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Dogan Ibrahim

SD Card Projects Using the PIC Microcontroller

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CHAPTER 3

Memory Cards

3.1 Memory Card Types

A memory card (also called a flash memory card) is a solid-state electronic data storage device. First invented by Toshiba in the 1980s, memory cards save the stored data even after the memory device is disconnected from its power source. This ability to retain data is the key for flash memory card applications, for example, in digital cameras, where the saved pictures are not lost after the memory card is removed from the camera.

Nowadays, memory cards are used in consumer electronics and industrial applications. In consumer devices, we see the use of memory cards in applications like

- Personal computers
- Digital cameras
- Mobile phones
- Video cameras
- Notebook computers
- Global positioning systems
- MP3 players
- Personal digital assistants

In industrial applications, we see the use of memory cards in

- Embedded computers
- Networking products
- Military systems
- Communication devices
- Medical products

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- Security systems
- Handheld scanners

Memory cards are based on two technologies: NOR technology and NAND technology. NOR technology provides high-speed random access capabilities, where data as small as a single byte can be retrieved. NOR technology-based memory cards are often found in mobile phones, personal digital assistants, and computers. NAND technology was invented after the NOR technology, and it allows sequential access to the data in single pages but cannot retrieve single bytes of data like NOR flash. NAND technology-based memory cards are commonly found in digital cameras, mobile phones, audio and video devices, and other devices where the data is written and read sequentially.

There are many different types of memory cards available in the market. Some of the most commonly known memory cards are

- Smart media (SM) card
- Multimedia card (MMC)
- Compact flash (CF) card
- Memory stick (MS) card
- Microdrive
- xD card
- Secure digital (SD) card

The specifications and details of each card are summarized in the following sections.

3.2 Smart Media Card

The SM card was first developed in 1995 by Toshiba and was also called the Solid State Floppy Disc Card (SSFDC). The SM card consists of a single NAND flash chip embedded in a thin plastic card, and it is the thinnest card of all. Figure 3.1 shows a typical SM card. The dimensions of the card are $45.0 \times 37.0 \times 0.76$ mm, and it weighs only 1.8 g. The card consists of a flat electrode terminal with 22 pins.

The SM card was mainly used in Fuji and Olympus cameras, where it had approximately 50% of the memory card share in 2001. The capacities of these cards ranged from 0.5 to 128 MB, and the data transfer rate was approximately 2 MB/s. SM cards started having problems as camera resolution increased considerably and cards greater than 128 MB were

Figure 3.1: Smart Media Card

Figure 3.2: Multimedia Card

not available. SM cards were designed to operate at either 3.3 or 5 V, and a small notched corner was used to protect 3.3-V cards from being inserted into 5-V readers.

SM cards incorporated a copy protection mechanism known as the "ID," which gave every card a unique identification number for use with copy protection systems.

SM cards are no longer manufactured, and Fujifilm and Olympus both switched to xD cards. Now, no devices are designed to use SM cards, but 128-MB cards for old devices can still be obtained from memory card suppliers.

3.3 Multimedia Card

MMCs were first developed in the late 1970s by Intgenix and SanDisk. These cards were initially used in mobile phone and pager devices, but today they are commonly used in many other electronic devices. MMCs are backward compatible with SD cards, and they can be plugged into SD card slots. The reverse is not possible because SD cards are thicker (2.1 mm) and will not fit into MMC slots. Figure 3.2 is a picture of a typical MMC. The card dimensions are 24.0 × 32.0 × 1.4 mm and it has 8 pins.

The MMC operating voltage is 3.3 V, and the data transfer rate is approximately 2.5 MB/s. MMCs are available with capacities up to 4 GB. The older MMCs have been replaced by new multimedia *mobile* cards. These cards offer higher performance than older MMCs, and they offer lower working voltages (1.8–3.3 V) to reduce power consumption in portable devices.

3.4 Compact Flash Card

CF cards were first developed in 1994 by SanDisk. These are the cards offering the highest capacities, from 2 MB to 100 GB. Today, CF cards are used in expensive professional digital cameras and other professional mass storage devices. Low-capacity cards (up to 2 GB) use the FAT16 filing system, and cards with capacities higher than 2 GB use the FAT32 filing system.

There are two versions of CF cards: Type I and Type II. The only physical difference between the two types is that Type II cards are thicker than Type I cards. Type I card dimensions are $43.0 \times 36.0 \times 3.3$ mm and Type II cards are $43.0 \times 36.0 \times 5.0$ mm. Both cards have 50 pins. The Type I interface can supply up to 70 mA to the card, and the Type II interface can supply up to 500 mA. The card operating voltage is 3.3 or 5 V. Figure 3.3 shows a typical CF card.

There are four speeds of CF cards: a Standard CF, a CF High Speed (CF 2.0 with a data transfer rate of 16 MB/s), a faster CF 3.0 with a data transfer rate of 66 MB/s, and the fastest CF 4.0 standard with a data transfer rate of 133 MB/s. A future version of the CF cards, known as CFast, will be based on the Serial ATA bus with an expected speed of 300 MB/s.

The memory card speed is usually specified using the "x" rating. This is the speed of the first audio CD-ROM, which was 150 KB/s. For example, a card with a speed of 10x corresponds to a data transfer rate of 10×150 KB/s = 1.5 MB/s. Table 3.1 lists some of the commonly used speed ratings in memory cards.

The advantages of CF cards are as follows:

- CF cards are rugged and more durable than other types of cards, and they can withstand more physical damage than other cards.
- CF cards are available at very high storage capacities.
- CF cards operate at high speeds.
- CF cards are compatible with the IDE/ATA hard-disk standards, and thus they can be used in many embedded systems to replace hard disks.

Besides the advantages, the CF cards have some disadvantages, such as lack of a mechanical write protection switch or notch, and its large dimensions in comparison with other cards limit its use in slim devices.

Figure 3.3: Compact Flash Card

Table 3.1: Memory Card Speed Ratings

Speed Rating	Speed (MB/s)
6x	0.9
32x	4.8
40x	6.0
66x	10.0
100x	15.0
133x	20.0
150x	22.5
200x	30.0
266x	40.0
300x	45.0

Figure 3.4: Memory Stick Card

3.5 Memory Stick Card

The MS cards were first developed by Sony in 1998. Although the original MS was only 128 MB, the largest capacity currently available is 16 GB. Figure 3.4 shows a typical MS card.

The original MS, although it is not manufactured any more, is approximately the size and thickness of a stick of chewing gum. MS has now been replaced with Memory Stick PRO, Memory Stick Duo, and Memory Stick PRO-HG.

Memory Stick PRO was introduced in 2003 as a joint effort between Sony and SanDisk, and it allows a greater storage capacity and faster file transfer rate than the original MS.

Memory Stick Duo was developed as a result of the need for smaller and faster memory cards. It is smaller than the standard MS card, but an adapter allows it to be used in original MS applications.

Memory Stick PRO-HG was developed by Sony and SanDisk together in 2006. The data transfer speed of this card is 60 MB/s, which exceeds the speeds of all previous memory cards and is approximately three times faster than the Memory Stick PRO cards.

3.6 Microdrive

Microdrive is basically a hard disk designed to fit into a Type II CF card size enclosure. Although the size of a microdrive is same as that of a CF card, its power consumption is much higher than flash memories and therefore cannot be used in low-power applications. The capacity of microdrives is 8 GB or more. Figure 3.5 shows a typical microdrive.

The physical dimensions of microdrives are $42.8 \times 36.4 \times 5.0$ mm, and they weigh approximately 16 g. The first microdrive was developed by IBM in 1999 with a capacity of 170 and 340 MB. Soon after, the capacity was increased to greater than 2 GB in the year 2003 by Hitachi. Microdrives with a capacity of 8 GB were introduced in 2008 by Hitachi and Seagate.

The advantage of microdrives is that they allow more write cycles than the memory cards. In addition, microdrives are better at handling power loss in the middle of writing. One of the disadvantages of microdrives is that they do not survive if dropped from a height of 1.2 m. In addition, their transfer speeds are around 5 MB/s, which is lower than most of the present day high-end memory cards. In addition, they are not designed to operate at high altitudes, and their power consumption is high compared with memory cards.

3.7 xD Card

xD stands for e**x**treme **D**igital, and these cards are mainly used in digital cameras, digital voice recorders, and MP3 players. xD cards were developed by Olympus and Fujifilm in 2002 and then manufactured by Toshiba Corporation and Samsung Electronics. Figure 3.6 is a picture of a typical xD card. xD cards are available in three types: Type M, Type H, and Type M+.

Figure 3.5: Microdrive

Figure 3.6: xD Card

Type M cards were developed in 2005 and are available in capacities up to 2 GB. The read and write speeds of these cards are 4 and 2.5 MB/s, respectively.

Type H xD cards were first released in 2005 have the advantage of a higher data transfer speed. These cards are also available in capacities up to 2 GB with read and write speeds of 5 and 4 MB/s, respectively. Unfortunately, the production of Type H cards has now been discontinued due to their high production costs.

Type M+ xD cards were first released in 2008, and their capacities are up to 2 GB. These cards are the fastest xD cards, with read and write speeds of 6 and 3/75 MB/s, respectively.

The advantage of xD cards is that they are faster than SM cards, MMCs, and MS cards. In addition, their small size makes them attractive in portable low-power applications. Some of the disadvantages of xD cards are their higher cost, bigger size than some other memory cards (such as microSD), and the fact that they are proprietary to Fujifilm and Olympus. This means that there is no publicly available documentation on their design and implementation.

3.8 Secure Digital Card

SD cards are probably the most widely used memory cards today. The SD card was originally developed by Matsushita, SanDisk, and Toshiba in 2000. SD cards nowadays a used in many portable devices, such as digital cameras, mobile phones, PDAs, handheld computers, video recorders, GPS receivers, video game consoles, and so on.

Standard SD cards are available with capacities from 4 MB to 4 GB. Recently, a new type of SD card called the high-capacity SD card (SDHC) has been developed with capacities ranging from 4 to 32 GB. It has been announced that a new specification called eXtended Capacity (SDXC) will allow capacities to reach 2 TB.

SD cards are based on MMC, but they have a number of differences: SD cards are physically thicker than MMCs and would not fit into MMC slots. The MMC, on the other hand, can be easily inserted into SD card slots. In addition, SD cards are shaped asymmetrically to prevent them being inserted upside down, whereas an MMC would go in either direction, although it will not make contact if inserted upside down. In addition, the internal register structures of the two types of cards are not the same.

3.8.1 Standard SD Cards

SD cards are available in three different sizes: normal SD, miniSD, and microSD. Figure 3.7 shows the three types of SD cards.

Normal SD cards have the dimensions $24.0 \times 32.0 \times 2.1$ mm and a weight of 2 g. A write-protect switch is provided on the card to stop accidental deletion of the contents of

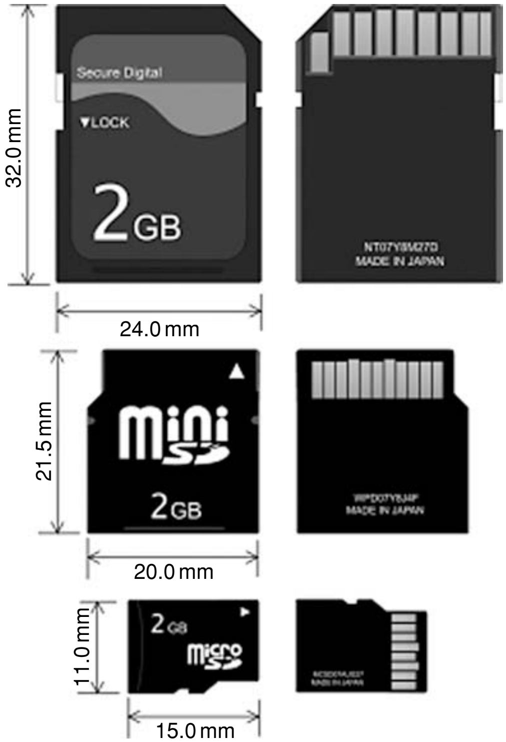


Figure 3.7: SD Cards

the card. The data transfer speed is approximately 15–20 MB/s. Normal SD cards operate at 2.7–3.6 V and have 9 pins.

miniSD cards were first released in 2003. They have the dimensions 20.0 × 21.5 × 1.4 mm and a weight of 1 g. A write-protect switch is not provided on the card. The data transfer speed is approximately 15 MB/s. miniSD cards operate at 2.7–3.6 V and have 11 pins. miniSD cards are available in capacities ranging from 16 MB to 8 GB.

microSD cards were released in 2008, and they have the dimensions 11.0 × 15.0 × 1.0 mm and a weight of 0.5 g. As in the miniSD cards, no write-protect switch is provided on the card. The data transfer rate and the card operating voltages are same as in miniSD cards, and they have 8 pins. microSD cards are available in capacities ranging from 64 MB to 4 GB.

Standard SD cards are available up to a capacity of 2 GB. Table 3.2 shows a comparison of all three standard SD cards. miniSD and microSD cards can be used with adapters in normal SD card applications. Figure 3.8 shows a typical miniSD card adapter.

Table 3.2: Comparison of Standard SD Cards

Property	SD	miniSD	microSD
Width	24 mm	20 mm	11 mm
Length	32 mm	21.5 mm	15 mm
Thickness	2.1 mm	1.4 mm	1 mm
Weight	2 g	1 g	0.5 g
Operating voltage	2.7–3.6 V	2.7–3.6 V	2.7–3.6 V
No. of pins	9	11	8

Figure 3.8: miniSD Card Adapter

Standard SD cards (up to 2 GB) are usually shipped with the FAT16 file system preloaded on the card.

3.8.2 High-Capacity SD Cards

Secure Digital SDHC was released in 2006 and is an extension of the standard SD card format. SDHC cards provide capacities f 2 GB up to 32 GB. It is important to realize that although the SDHC cards have the same physical dimensions as the standard SD cards, they use different protocols and as such will only work in SDHC-compatible devices and not in standard SD card applications. SDHC cards should not be used in standard SD compatible devices. Standard SD cards are, however, forward compatible with SDHC host devices, making standard SD cards compatible with both SD and SDHC host devices.

SDHC cards offer

- Larger data capacities
- Larger number of files
- FAT32 filing system (instead of the FAT16)
- Higher data transfer rates
- Content protection for recordable media (CPRM) copyright protection
- Standard SD card physical size compatibility

Figure 3.9: Class 6 SDHC Card

Figure 3.10: A Typical Memory Card Reader

SDHC cards have Speed Class Ratings defined by the SD Association. The defined classes are

- Class 2: data transfer rate 2 MB/s
- Class 4: data transfer rate 4 MB/s
- Class 6: data transfer rate 6 MB/s

The Speed Class Rating of a card is labeled on the card. Figure 3.9 shows a typical Class 6 SDHC card. SDHC cards are identified with the letters “HC” labeled on the card as a logo.

SDHC cards are normally shipped with the FAT32 filing system preloaded on the card. These cards are used in applications requiring high capacities, such as video recorders, MP3 players, and general large-volume data storage, and by users in general who want higher performance from their high-end digital devices.

Like standard SD cards, SDHC cards come in three types: normal SDHC, miniSDHC, and microSDHC.

3.9 Memory Card Readers

Memory card readers are usually in the form of small devices with many different types of sockets compatible with various memory cards. Figure 3.10 shows a typical memory card reader. The card reader is normally connected to the USB port of the PC, and most card readers accept most of the popular cards available on the market. Old card readers are based on the USB 1.1 specification with 12 Mb/s, whereas new card readers are based on the USB 2.0 specification, with a maximum data transfer rate of 480 Mb/s. When a memory card is inserted into it, the device automatically detects the card and assigns a drive letter to the slot where the card is inserted. Data on the card can be read as files or files can be copied to the card using the standard Windows Explorer functions.

3.10 Memory Card Physical Properties

Table 3.3 gives a comparison of the physical properties of commonly used memory cards. As can be seen from the table, the microSD card has the smallest form factor.

3.11 Memory Card Technical Properties

Table 3.4 gives a comparison of the technical properties of commonly used memory cards.

Table 3.3: Physical Properties of Memory Cards

Card	Width (mm)	Length (mm)	Thickness (mm)	Weight (g)
CF – Type I	43.0	36.0	3.3	3.3
CF – Type II	43.0	36.0	5.0	5.0
SM	37.0	45.0	0.76	2.0
MMC	24.0	32.0	1.4	1.3
RS-MMC	24.0	16.0	1.4	1.3
MMC-micro	14.0	12.0	1.1	1.0
MS	21.5	50.0	2.8	4.0
MS PRO Duo	20.0	31.0	1.6	2.0
SD	24.0	32.0	2.1	2.0
miniSD	20.0	21.5	1.4	0.5
microSD	15.0	11.0	1.0	0.27
xD	25.0	20.0	1.78	2.8

Table 3.4: Technical Properties of Memory Cards

Card	Max Capacity (2009)	Max Write Speed (MB/s)	Max Read Speed (MB/s)	Operating Voltage (V)	Pin Count
CF – Type I	32 GB	133	133	3.5 and 5.0	50
CF – Type II	32 GB	133	133	3.3 and 5.0	50
SM	128 MB	20	20	3.3 and 5.0	22
MMC	4 GB	52	52	3.3	7
RS-MMC	2 GB	52	52	3.3	7
MMC micro	2 GB	40	40	3.3	13
MS	128 MB	160	160	3.3	10
MS PRO Duo	16 GB	160	160	3.3	10
SD	4 GB	150	150	3.3	9
miniSD	4 GB	100	100	3.3	11
microSD	4 GB	100	100	3.3	8
SDHC	64 GB	48	48	3.3	9

3.12 Detailed SD Card Structure

As the topic of this book is SD cards, the internal structure and the use of these cards in PIC microcontroller-based systems will be described in this section.

3.12.1 SD Card Pin Configuration

Figure 3.11 shows the pin configuration of a standard SD card. The card has nine pins, as shown in the figure, and a write-protect switch to enable/disable writing onto the card.

A standard SD card can be operated in two modes: the *SD Bus mode* and the *SPI Bus mode*. SD Bus mode is the native operating mode of the card, and all the pins are used in this mode. Data is transferred using four pins (D0–D3), a clock (CLK) pin, and a command line (CMD). Data can be transferred from the card to the host or vice versa over the four data lines. Figure 3.12 shows the SD card connection in SD Bus mode.

SPI Bus mode is the more commonly used mode, and it allows data to be transferred on two lines (DO and DI) in serial format using a chip select (CS) and a CLK line. The SPI mode is easier to use, but it has the disadvantage of reduced performance compared with the SD mode of operation. Figure 3.13 shows the SD card connections in SPI mode.

SD card pins have different meanings depending upon the mode of operation. Table 3.5 shows the pin assignments when the card is operated in SD Bus and SPI Bus modes.

The projects in this book are based on the operations in the SPI Bus mode. The following pins are used in SPI Bus mode:

- Chip select – Pin 1
- Data in – Pin 2
- Clock – Pin 5
- Data out – Pin 7

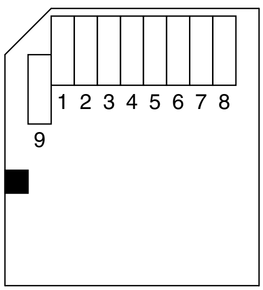


Figure 3.11: Standard SD Card Pin Configuration

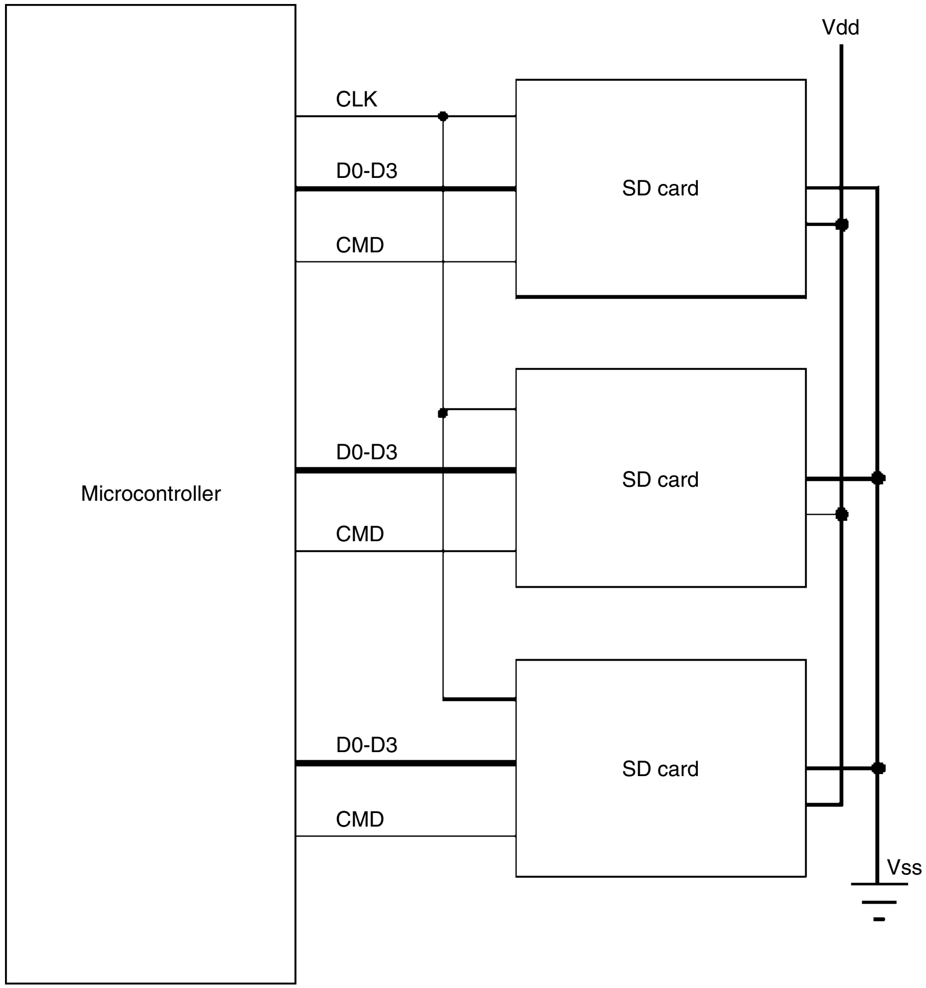


Figure 3.12: SD Card in SD Bus Mode

In addition, pin 4 must be connected to the supply voltage, and pins 3 and 6 must be connected to the supply ground.

3.12.2 SD Card Interface

Before we can use an SD card in an electronic circuit, we have to know the interface signal levels. Table 3.6 shows the input–output voltage levels of the standard SD cards.

According to Table 3.6,

Minimum logic 1 output voltage, VOH = 2.475 V

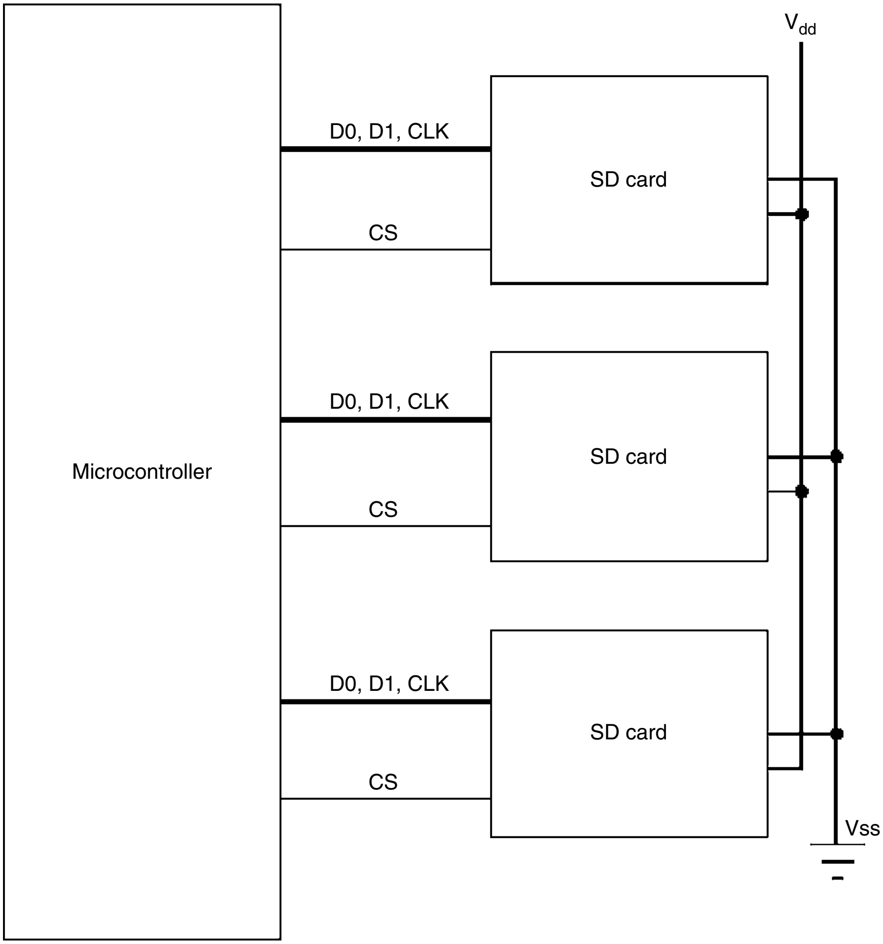


Figure 3.13: SD Card in SPI Bus Mode

Table 3.5: SD Card Pin Assignments

Pin No	Name	SD Mode	SPI Mode
1	CD/DAT3	Card detect/Data line	Chip select
2	CMD	Command response	Data in
3	Vss	Ground	Ground
4	Vdd	Supply voltage	Supply voltage
5	CLK	Clock	Clock
6	Vss	Ground	Ground
7	DAT0	Data line	Data out
8	DAT1	Data line	Reserved
9	DAT2	Data line	Reserved

Table 3.6: SD Card Input–Output Voltage Levels

	Symbol	Minimum	Maximum
Logic 1 output voltage	VOH	$0.75 \times Vdd$	
Logic 0 output voltage	VOL		$0.125 \times Vdd$
Logic 1 input voltage	VIH	$0.625 \times Vdd$	$Vdd + 0.3$
Logic 0 input voltage	VIL	$Vss - 0.3$	$0.25 \times Vdd$

Maximum logic 0 output voltage, VOL = 0.4125 V

Minimum required logic 1 input voltage, VIH = 2.0625 V

Maximum logic 1 input voltage = 3.6 V

Maximum required logic 0 input voltage, VIL = 0.825 V

When connected to a PIC microcontroller, the output voltage (2.475 V) of the SD card is enough to drive the input circuit of the microcontroller. The typical logic 1 output voltage of a PIC microcontroller pin is 4.3 V, and this is too high when applied as an input to a microcontroller pin, where the maximum voltage should not exceed 3.6 V. As a result of this, it is required to use resistors at the inputs of the SD card to lower the input voltage. Figure 3.14 shows a typical SD card interface to a PIC microcontroller. In this figure, 2.2- and 3.3-K resistors are used as a potential divider circuit to lower the SD card input voltage to approximately 2.48 V, as shown below.

$$\text{SD card input voltage} = 4.3\,\text{V} \times 3.3\,\text{K}/(2.2\,\text{K} + 3.3\,\text{K}) = 2.48\,\text{V}.$$

In Figure 3.14, the SD card is connected to PORTC pins of the microcontroller as follows:

SD Card Pin	Microcontroller Pin
CS	RC2
CLK	RC3
DO	RC4
DI	RC5

This is the recommended connection because it uses the SPI Bus port pins of the microcontroller (RC3, RC4, and RC5).

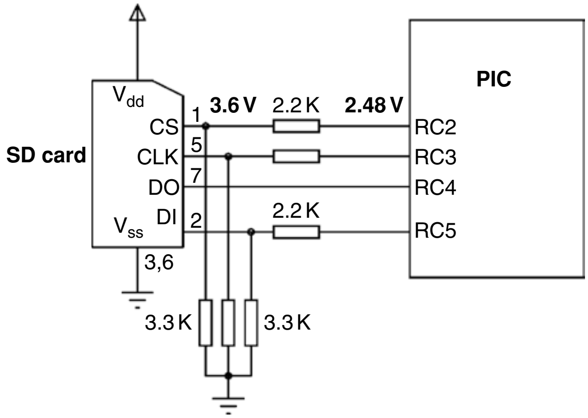


Figure 3.14: PIC Microcontroller SD Card Interface

SD cards support "hot" insertion of the card, i.e., the card can be inserted into the circuit without powering down the host. This is usually achieved through the card connector. Connector manufacturers usually provide sockets that have power pins long enough to power the card before any contact is made with the other pins.

A feature of most SD cards is the automatic entry and exit from sleep mode. After an operation, cards usually enter a sleep mode to conserve power-in, if no more commands are received within 5 ms. Although the host does not need to do anything for this to happen, it is recommended that the host shut the clock generation. Any command sent to the card will force it to exit from the sleep mode.

SD cards can consume up to 100–200 mA while reading or writing onto the card. This is usually a high current, and an appropriate voltage regulator capable of supplying the required current must be used in the design. The card consumes approximately 150 µA in sleep mode.

3.13 SD Card Internal Registers

The operations of SD cards are controlled by a number of internal registers. Some registers are 16 bits wide, some are 32 bits wide, and some are 128 bits wide. Table 3.7 gives a list of all the registers.

Detailed information on the functions and bit definitions of all the registers can be found in the product manuals of card manufacturers (e.g., *SanDisk Secure Digital Card, Product Manual, Document no: 80-13-00169, 2003*). The details of the important registers and their bit definitions are given in this section.

Table 3.7: SD Card Registers

Register	Width (Bits)	Description
OCR	32	Operation condition
CID	128	Card information
CSD	128	Card specific information
RCA	16	Relative card address
DSR	16	Driver stage register
SCR	64	Special features
Status	512	Status bits

3.13.1 OCR Register

The OCR register is 32 bits wide, and it describes the operating voltage range and status bits in the power supply. Table 3.8 shows the bit definitions of the OCR register. In summary,

- Bits 0–3 are reserved
- Bits 4–23 describe the SD card voltage
- Bits 24–30 are reserved
- Bit 31 is the power-up busy status bit. This bit is set to "1" after the power-up initialization of the card has been completed.

The initial value of the OCR register is usually set to binary value:

"*000 0000 1111 1111 1000 0000 0000 0000," which corresponds to 2.7–3.6 V operation (OCR bits 15–23 are all logic 1). Bit "*" indicates the busy status of the card at power-up.

3.13.2 CID Register

This is a 128-bit register that contains the card identification information specific to card manufacturers. Table 3.9 shows the bit definitions of the CID register. In summary,

- Bit 0 is reserved and is always "1."
- **CRC:** Bits 1–7 are CRC bits.
- **MDT:** Bits 8–19 are the manufacturing date.
    - Bits 8–11 are the Month field (01h = January).
    - Bits 12–19 are the Year field (00h = 2000).
    - Bits 20–23 are reserved (all "0"s).
- **PSN:** Bits 24–55 are the serial number (unsigned integer).

Table 3.8: OCR Register Bit Definitions

OCR Bit	Card Voltage	Initial Value
31	Card busy bit	"0" = busy, "1" = ready
30–24	Reserved	All "0"s
23	3.6–3.5	1
22	3.5–3.4	1
21	3.4–3.3	1
20	3.3–3.2	1
19	3.2–3.1	1
18	3.1–3.0	1
17	3.0–2.9	1
16	2.9–2.8	1
15	2.8–2.7	1
14	2.7–2.6	0
13	2.6–2.5	0
12	2.5–2.4	0
11	2.4–2.3	0
10	2.3–2.2	0
9	2.2–2.1	0
8	2.1–2.2	0
7	2.0–1.9	0
6	1.9–1.8	0
5	1.8–1.7	0
4	1.7–1.6	0
3–0	Reserved	All "0"s

Table 3.9: CID Register Bit Definitions

Field	Width	Bit Position	Description
MID	8	127–120	Manufacturer's ID
OID	16	119–104	Card OEM
PNM	40	103–64	Product code
PRV	8	63–56	Product revision
PSN	32	55–24	Serial number
—	4	23–20	0
MDT	12	19–8	Manufacturing date
CRC	7	7–1	Checksum
—	1	0	1

- **PRV:** Bits 56–63 are the Product Revision of the card.
- **PNM:** Bits 64–103 are the 5-ASCII-character Product Code, for example,
    - SD064 is 64 MB card.
    - SD128 is 128 MB card.
    - SD256 is 256 MB card.
- **OID:** Bits 104–119 are the card OEM, allocated by the SD Card Association, for example,
    - TM indicates Toshiba.
    - SD indicates SanDisk.
- **MID:** Bits 120–127 are the Manufacturer's ID, for example,
    - 02h indicates Toshiba.
    - 03h indicates SanDisk.

As an example, the Toshiba 64-MB card has the following initial values in its 128-bit CID register (in hexadecimal, "*" depends on the card, and "#" depends on values on the card):

MID: 02

OID: 54 4D

PNM: 53 44 30 36 34

PRV: * *

PSN: * * * * * * * *

0

MDT: * * *

CRC: # #

3.13.3 CSD Register

CSD is the 128-bit Card Specific Data register that contains information required to access the data on the card. Some fields of the CSD register are read only, whereas some other fields are writeable. Table 3.10 shows bit definitions of the CSD register. In summary,

- **CSD_STRUCTURE:** Bits 126–127 are the CSD structure version number.
- Bits 120–125 are reserved (all "0").

Table 3.10: CSD Register Bit Definitions

Field	Description	Width	Bits	*Value	Code
CSD_STRUCTURE	CSD structure	2	127–126	1.0	00b
—		6	125–120	—	000000b
TAAC	Data read access time	8	119–112	10 ms	00001111b
NSAC	Data read access time	8	111–104	0	00000000b
TRAN_SPEED	Max data transfer rate	8	103–96	25 MHz	00110010b
CCC	Command classes	12	95–84	All	1F5h
READ_BL_LEN	Max read block length	4	83–80	512 bytes	1001h
READ_BL_PARTIAL	Partial read blocks allowed	1	79–79	Yes	1b
WRITE_BLK_MISALIGN	Write block misalignment	1	78–78	No	0b
READ_BLK_MISALIGN	Read block misalignment	1	77–77	No	0b
DSR_IMP	DSR implemented	1	76–76	No	0b
—	Reserved	2	75–74	—	00b
C_SIZE	Device size	12	73–62	899	383h
VDD_R_CURR_MIN	Max. Read current at Vdd min	3	61–59	100 mA	111b
VDD_R_CURR_MAX	Max. Read current at Vdd max	3	58–56	80 mA	110b
VDD_W_CURR_MIN	Max. Write current at Vdd min	3	55–53	100 mA	111b
VDD_W_CURR_MAX	Max. Write current at Vdd max	3	52–50	80 mA	110b
C_SIZE_MULT	Device size multiplier	3	49–47	32	011b
ERASE_BLK_EN	Erase single block enable	1	46–46	Yes	1b
SECTOR_SIZE	Erase sector size	7	45–39	32 blocks	0011111b
WP_GRP_SIZE	Write protect group size	7	38–32	128 sectors	1111111b
WP_GRP_ENABLE	Write protect group enable	1	31–31	Yes	1b
—	Reserved	2	30–29	—	00b
R2W_FACTOR	Write speed factor	3	28–26	X16	100b
		3	28–26	X4	010b
WRITE_BL_LEN	Max write block length	4	25–22	512 bytes	1001b
WRITE_BL_PARTIAL	Partial write allowed	1	21–21	No	0b
—	Reserved	5	20–16	—	00000b
FILE_FORMAT_GRP	File format group	1	15–15	0	0b
COPY	Copy flag	1	14–14	Not original	0b
PERM_WRITE_PROTECT	Permanent write protection	1	13–13	Not protected	0b
TMP_WRITE_PROTECT	Temporary write protection	1	12–12	Not protected	0b
FILE_FORMAT	File format	2	11–10	HD w/ partition	00b
—	Reserved	2	9–8	—	00b

Table 3.10: CSD Register Bit Definitions —cont'd

Field	Description	Width	Bits	*Value	Code
CRC	CRC	7	7–1	–	
–	Always 1	1	0–0	–	1b

*values are based on a 16 MB SanDisk card.

- **TAAC:** Bits 112–119 define the asynchronous part of the read access time of the card. The bits are decoded as follows:

TAAC bit	Code
2–0	Time unit. 0 = 1 ns, 1 = 10 ns, 2 = 100 ns, 3 = 1 µs, 4 = 10 µs, 5 = 100 µs
6–3	Time value. 0 = Reserved, 1 = 1.0, 2 = 1.2, 3 = 1.3, 4 = 1.5, 5 = 2.0, 6 = 2.5, 7 = 3.0, 8 = 3.5, 9 = 4.0, A = 4.5, B = 5.0, C = 5.5, D = 6.0, E = 7.0, F = 8.0
7	Reserved

- **NSAC:** Bits 104–111 define the worst case for the clock-dependent factor of the data access time. The unit is 100 clock cycles. The total access time is equal to TAAC plus NSAC.

- **TRAN_SPEED:** Bits 96–103 define the maximum data transfer rate. The bits are decoded as follows:

TRAN_SPEED bit	Code
2–0	Transfer Rate Unit. 0 = 100 kb/s, 1 = 1 Mb/s, 2 = 10 Mb/s, 3 = 100 Mb/s, 4–7 = Reserved
6–3	Time Value. 0 = Reserved, 1 = 1.0, 2 = 1.2, 3 = 1.3, 4 = 1.5, 5 = 2.0, 6 = 2.5, 7 = 3.0, 8 = 3.5, 9 = 4.0, A = 4.5, B = 5.0, C = 5.5, D = 6.0, E = 7.0, F = 8.0
7	Reserved

- **CCC:** Bits 84–95 define the command classes that are supported by the card. The bit definitions are as follows:

CCC bit	Supported card command class
0	Class 0
1	Class1

…	…
11	Class 11

- **READ_BL_LEN:** Bits 80–83 define the maximum read data block length, which is equal to $2^{READ\_BL\_LEN}$. The data block length is specified as follows:

READ_BL_LEN	**Block Length**
0–8	Reserved
9	$2^9 = 512$ bytes
…	…
10	$2^{11} = 2048$ bytes
12–15	Reserved

- Bit 79 is always "1."
- **WRITE_BLK_MISALIGN:** Bit 78 defines whether the data block to be written by one command can be spread over more than one physical block:

WRITE_BLK_MISALIGN	**Access Block boundary write**
0	Not allowed
1	Allowed

- **READ_BLK_MISALIGN:** Bit 77 defines whether the data block to be read by one command can be spread over more than one physical block:

READ_BLK_MISALIGN	**Access Block boundary read**
0	Not allowed
1	Allowed

- **DSR_IMP:** Bit 76, if set, a driver stage register (DSR) is implemented.
- Bits 74–75 are reserved.
- **C_SIZE:** Bits 62–73 define the user's data card capacity as follows:

$$\text{Memory capacity} = \text{BLOCKNR} * \text{BLOCK\_LEN},$$

where

$$\text{BLOCKNR} = (\text{C\_SIZE} + 1) * \text{MULT}$$

$$\text{MULT} = 2^{\text{C\_SIZ\_MULT} + 2} \qquad \text{if C\_SIZE\_MULT} < 8$$

and

$$\text{BLOCK\_LEN} = 2^{\text{READ\_BL\_LEN}} \qquad \text{if READ\_BL\_LEN} < 12.$$

- Bits 50–61 define the maximum and minimum values for read/write currents

- **C_SIZE_MULT:** Bits 47–49 are used to compute the user's data card capacity multiply factor:

C_SIZE_MULT	MULT
0	$2^2 = 4$
1	$2^3 = 8$
2	$2^4 = 16$
3	$2^5 = 32$
4	$2^6 = 64$
5	$2^7 = 128$
6	$2^8 = 256$
7	$2^9 = 512$

- **ERASE_BLK_EN:** Bit 46 defines if host can erase by WRITE_BL_LEN:

ERASE_BLK_EN	Description
0	Host cannot erase by WRITE_BL_LEN
1	Host can erase by WRITE_BL_LEN

- **SECTOR_SIZE:** Bits 39–45 define the minimum erasable size as the number of write blocks.

- **WP_GRP_SIZE:** Bits 32–38 define the minimum number of sectors that can be set for the write protect group.

- **WP_GRP_ENABLE:** Bit 31 defines the write protect group functions:

WP_GRP_ENABLE	Description
0	Not implemented
1	Implemented

- Bits 29–30 are reserved.

- **R2W_FACTOR:** Bits 26–28 define a multiple number for a typical write time as a multiple of the read access time.

- **WRITE_BL_LEN:** Bits 22–25 define the maximum write block length, which is calculated as $2^{\text{WRITE\_BL\_LEN}}$. The data block length is specified as follows:

WRITE_BL_LEN	Block Length
0–9	Reserved
11	$2^9 = 512$ bytes
…	…
12	$2^{11} = 2048$ bytes
12–16	Reserved

- **WRITE_BL_PARTIAL:** Bit 21 defines whether partial block write is available:

WRITE_BL_PARTIAL	Write data size
0	Only WRITE_BL_LEN size of 512 bytes is available
1	Partial size write available

- Bits 16–20 are reserved.
- **FILE_FORMAT_GRP:** Bit 15 indicates the selected group of file format group and file format:

FILE_FORMAT_GRP	FILE_FORMAT	Kinds
0	0	Hard disk-like file system with partition table
0	1	DOS FAT with boot sector only (no partition table)
0	2	Universal File Format
0	3	Others
1	0, 1, 2, 3	Reserved

- **COPY:** Bit 14 defines the contents of the card as original or duplicated. The bit definition is:

COPY	Description
0	Original
1	Copy

- **PERM_WRITE_PROTECT:** Bit 13, if set, permanently write protects the card.
- **TMP_WRITE_PROTECT:** Bit 12, if set, temporarily write protects the card.
- **FILE_FORMAT:** Bits 10–11 define the file format on the card. This field is used together with field FILE_FORMAT_GRP as in the above table.
- Bits 8–9 are reserved.
- **CRC:** Bits 1–7 are the CRC error checking bits.
- Bit 0 is not used and is always "1."

3.13.4 RCA Register

This 16-bit register carries the card addresses in SD card mode.

3.13.5 DSR Register

This register is not implemented in many cards.

3.13.6 SCR Register

This 64-bit register provides information on the SD card's special features, such as the structure version number, the physical layer specification, the security algorithm used, and the bus width.

3.13.7 SD Status Register

This 512-bit register defines the card status bits and card features.

3.14 Calculating the SD Card Capacity

An example is given in this section to show how the capacity of an SD card can be calculated.

Example 3.1

The following CSD register fields are given by a card manufacturer:

C_SIZE = E27h (or decimal 3623)
C_SIZE_MULT = 3
READ_BL_LEN = 9

Calculate the capacity of this card.

Solution

The card capacity is defined by two fields within the CSD register: C_SIZE and C_SIZE_MULT. C_SIZE is a 12-bit value with an offset of 1 (1–4096), and C_SIZE_MULT is a 3-bit value with an offset of 2 (2–9).

The number of blocks on the card is given by

$$\text{BLOCKNR} = (\text{C\_SIZE} + 1) \times 2^{(\text{C\_SIZE\_MULT} + 2)},$$

where

$$\text{C\_SIZE\_MULT} < 8.$$

The default block length is 512 bytes (but it can also be specified as 1024 or 2048 bytes). The block length is calculated from

$$\text{BLOCK\_LEN} = 2^{\text{READ\_BL\_LEN}},$$

where

$$\text{READ\_BL\_LEN} = 9,\ 10,\ \text{or}\ 11.$$

Combining the two equations, we get the card capacity as

$$\text{Card Capacity (in bytes)} = \text{BLOCKNR} \times \text{BLOCK\_LEN}$$

or

$$\text{Card Capacity (in bytes)} = (\text{C\_SIZE} + 1) \times 2^{(\text{C\_SIZE\_MULT} + 2)} \times 2^{\text{READ\_BL\_LEN}}.$$

The capacity is usually shown in MB and

$$\text{Card Capacity (Megabyte)} = (\text{C\_SIZE} + 1) \times 2^{(\text{C\_SIZE\_MULT} + 2)} \times 2^{\text{READ\_BL\_LEN}}/(1024 \times 1024)$$

Using the CSD parameters given in this example, we get

$$\text{Card Capacity (Megabyte)} = 3624 \times 32 \times 512/(1024 \times 1024) = 56.525 \ \text{Megabytes}$$

It is interesting to note that when a block length of 1024 bytes is used (READ_BL_LEN = 10), cards up to 2 GB can be specified, and with a block length of 2048 bytes (READ_BL_LEN = 11), cards up to 4 GB can be specified. ■

3.15 SD Card SPI Bus Protocol

All communications between the host and the card are controlled by the host. Messages in the SPI bus protocol consist of commands, responses, and tokens. The card returns a response to every command received and also a data response token for every write command.

The SD card wakes up in SD card mode, and it will enter the SPI mode if its CS line is held low when a reset command is sent to the card. The card can only be returned to the SD mode after a power-down and power-up sequence.

When the SPI mode is entered, the card is in the nonprotected mode, where CRC checking is not used (CRC checking can be turned on and off by sending command CRC_ON_OFF, command name CMD59, to the card).

3.15.1 Data Read

Data can be read in either single or multiple blocks. The basic unit of data size is blocks, defined by field READ_BL_LEN of the CSD register. In this book, we shall be using only single-block reads. Single-block reads are initiated by issuing the command READ_SINGLE_BLOCK (CMD17) to the card. Any valid address can be used as the starting address.

3.15.2 Data Write

Data can be written in either single or multiple blocks. After receiving a valid write command, the card sends a response token and then waits for the data block to be sent from the host. The starting address can be any valid address. After receiving a data block from the host, the card returns a data response token and writes the data on the card if the data contains no errors.

Table 3.11: Some Important SD Card Commands

Command	Abbreviation	Argument	Response	Description
CMD0	GO_IDLE_STATE	None	R1	Reset the SD card
CMD1	SEND_OP_COND	None	R1	Initialize card
CMD9	SEND_CSD	None	R1	Get CSD register data
CMD10	SEND_CID	None	R1	Get CID register data
CMD17	READ_SINGLE_BLOCK	Data address (0:31)	R1	Read a block of data
CMD24	WRITE_BLOCK	Data address (0:31)	R1	Write a block of data

Table 3.12: Command Format

Byte 1			Bytes 2–5	Byte 6	
7	6	5 4 3 2 1 0	31...0	7 6 5 4 3 2 1	0
0	**1**	**Command**	**Command Argument**	**CRC**	**1**

There are a large number of commands available in SPI mode for reading the card registers, reading and writing single and multiple blocks of data, erasing blocks, etc. Table 3.11 gives a list of the important SD card commands. All SPI mode commands are 6 bytes long (48 bits). As shown in Table 3.12, the commands start with the most significant bit (MSB) as logic 0, a transmission bit as logic 1, 6 bits of command index, 32 bits of argument (not all commands need arguments), 7 bits of CRC, and an end-bit (logic 1). The commands are divided into classes. If no argument is required in a command, the value of the argument filed should be all "0"s. The command index contains the actual command number. For example, the command index value for command CMD8 is binary number 8 in 6 bits, i.e., "001000."

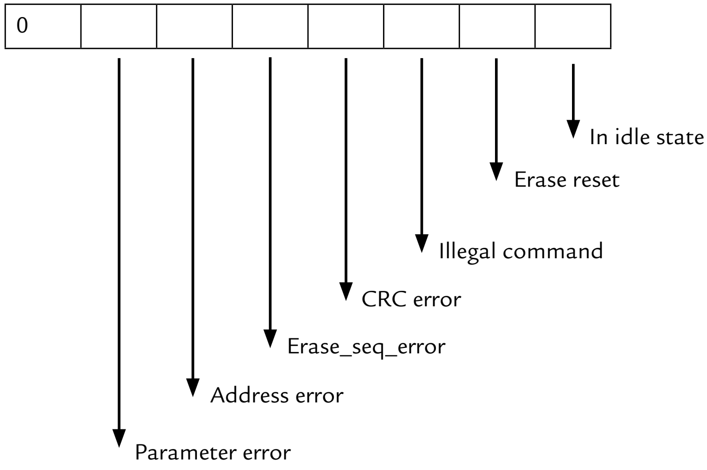
3.15.3 Response Tokens

There are several types of response tokens that can be sent by the card. A token is transmitted with the MSB bit sent first. The response tokens are as follows:

R1 Format: This response token is 1 byte long and is sent by the card after every command (except the SEND_STATUS command). The MSB bit is "0," and other bits indicate an error ("1" bit). For example, if bit "0" is set, it indicates that the card is in Idle State and running initialization sequence. Table 3.13 shows bit definitions of the R1 Format.

R1b Format: This format is similar to R1 Format with the addition of the busy signal.

Table 3.13: R1 Format bits



R2 Format: This response token is 2 bytes long and is sent as a response to command SEND_STATUS.

R3 Format: This response token is 5 bytes long and is sent in response to command READ_OCR. The first byte is identical to R1 format, whereas the other bytes contain the OCR register data.

Data Response Token: Whenever a data block is written to the card, the card acknowledges with a data response. This token is 1 byte long and has the following bit definitions:

Bit 0	Always 1
Bits 1–2	Status
Bit 3	Always 0
Bit 4	Reserved

The Status bits are defined as follows:

010	Data accepted
101	CRC error, data rejected
110	Write error, data rejected

3.16 Data Tokens

Data is received or transmitted via data tokens with all data bytes transmitted with the MSB first.

Data tokens are 4–515 bytes long and have the following format (for single-block operations):

- First Byte: START BLOCK

This block is identified by data "11111110," i.e., FEh.

- Bytes 2–513: USER DATA
- Last 2 bytes (byte 514 and byte 515): CRC

3.17 Card Reset State

After power-up, the SD card is in the Idle State. Sending command CMD0 also puts the card in the Idle State. At least 74 clock cycles should be sent to the card with the Data Out and CS lines set to logic "1" before starting to communicate with the card.

The SD card is initially in the SD Bus mode. It will enter the SPI mode if the CS line is held low while sending the CMD0 command. When the card switches to the SPI mode, it will respond with the SPI mode R1 response format. In SPI mode, CRC checking is disabled by default. However, because the card powers-up in the SD Bus mode, CMD0 command must be sent with a valid CRC byte before the card is put into SPI mode. When sending the CMD0 command, the CRC byte is fixed and is equal to 95h. The following hexadecimal 6-byte command sequence can then be used to send the CMD0 command after a power-up (see Table 3.12 with the command field set to "000000" for CMD0):

40 00 00 00 00 95

The steps to switch the SD card into SPI mode should therefore be as follows:

- Power-up.
- Send at least 74 clock pulses to the card with CS and Data Out lines set to logic "1."
- Set CD line low.
- Send 6-byte CMD0 command "40 00 00 00 00 95" to put the card in SPI mode.
- Check R1 response to make sure there are no error bits set.
- Send command CMD1 repeatedly until the "in-idle-state" bit in R1 response is set to "0," and there are no error bits set.
- The card is now ready for read/write operations.

During the reset state, the card clock frequency should be between 10–400 KHz. After the reset state, the maximum clock frequency can be increased to 25 MHz (20 MHz for the MMC).

3.18 Summary

The brief details of commonly used memory cards are given in this chapter. SD cards are currently the most widely used memory cards. The technical details and communication methods of these cards have been described in detail in the chapter.

3.19 Exercises

1. Explain the main differences between the standard SD cards and the new SDHC cards. Which card would you choose in a long video recording application?
2. How many types of standard SD cards are there? Explain their main differences.
3. Which memory card would you choose in very high-speed data transfer applications?
4. Explain how you could read the data stored on a memory card using your PC.
5. What are the names of the internal registers of a standard SD card?
6. Explain functions of the CID register of an SD card.
7. Explain functions of the CSD register of an SD card.
8. The TAAC field of the CSD register of an SD card is binary "00101101." Explain what this means.
9. The TRAN_SPEED field of the CSD register of an SD card is binary "00110010." Explain what this means.
10. Explain the two operating modes of SD cards. Which mode is commonly used?
11. What is the operating voltage range of an SD card? Explain how this voltage can be obtained from a standard +5 V regulated supply.
12. Draw a circuit diagram to show how an SD card can be connected to a PIC microcontroller in SPI mode.
13. Explain how an SD card can be put into the SPI mode after power-up.
14. Explain how an SD card can be put into SD card mode after operating in the SPI mode.
15. How many types of response tokens are there? Explain where each token is used and also give their differences.