AN5595

Application note

SPC58xEx/SPC58xGx multimedia card via SPI interface

Introduction

The multimedia card is a universal data storage and communication media device. It is designed to support a wide range of applications, in particular more recently on automotive products.

This AN5595 describes about the SPI mode to control the MMC/SD cards. The software application has been developed by using the SPC58xEx/SPC58xGx microcontroller and its software development is based on top of SPC5-STUDIO tool available at the following link: https://www.st.com/en/development-tools/spc5-studio.html.

The SPI mode is an alternative operating mode that is defined to use the MMC/SD cards on microcontrollers without a native host interface. The MMC/SD can be used on a microcontroller via a generic SPI interface or some GPIO ports. Therefore, the SPI mode is suitable for low cost embedded applications. This mode can be accepted on platforms where no specific performances are required and where some limitations of the MMC/SD protocol via SPI mode do not impact on system requirements.

1 MMC basic concepts

The multimedia card transfers data via a configurable number of data bus signals:

- CLK: the frequency may vary according to the card speed
- CMD: is a bidirectional command channel used for card initialization and transfer of commands
- DAT0-DAT7: these are bidirectional data channels; the multimedia card includes internal pull-ups for all data lines

Useful terms and definitions while talking about the multimedia card:

- Block: number of bytes, basic data transfer unit
- CID: card identification number register
- CLK: clock signal
- CMD: command line or multimedia card bus command (if extended CMDXX)
- CSD: card specific data register
- OCR: operation conditions register
- CD: card detection
- W/P: write protection

2 Card registers

Within the card interface six register classes are defined:

- The operation conditions register (OCR) stores the VDD voltage profile
- The card identification (CID): manufacturer ID, product name, revision
- The card-specific data (CSD) register provides information on how to access the card contents. The CSD defines the data format, error correction type, maximum data access time, data transfer speed, whether the DSR register can be used
- The extended CSD register defines the card properties and selected modes
- The relative card address (RCA) register carries the card address assigned by the host during the card identification
- The driver stage register (DSR) optionally used to improve the bus performance for extended operating conditions

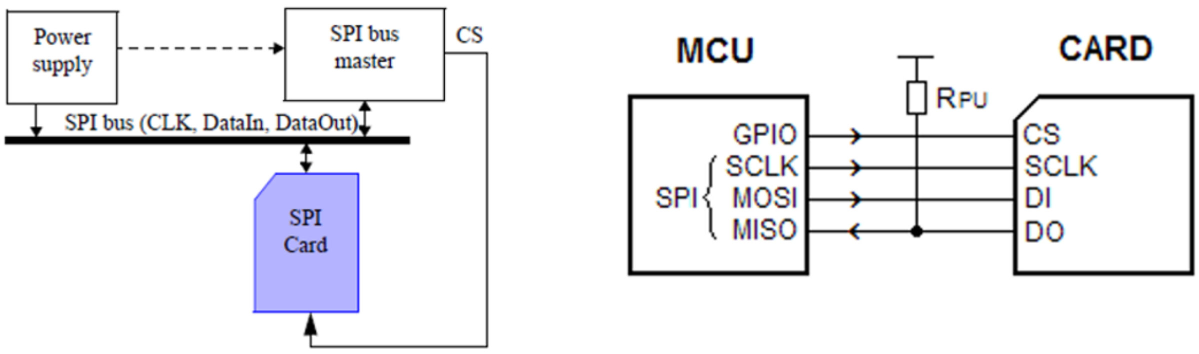
3 MMC/SD SPI mode introduction

The SPI mode has been removed from new specifications, but it can be found in previous JEDEC standard No. JESD84-B41.

The communication protocol of the SPI mode is rather simple compared to its native operating mode.

The MMC/SDC can be attached to the microcontroller via a generic SPI interface as shown below:

Figure 1. **SPI bus connection**



While the multimedia card is based on command and data bit streams which are initiated by a start bit and terminated by a stop bit, the SPI channel is byte oriented. Each command or data block consists of 8-bit bytes and his octet aligned on the CS signal. Like the multimedia card protocol, the SPI messages consist of command, response, and data-block tokens.

The response behavior in the SPI mode differs from the multimedia card mode in the following three aspects:

- The selected card always responds to the command
- Additional (8-, 16- and 40-bit) response structures are used
- When the card encounters a data retrieval problem, it will respond with an error response rather than a time-out

4 DSPI overview

The SPC58x microcontroller embeds the deserial serial peripheral interface (DSPI) module. This provides a synchronous serial bus for communication between an MCU and an external peripheral device.

The DSPI supports the MCU pin count reduction through serialization and deserialization of the MCU internal signals transmitted over the SPI serial link. The DSPI supports different modes including the SPI. All the necessary information about the DSPI can be found inside the microcontroller’s reference manual.

5 SPI signals

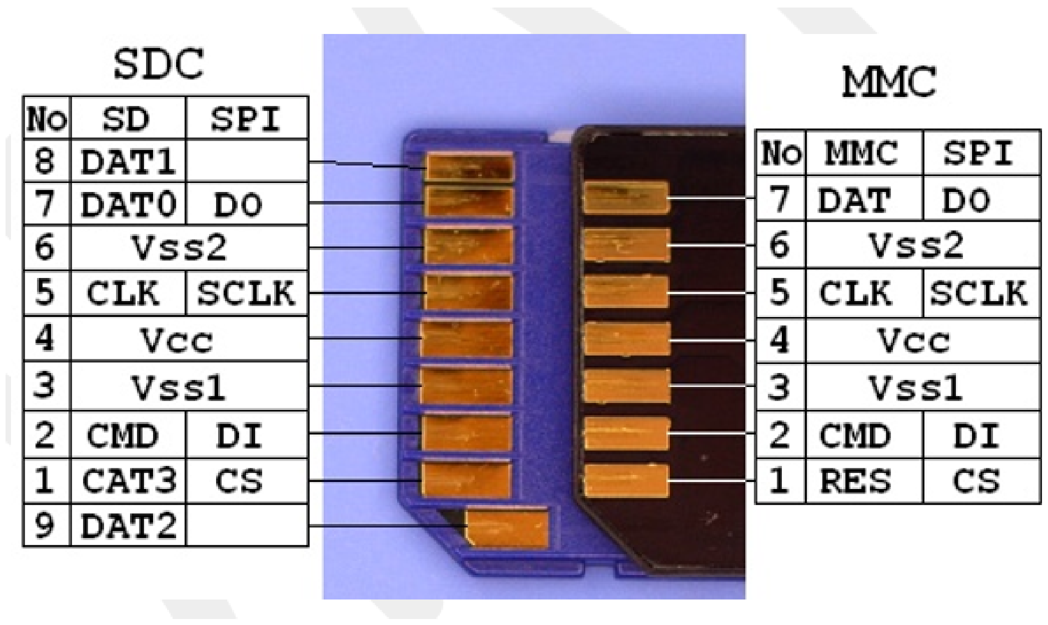
The SPI mode is compliant with the serial peripheral interface (SPI) specification: its bus architecture includes the following signals:

- CS: host to card chip select signal
- CLK: host to card clock signal
- MOSI: (master out slave in) host to card single bit data signal
- MISO: (master in slave out) card to host single bit data signal

The SPI mode is implemented to access the MMC/SD media card so:

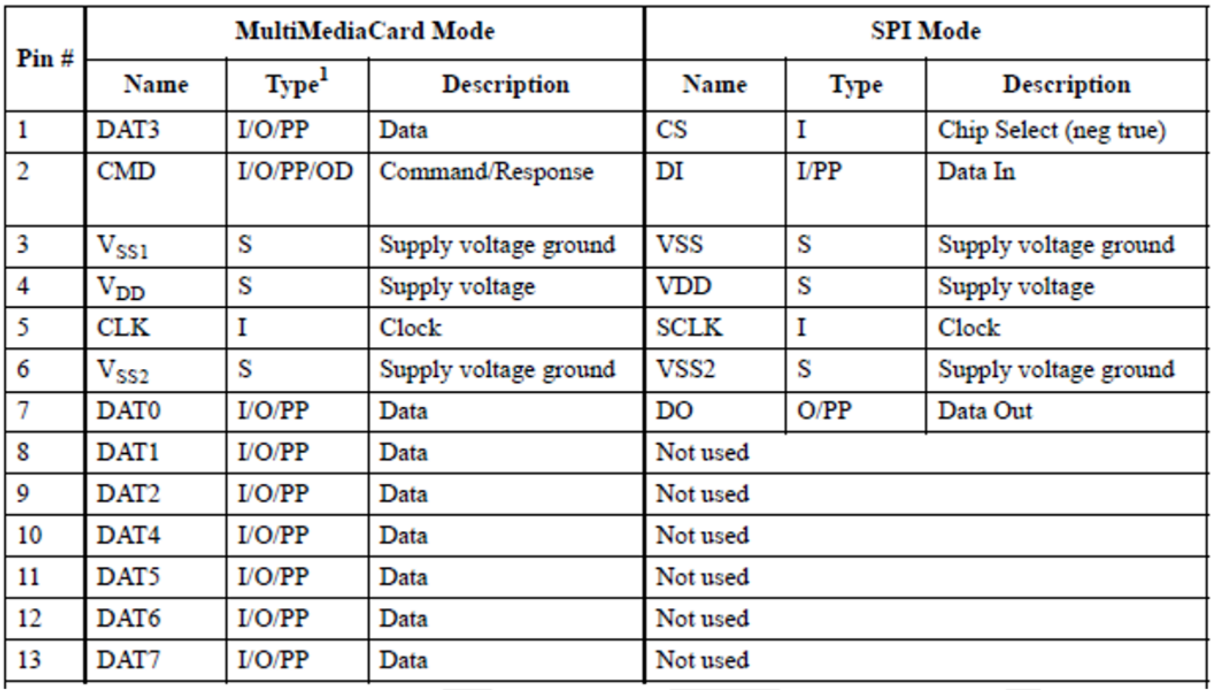
- Every transaction by asserting the CS signal low
- Commands and tx data are sent to the media card on the MOSI line
- Command response and RX data are received from the media card on the MISO line
- The CLK signal is used to synchronize the data transfer on the bus

Figure 2. Card signals



No	SD	SPI
8	DAT1	
7	DAT0	DO
6	Vss2	
5	CLK	SCLK
4	Vcc	
3	Vss1	
2	CMD	DI
1	CAT3	CS
9	DAT2	

No	MMC	SPI
7	DAT	DO
6	Vss2	
5	CLK	SCLK
4	Vcc	
3	Vss1	
2	CMD	DI
1	RES	CS



Pin #	MultiMediaCard Mode			SPI Mode		
	Name	Type[1]	Description	Name	Type	Description
1	DAT3	I/O/PP	Data	CS	I	Chip Select (neg true)
2	CMD	I/O/PP/OD	Command/Response	DI	I/PP	Data In
3	V_{SS1}	S	Supply voltage ground	VSS	S	Supply voltage ground
4	V_{DD}	S	Supply voltage	VDD	S	Supply voltage
5	CLK	I	Clock	SCLK	I	Clock
6	V_{SS2}	S	Supply voltage ground	VSS2	S	Supply voltage ground
7	DAT0	I/O/PP	Data	DO	O/PP	Data Out
8	DAT1	I/O/PP	Data	Not used		
9	DAT2	I/O/PP	Data	Not used		
10	DAT4	I/O/PP	Data	Not used		
11	DAT5	I/O/PP	Data	Not used		
12	DAT6	I/O/PP	Data	Not used		
13	DAT7	I/O/PP	Data	Not used		

Figure 3. Signal comparisons (MMC versus SPI) from standard

6 MMC/SD SPI protocol

6.1 Initialization procedure

After power on reset, MMC/SDC enters are native operating modes.

The card will enter SPI mode if the CS signal is low during the reception of the reset command (CMD0) and it will respond with SPI mode R1 response.

The only way to return to the multimedia card mode is by a power cycle (turn the power off and on).

Since CMD0 has no arguments, the content of all the fields plus the CRC (not calculated by the card) field are constant.

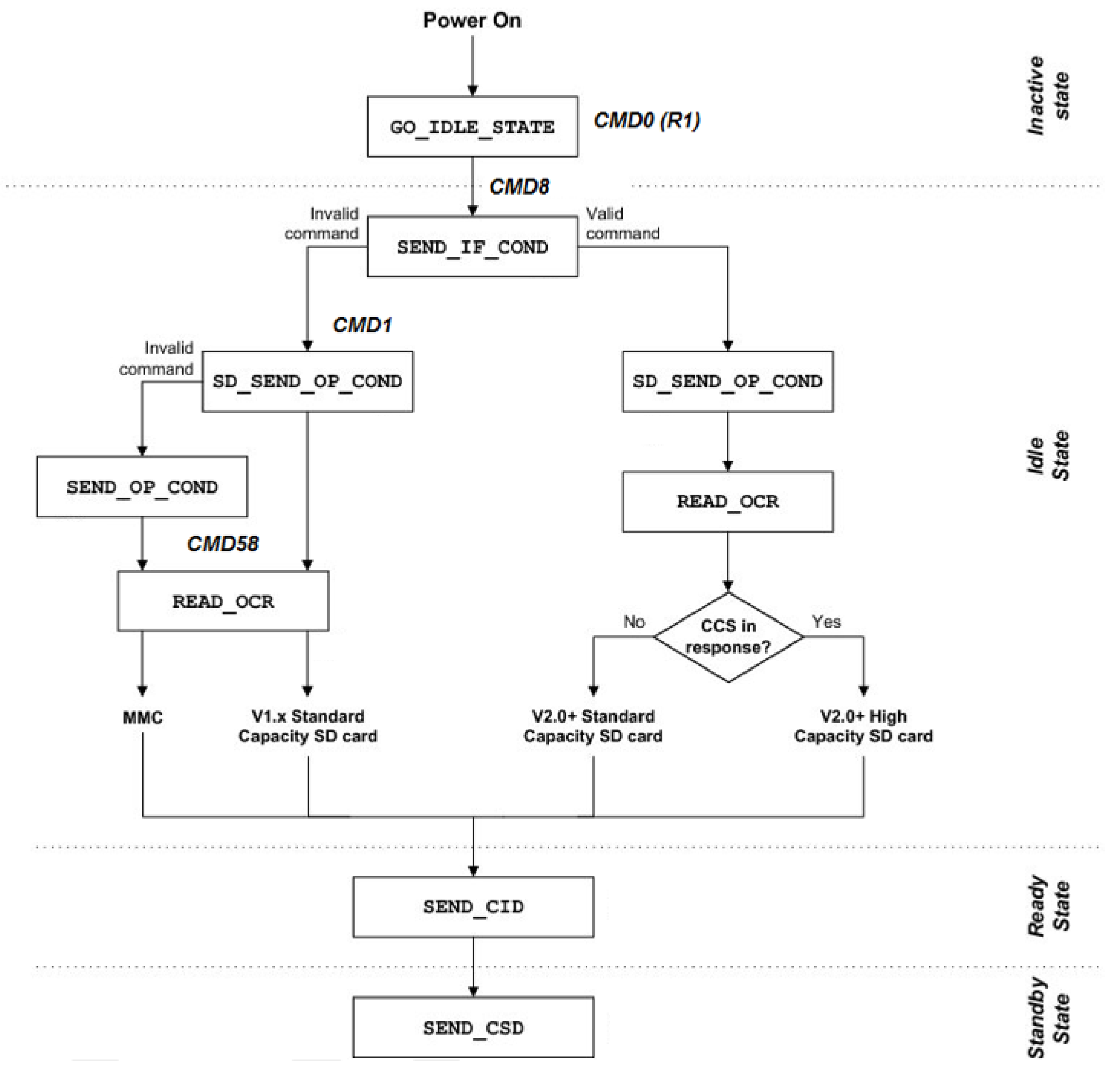
Reset command:`0x40, 0x0, 0x0, 0x0, 0x0, 0x95`

In idle state, the card accepts only CMD0, CMD1, ACMD41, CMD58 and CMD59.

Note that all cards work at supply voltage range of 2.7 to 3.6 V at least, so that the host controller doesn't need to check the OCR if the supply voltage is in this range.

In SPI mode the CMD1 has no operands and does not return the contents of the OCR register. Instead, the host may use CMD58 (only in SPI mode) to read the OCR.

Figure 4. **Example of initialization flow chart**



6.2 Clock control

The SPI bus clock signal can be used to put the card into energy saving mode or to control the data flow.

There are a few restrictions the SPI host must follow:

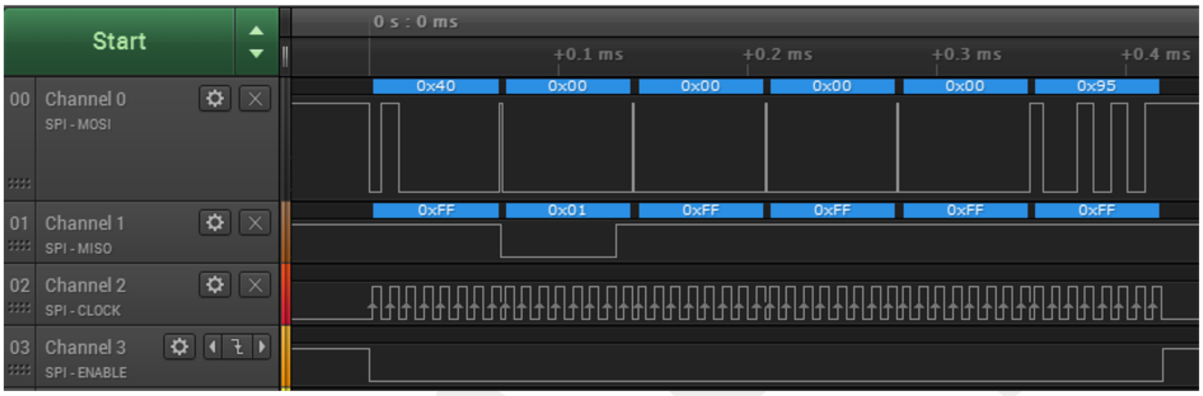
- The frequency can be changed at any time
- After the last SPI bus transaction, the host is required to provide 8 clock cycles for the card to complete the operation before shutting down the clock.
- A command / response sequence, 8 clocks after the card response end bit. The CS signal can be asserted or de-asserted during these 8 clocks.
- A read data transaction, 8 clocks after the end bit of the last data block.
- A write data transaction, 8 clocks after the CRC status token.
- The host can shut down the clock of a “busy” card

6.3 CMD0 and R1 response

Host controller sends the CMD0 reset command:

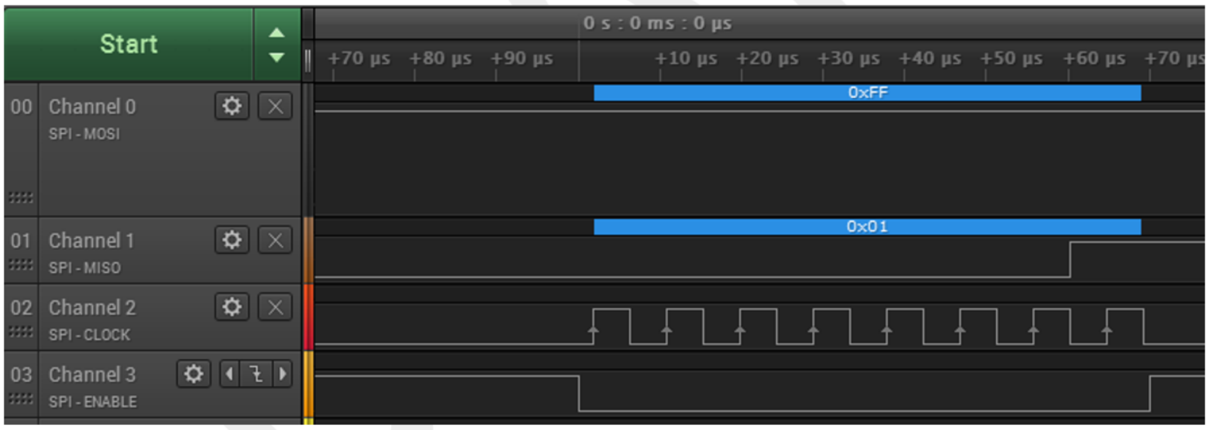
`0x40, 0x0, 0x0, 0x0, 0x0, 0x95`

Figure 5. CMD0 reset command



Card R1 response: `0x1 (IDLE_STATE)`

Figure 6. R1 response



6.4 Data transfer - Data read

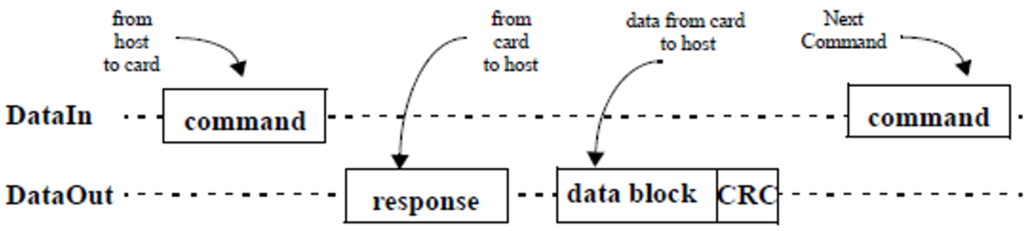
The SPI mode supports single and multiple blocks read operations.

6.4.1 SPI single block read operation

When a `READ_SINGLE_BLOCK` (CMD17) is accepted, a read operation is initiated, and the read data block is sent. After a valid data token, the host controller receives the data field and CRC.

CID/CSD registers: in SPI mode is a simple read-block transaction.

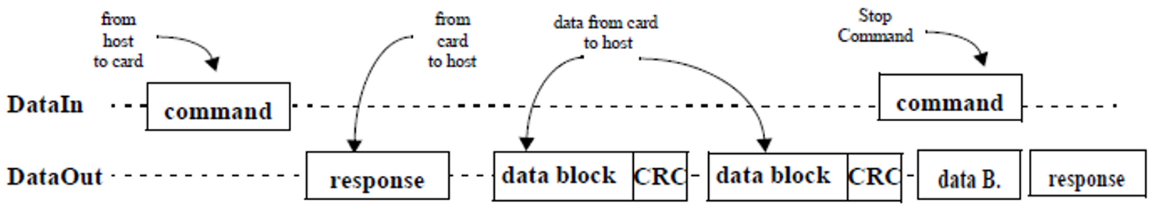
Figure 7. SPI single block read operation



6.4.2 SPI multiple blocks read operation

The CMD18 is to read multiple blocks in sequence. To terminate the transaction, send a CMD12 to the card.

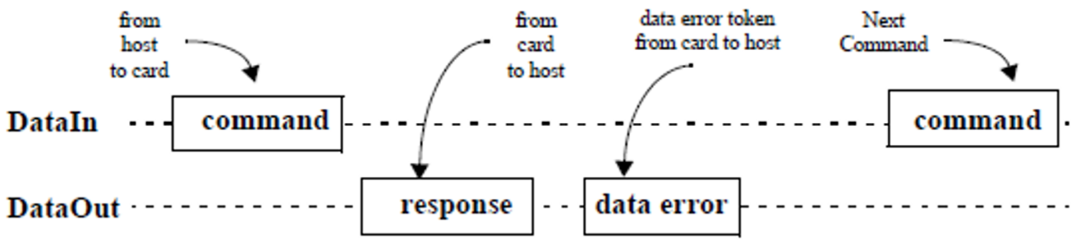
Figure 8. SPI multi block read operation



6.4.3 SPI read operation - data error

Multiple blocks read operation can be terminated the same way, the error token replacing a data block anywhere in the sequence. After receiving the CMD12 the card replies with `ADDRESS_MISALIGN` bit set.

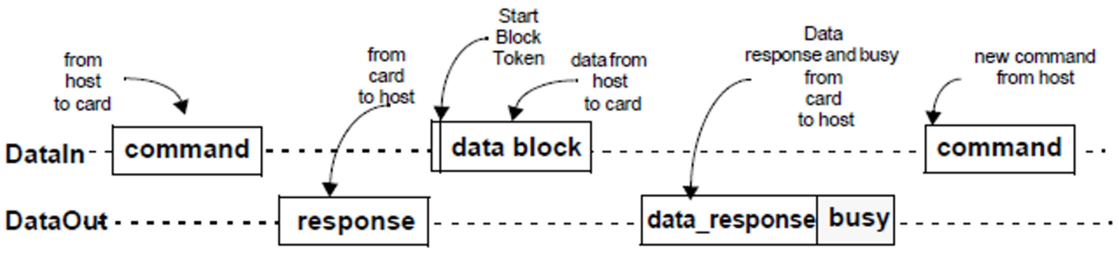
Figure 9. SPI read operation—data error



6.4.4 SPI single block write operation

The SINGLE_BLOCK_WRITE writes a block to the card. After a CMD24 is accepted, the host controller sends a data packet to the card. Often the block size is fixed to 512 bytes. The CS signal must be kept low during a transaction. The data response trails a busy flag and host controller must wait until the card goes ready.

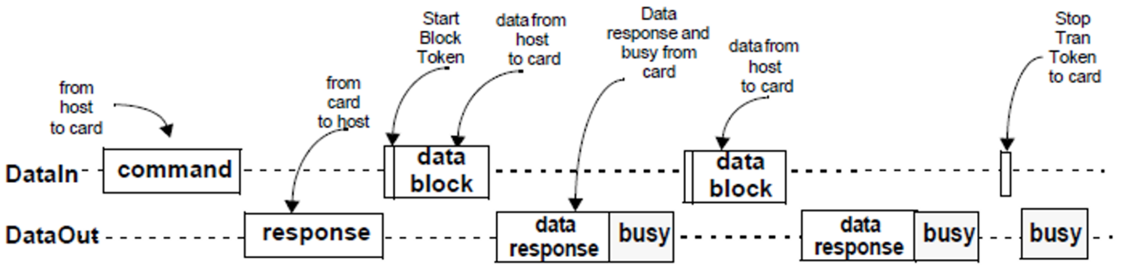
Figure 10. SPI single block write operation



6.4.5 SPI multiple blocks write operation

After a CMD25 is accepted, the host controller sends one or more data packets to the card. The write operation continues until terminated with a STOP_TOKEN. The number of block to write can be pre-defined by CMD23.

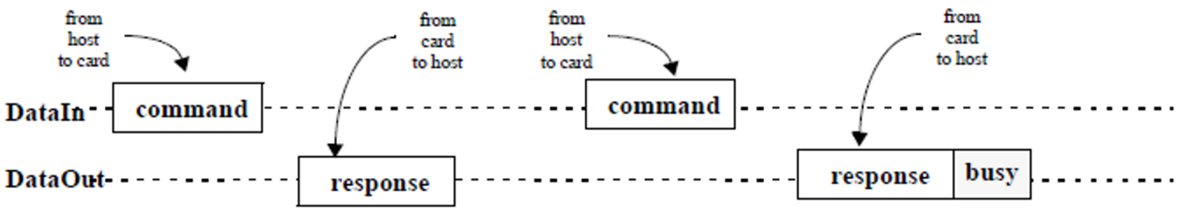
Figure 11. SPI multi block write operation



6.4.6 SPI erase operation

The erase and write protect management procedures in the SPI mode are identical to those of the multimedia card mode.

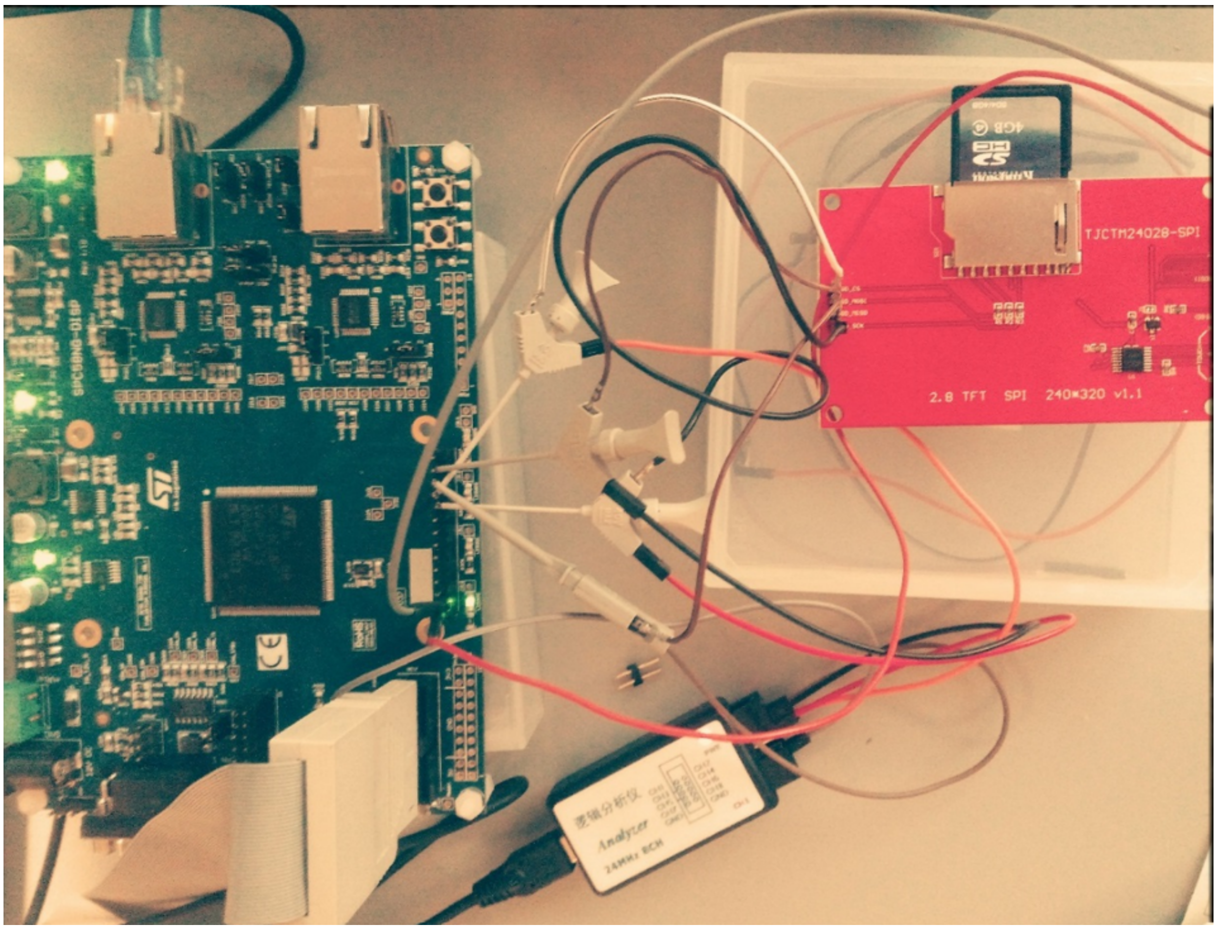
Figure 12. SPI erase operation



7 Hardware setup

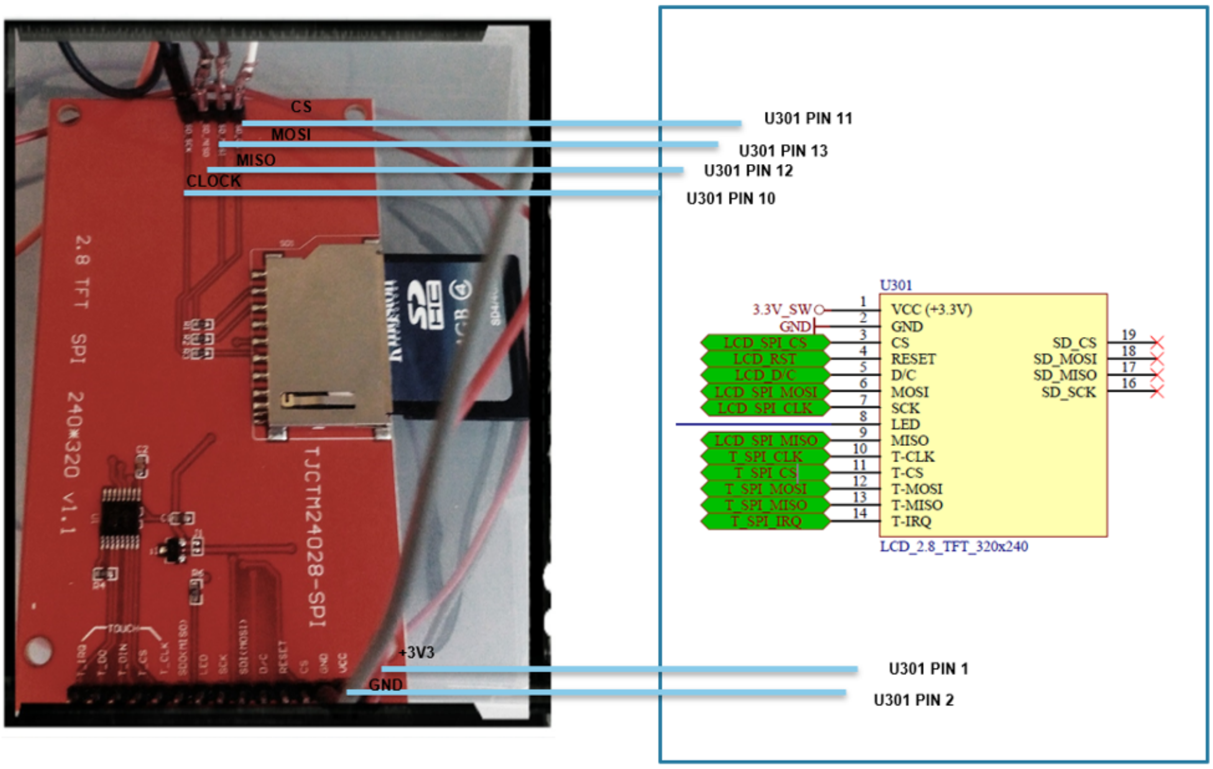
The Figure 13 shows the SPC58G discovery board connected to the TJCTM24028-SPI module. This is a commercial module that provides both a display (not used in this demo application) and an SD slot that can be programmed by an SPI interface.

Figure 13. **Board connection**



Note: the Figure 13 also shows an analyzer hardware plugged on the signals, this has been used for analyzing the SPI protocol and look at the commands and SD card response.

Figure 14. **Wiring details**



8 DSPI1 signal configuration

DSPI 1 has been used with the following signal configuration. For details about the SIUL2 refer to the microcontroller's reference manual.

Table 1. **DSPI1 signal pins configuration**

U301 pin	SPI signals	GPIO	Direction	SIUL2
10	T_SPI_CLK	PD[6]	OUT	MSCR_54 (SSS 0x10)
11	T_SPI_CS	PA[4]	IN/OUT	MSCR_4 (SSS 0x1)
				MSCR_885 (SSS 0x100)
12	T_SPI_SIN	PF[13]	IN	MSCR_883 (SSS 0x111)
13	T_SPI_OUT	PD[7]	OUT	MSCR_55 (SSS 0x011)

Note: the SIUL2 programming is detailed inside the MCU's reference manual, SPC5-STUDIO provides a graphical interface to configure the MCU signals too.

9 Application

The following diagram in the Figure 15 aims at showing the basic application flow.

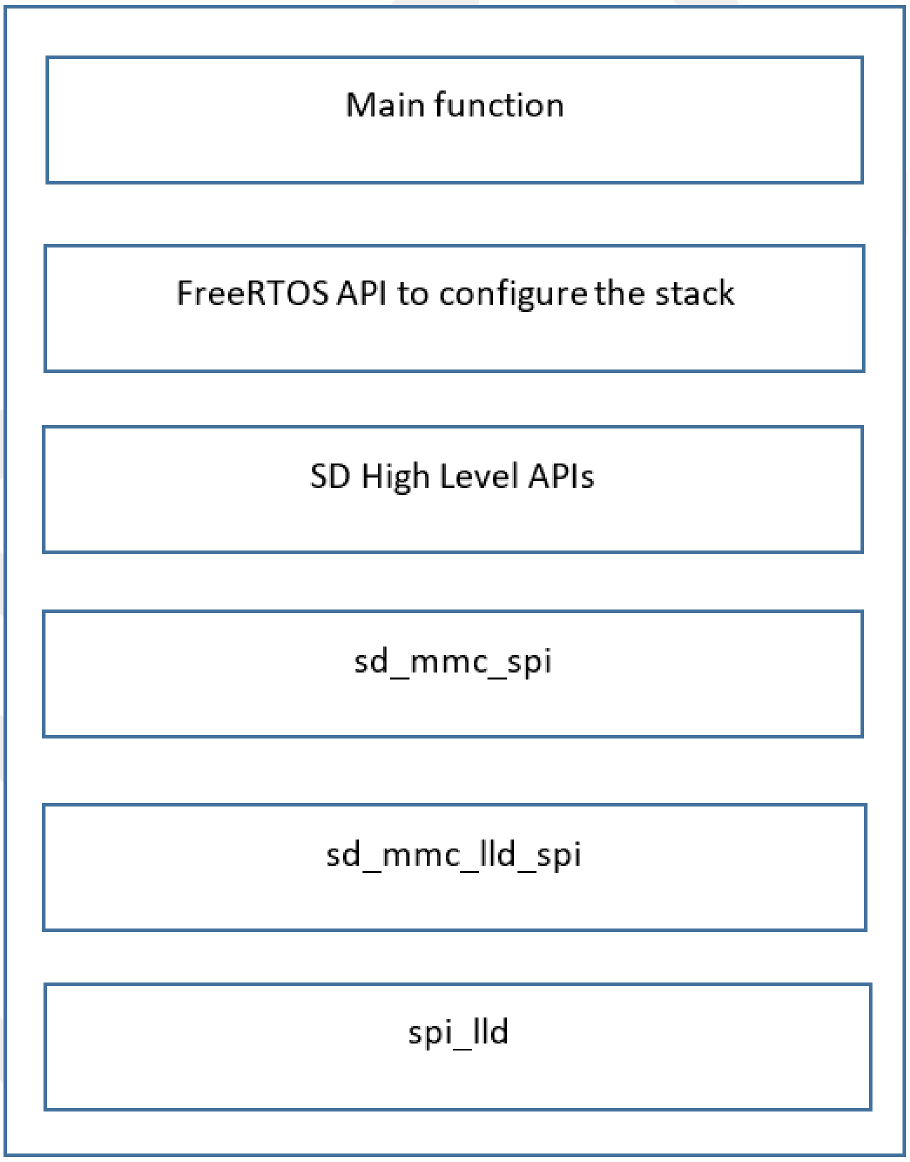
The software is based on FreeRTOS provided by the SPC5-STUDIO tool.

The main configures the microcontroller by using the API set provided by the SPC5-STUDIO tool. User can point to the related SPC5-STUDIO documentation to become familiar with that.

As soon as the platform is configured (clock, signals, interrupts) the main function invokes the low-level APIs designed to configure the SD card.

To dialog with the SD card the SPI low-level driver (available in SPC5-STUDIO) is configured since the beginning.

Figure 15. Application flow diagram



Optionally the FreeRTOS can use a file system to manage the SD card or the application can perform raw access to it.

9.1 Code example

This chapter will focus on the low-level part of the driver.

This is mainly composed by the `sd_mmc_spi, sd_mmc_lld_spi and sp_lld` driver components.

Due to the complexity of the code design, this document just reports some part of the software that can inspire the user on developing his/her own one.

The `sd_mmc.c` file exposes the functions to manage the card, so these can be invoked by the upper layer stack (e.g. operating file system support).

This is an example of the function used to check if the external card device can be initialized.

```
{
    // Initialization of the card in SPI mode
    if (sd_mmc_spi_card_init(sd_mmc_card)) {
        sd_mmc_card->state = SD_MMC_CARD_STATE_READY;
        SD_PRINT_DEBUG("MMC/SD card ready\n");
        return SD_MMC_INIT_ONGOING;
    }
    SD_PRINT_DEBUG("MMC/SD card initialization failed\n");
    sd_mmc_card->state = SD_MMC_CARD_STATE_UNUSABLE;

    return SD_MMC_ERR_UNUSABLE;
}
```

Note: the `SD_PRINT_DEBUG` is used to dump the message through the UART console.

The code below implements the read and write operations:

```
int sd_mmc_data_write (int aSecNr, const unsigned char *apBuf, int aSecCount, uint8_t type,
uint8_t wp)
{
    uint8_t rc;
    rc = sd_mmc_init_write_blocks(aSecNr, aSecCount, type, wp);
    if (rc == SD_MMC_OK) {
        rc = sd_mmc_start_write_blocks(apBuf, aSecCount);
        if (rc == SD_MMC_OK) {
            rc = sd_mmc_wait_end_of_write_blocks();
        }
    } else {
        SD_PRINT_DEBUG ("sd_mmc_data_write(%lu) returns %d\n", aSecNr, rc);
    }
    rc = sd_mmc_check_status();
    if (rc != SD_MMC_OK) {
        SD_PRINT_DEBUG ("Warn: mmc_check_status %d\n", rc);
    }
    return rc == SD_MMC_OK;
}
```

```
int sd_mmc_data_read (int aSecNr, unsigned char *apBuf, int aSecCount, uint8_t type)
{
    uint8_t rc;

    rc = sd_mmc_init_read_blocks(aSecNr, aSecCount, type);
    if (rc == SD_MMC_OK) {
        rc = sd_mmc_start_read_blocks(apBuf, aSecCount);
        if (rc == SD_MMC_OK) {
            rc = sd_mmc_wait_end_of_read_blocks();
        }
    } else {
        SD_PRINT_DEBUG ("sd_mmc_data_read(%lu) returns %d\n", aSecNr, rc);
    }
    return rc == SD_MMC_OK;
}
```

The `sd_mmc_spi` implements the SPI protocol and all the commands necessary to control MMC and SD cards. For example, the card initialization is done by invoking the following function.

```
bool sd_mmc_spi_card_init(struct sd_mmc_card_t *card)
{
    uint8_t v2 = 0;

    sd_mmc_card = card;
    sd_mmc_card->type = CARD_TYPE_SD;
    sd_mmc_card->version = CARD_VER_UNKNOWN;
    sd_mmc_card->rca = 0;
    // CMD0 - Reset all cards to idle state.
    if (!spi_dvr_send_cmd(SDMMC_SPI_CMD0_GO_IDLE_STATE, 0)) {
        return false;
    }
    SD_PRINT_DEBUG("%s: card reset to IDLE: done\n", __func__);
    if (!sd_cmd8(&v2)) {
        return false;
    }
    // Configure according the card type.
    if (sd_mmc_card->type & CARD_TYPE_SD) {
        // Try to get the SD card's operating condition
        if (!sd_spi_op_cond(v2)) {
            // It is not a SD card
            SD_PRINT_DEBUG("No SD card, try to init MMC device...\n");
            sd_mmc_card->type = CARD_TYPE_MMC;
            return sd_mmc_spi_init_protocol();
        }
        if (!spi_dvr_send_cmd(SDMMC_SPI_CMD59_CRC_ON_OFF, 0)) {
            return false;
        }
    }
    // SD MEMORY
    if (sd_mmc_card->type & CARD_TYPE_SD) {
        // Get the Card-Specific Data
        if (!sd_mmc_cmd9_spi()) {
            return false;
        }
        sd_decode_csd();
        // Read the SCR to get card version
        if (!sd_acmd51()) {
            return false;
        }
    }
    if ((sd_mmc_card->type & CARD_TYPE_SDIO)) {
            SD_PRINT_DEBUG("ERROR: Do not support SDIO device\n");
            return false;
    }
    // SD MEMORY not HC, Set default block size
    if ((sd_mmc_card->type & CARD_TYPE_SD) &&
            (0 == (sd_mmc_card->type & CARD_TYPE_HC))) {
        if (!spi_dvr_send_cmd(SDMMC_CMD16_SET_BLOCKLEN, SD_MMC_BLOCK_SIZE))
        {
            return false;
        }
    }
    // Check communication
    if (sd_mmc_card->type & CARD_TYPE_SD) {
        if (!sd_mmc_cmd13()) {
            return false;
        }
    }
    // Reinitialize the slot with the new speed
    return true;
}
```

In the end, the `sd_mmc_lld_spi` calls the SPI low-level driver (`sd_lld`) to implement each command. According to the driver included inside SPC5-STUDIO when this application has been developed, the following APIs are used to send and receive over the SPI bus.

```
static inline void spi_lld_send_wrap(size_t n, const void *buf)
{
      spi_lld_start(spip, spi_config);
      spi_lld_send(spip, n, buf);
      spi_lld_stop(spip);
}
static inline void spi_lld_rx_wrap(size_t n, void *buf)
{
      spi_lld_start(spip, spi_config);
      spi_lld_receive(spip, n, buf);
      spi_lld_stop(spip);
}
```

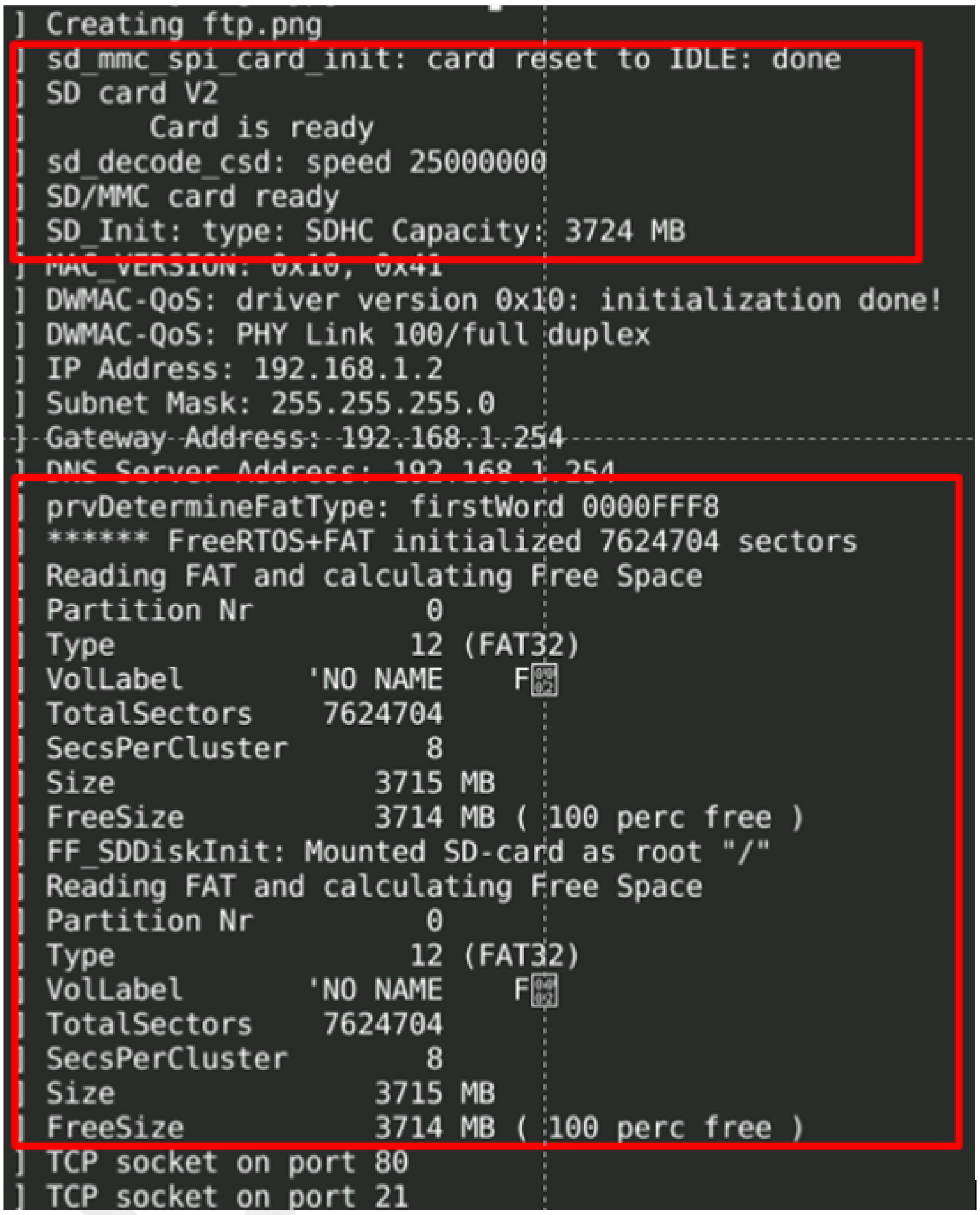
The following function is an example of the low-level function to read a block:

```
bool spi_dvr_start_read_blocks(void *dest, uint16_t nb_block)
{
    uint32_t pos;
    spi_dvr_err = SD_MMC_SPI_NO_ERR;
    pos = 0;
    while (nb_block--) {
        configASSERT(spi_dvr_nb_block >
                (spi_dvr_transfert_pos / spi_dvr_block_size));
        if (!spi_dvr_start_read_block()) {
            return false;
        }
        // Read block
        spi_lld_rx_wrap(spi_dvr_block_size, &((uint8_t*)dest)[pos]);
        pos += spi_dvr_block_size;
        spi_dvr_transfert_pos += spi_dvr_block_size;
        spi_dvr_stop_read_block();
    }
    return true;
}
```

9.2 Application output

The Figure 16 shows a part of the output from the serial console where the SD card is initialized and the file system is recognized.

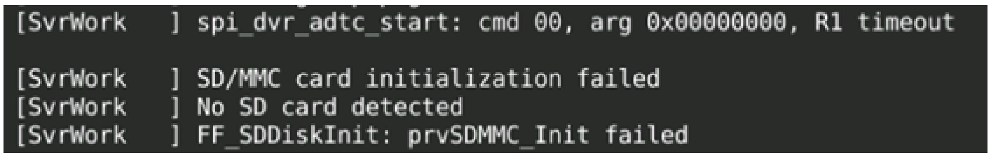
Figure 16. Application output



```
] Creating ftp.png
] sd_mmc_spi_card_init: card reset to IDLE: done
] SD card V2
]       Card is ready
] sd_decode_csd: speed 25000000
] SD/MMC card ready
] SD_Init: type: SDHC Capacity: 3724 MB
] MAC_VERSION: 0x10, 0x41
] DWMAC-QoS: driver version 0x10: initialization done!
] DWMAC-QoS: PHY Link 100/full duplex
] IP Address: 192.168.1.2
] Subnet Mask: 255.255.255.0
] Gateway Address: 192.168.1.254
] DNS Server Address: 192.168.1.254
] prvDetermineFatType: firstWord 0000FFF8
] ****** FreeRTOS+FAT initialized 7624704 sectors
] Reading FAT and calculating Free Space
] Partition Nr          0
] Type                 12 (FAT32)
] VolLabel        'NO NAME    F
] TotalSectors     7624704
] SecsPerCluster        8
] Size               3715 MB
] FreeSize           3714 MB ( 100 perc free )
] FF_SDDiskInit: Mounted SD-card as root "/"
] Reading FAT and calculating Free Space
] Partition Nr          0
] Type                 12 (FAT32)
] VolLabel        'NO NAME    F
] TotalSectors     7624704
] SecsPerCluster        8
] Size               3715 MB
] FreeSize           3714 MB ( 100 perc free )
] TCP socket on port 80
] TCP socket on port 21
```

Without the card plugged on, the following message is dumped:

Figure 17. Output with no card



```
[SvrWork   ] spi_dvr_adtc_start: cmd 00, arg 0x00000000, R1 timeout

[SvrWork   ] SD/MMC card initialization failed
[SvrWork   ] No SD card detected
[SvrWork   ] FF_SDDiskInit: prvSDMMC_Init failed
```

10 Conclusions

The main purpose of this document is to present a low-cost solution to support, on top of the SPC58 microcontroller family, the SD and MMC card on-board. The application is focused on the feasibility of this kind of support and it has been demonstrated that external SD card can be configured and used by adopting the DSPI controller.

The application shows how to setup the hardware, introduces the SPI protocol for MMC/SD card and shows some basic APIs to manage the card.

Having an extra and large storage device, like MMC or SD cards, application can take the advantage to store files for FOTA or other information (debug or diagnostic details). So, this can cover some ad-hoc requirements and needs.

The application could be ported on other microcontrollers in this family, the software has been tested on the SPC58xEx/SPC58xGx microcontroller. Minor changes or re-adaptation could be necessary to have the code on top of the latest SPC5-STUDIO tool.

Due to the relationship with the card and software implementation, no performances have been measured in this application as well as no test on critical conditions.

Revision history

Table 2. **Document revision history**

Date	Version	Changes
19-Jan-2021	1	Initial release.

Contents

List of tables

List of figures