the first 16 bits of the challenge.
5. Issue 128 RDBIT commands.

Note: The bits read are the first 128 bits in the EEPROM without any output mapping; these bits must be used in checking the result of the signature function.

6. Issue 16 PUTBIT commands to enter the second 16 bits of the challenge.
7. Wait for the signature computation to complete.
8. Issue 8 RDBIT command to read the result of the signature computation.
9. Updating the token counter.

4.2 Subtraction Procedure

The following procedure can be used to subtract a number of tokens:

1. Read the token counter value.
2. Convert the token counter value into an octal format.
3. Convert the number of tokens to subtract into an octal format.
4. Do the subtraction using 'long subtraction' making note of the borrows.

Note: If the subtraction generated a borrow from digit 4, the token counter is smaller than the number subtracted.

5. To update each digit in the order they are read out (i.e., D4, then D3, then D2, etc.):
 - a) Calculate by how much this digit must be decremented. If, during subtraction, a borrow was generated from this digit to the next higher digit, the decrement amount is eight minus this digit's final value, else it is its initial value minus its final value.
 - b) Read to the first '1' bit in the field.
 - c) If the following digit generated a borrow from this digit, issue a BITPROG command, followed by an ERASE command. (See Section 5.1 on fail safe counter updating.)
 - d) Decrement this digit as many times as calculated in Step 5a, taking into account that Step 5c may already have decremented this digit. Each decrement is done by reading the next bit in the field and issuing a BITPROG command.

EXAMPLE 4-1: SUBTRACT EXAMPLE

Suppose the token counter contains 30713₈, and 20₁₀ (24₈) tokens must be deducted from the counter. Using 'long subtraction' to do the calculation the result is 30677₈.

$$\begin{array}{r} 30713_8 \\ 00024_8 \\ \hline 30667_8 \end{array}$$

Note the borrows from digits D2 and D1.

Digits 4 and 3 do not change. The sequence of commands to update digit 2 is: read the second bit in the field to field D2, BITPROG, and ERASE. The ERASE command is required because of the borrow.

Updating digit '1' requires the following sequence of commands: read the first bit to field D1, BITPROG, ERASE, RDBIT, and BITPROG. Once again, the ERASE command is required because of the borrow.

Updating digit '0' requires the sequence of commands: read the first bit to field D0 and BITPROG.

EXAMPLE 4-2: DECREMENTING 320:

$$\begin{array}{r} 00500_8 \\ 00001_8 \\ \hline 00477_8 \end{array}$$

Updating this token counter goes through the following values: 00400₈, after the first BITPROG; 00480₈, after the ERASE; 00470₈, after BITPROG; 00478₈, after the ERASE; 00477₈, after the final BITPROG.

Note: The final BITPROG actually decrements the value.

5.0 COMPATIBILITY WITH INDUSTRY STANDARD DEVICES

The RESET and RDBIT commands meet the requirements of ISO 7816-3 for the 'Answer-to-Reset' sequence for **synchronous** chip cards.

The basic counter modification commands BITPROG and ERASE correspond with the WRITE and ERASE-WITH-CARRY commands of industry standard devices. However, industry standard devices use eight bits to represent each digit, and a WRITE command will program the current bit to '0'.

The application can, therefore, decrement a digit by programming any of the eight bits to '0', whereas with the SCS152, any BITPROG command will always decrement the current digit value. If the application decrements each digit as described above, the WRITE command will appear to program the current bit to '0'. Thus, while the SCS152 will accept and interpret the commands correctly, the changes to the memory map will only correspond to that of the other cards, if the first '1' in a digit field is always programmed '0' with a WRITE command.

For example, if digit field D3 contains the value '6', it will be read out as 00111111. If a BITPROG command is issued anywhere in D3, its value will be decremented to '5', and it will always read out as 00011111, regardless of which address in the digit the BITPROG command was issued.

The ISS is only an external view of the CFG field and cannot be changed. A BITPROG command at this address will actually decrement digit D4. It should also be noted that the address counter appears to wrap from 275 back to 0, which differs from other similar devices.

5.1 Fail Safe Counter Update

The carry is performed by a BITPROG, followed by an ERASE. This process first deducts a number of tokens (the BITPROG command) and then adds some again (with the ERASE command), but never more than previously deducted with the BITPROG command. If the device is pulled from the reader between the BITPROG and ERASE commands, the user may lose many tokens.

This situation can be avoided by substituting the DECR-ERASE command whenever a sequence of BITPROG and ERASE commands are needed to update the token counter (Step 5c in Section 4.2). This will modify the contents of the EEPROM in one indivisible operation that will either complete or not modify the EEPROM in any way, if external power is removed early on during the EEPROM programming.

6.0 PERSONALIZATION

During the typical life of the device, it must be personalized. The following procedure personalizes the device:

1. Issue a RESET command.
2. Issue 147 RDBIT commands.
3. Issue 64 PUTBIT commands to present the transport code.
4. Issue 88 RDBIT commands.
5. Program the SER field by issuing BITPROG commands at the appropriate addresses.
6. Decrement each digit in the token counter to the proper value by issuing BITPROG and RDBIT commands as needed.
7. Program the USER area.
8. Program the UKEY0 area by clocking to the first bit of each byte (i.e., addresses 148, 156, 164, ...) issuing BITPROG and ERASE commands, and then programming the byte with BITPROG commands.
9. Check the contents via the signature function.
10. Set the device to user mode by issuing a BITPROG commands at addresses 104 and 105.

Note: The internal transport code OK status bit is reset by the RESET command or when the device is no longer in issuer mode (which happens when PC0 and PC1 are programmed).

7.0 MEMORY CONTENTS

7.1 Shipped Devices

Field Name	Contents
CID	Chip identification data
SER	all 1
ISS	1
D4	all 1
D3	all 1
D2	all 1
D1	all 1
D0	all 1
CFG	PC0 = 0, PC1 = 1, LOCK0 = 1
USER0	All 1
UKEY0	Transport code

7.2 After Personalization

Field Name	Contents
CID	Chip identification data
SER	Device serial number
ISS	0
D4	Digit 4 of counter
D3	Digit 3 of counter
D2	Digit 2 of counter
D1	Digit 1 of counter
D0	Digit 0 of counter
CFG	PC0 = 1, PC1 = 0, LOCK0 = 1/0 depending on application
USER0	All 1
UKEY0	Transport code

8.0 DEVICE CHARACTERISTICS**TABLE 8-1: ABSOLUTE MAXIMUM RATINGS**

Description	Symbol	Min.	Max.	Units
Supply voltage, with respect to GND	V _{DD}	-0.3	6.0	V
Input voltage, with respect to GND	V _I	-0.3	6.0	V
Storage temperature	T _S	-55	+85	°C
ESD protection on all pins (HBM)	V _{ESD}	—	4000	V

TABLE 8-2: DC CHARACTERISTICSV_{DD}: 5.0 V ± 10%T_A: -40°C to +85°C

Description	Symbol	Min.	Typ.	Max.	Units	Condition
Current when reading	I _{DDR}	—	300	600	μA	SDIO = V _{DD}
Current when programming	I _{DDP}	—	1.2	1.6	mA	SDIO = V _{DD}
Input low voltage	V _{IL}	—	—	0.8	V	
Input high voltage	V _{IH}	3.0	—	—	V	
Output low voltage	V _{OL}	—	—	0.4	V	Sinking current, I _O = 1 mA

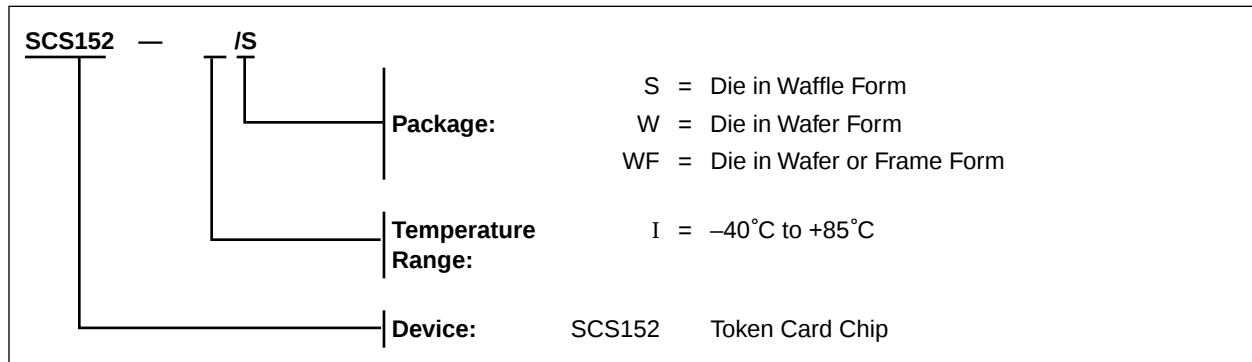
TABLE 8-3: AC CHARACTERISTICSV_{DD}: 5 V ± 10%T_A: -40°C to +85°CR_{PU} = 10K

Description	Symbol	Min.	Typ.	Max.	Units
Time from V _{DD} high until device accepts commands	T _{POR}	—	—	3.5	ms
Overlap of SCI with SCK during RESET	T _{OX}	2.0	—	—	μs
Overlap period of SCI and SCK during RESET	T _R	35.0	—	—	μs
SCK high	T _H	10.0	—	—	μs
SCK low	T _L	10.0	—	—	μs
SCK/SCI falling to SCI changing for BITPROG, ERASE, etc.	T _C	5.0	—	—	μs
SCI high pulse during BITPROT, ERASE, etc.	T _S	2.0	—	—	μs
SDIO changing from falling edge of SCI/SCK during RESET	T _{D1}	—	1.8	—	μs
SDIO changing from falling edge of SCK during RDBIT	T _{D2}	—	1.8	4.7	μs
SDIO tri-state after rising edge of SCK	T _{D3}	—	4.5	—	μs
Time to program EEPROM during BITPROG, ERASE, DECR-ERASE, etc.	T _{PROG}	1.4	—	3.4	ms
Time to compute signature from falling edge of SCK where last challenge bit is entered	T _{SIGN}	—	—	2.5	ms

NOTES:

SCS152 PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

**Sales and Support****Data Sheets**

Products supported by a preliminary Data Sheet may have an errata sheet describing minor operational differences and recommended workarounds. To determine if an errata sheet exists for a particular device, please contact one of the following:

1. Your local Microchip sales office.
2. The Microchip Corporate Literature Center U.S. FAX: (602) 786-7277.
3. The Microchip's Bulletin Board, via your local CompuServe number (CompuServe membership NOT required).



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