COMPACTFLASH MEMORY CARD
FAT16 / FAT32 DRIVER

TECHNICAL MANUAL

V1.02

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INDEX

COMPACTFLASH MEMORY CARDS & FAT FILING SYSTEM

CompactFlash memory cards provide embedded devices with a very inexpensive and convenient way of storing anything from very small to very large amounts of data. Applications are endless and may include devices that use CompactFlash cards to store their own data, or to exchange data between other embedded devices or to exchange data between embedded devices and a PC.

Mechanically CompactFlash cards are small, but with enough size to provide very large capacities at low cost. They are low power and may be used with both 3V3 (+-5%) or 5V (+-10%) systems with no requirements for external power switching or interface circuitry (just power the card with either voltage). They use a parallel interface to allow fast data transfers with relatively few additional control connections required. Data reliability is also provided by built-in dynamic defect management and error correction technologies.

At the simplest level a CompactFlash card is just a large memory array which may be used in a similar way to a standard parallel memory IC. Very simple applications may just use a CompactFlash card like any other memory device, storing data on it as required by the application. However this has the obvious limitation that the contents of the card is only readable and writable by the device that is using it. To allow other devices to easily read and write data to the card requires the use of a standardised file system. If a filing system is chosen that is also used by PC's then sharing data with PC applications is made very simple.

There are 3 flavours of FAT (File Allocation Table):- FAT12, FAT16 and FAT32. FAT12 has now effectively become obsolete as the very small memory sizes of card this was useful for (<=16MB) are no longer generally available. This leaves FAT16 and FAT32. The 16 and 32 simply refer to the size of the cluster value in bits, although FAT32 is actually only 28 bits as 4 bits are reserved (see below for an explanation of clusters etc). This simply means that a FAT32 table takes up more space on a disk (or memory card), as each entry uses more bytes, but it allows addressing of larger memory sizes with smaller cluster sizes, resulting in less wastage of disk space. This use of smaller cluster sizes can quickly pay off in terms of efficiency as less space wastage at the end of each file frees up more space than the larger FAT32 table uses up.

Limits of FAT16

- Maximum volume size is 2GB
- Maximum file size is 2GB
- Maximum number of files is 65,517
- Maximum of 512 files or folders per folder

Limits of FAT32

- Maximum volume size is 2TB
- Maximum file size is 4GB
- Maximum number of files is 268,435,437
- Maximum of 65,534 files or folders per folder

You may think that you don't need anything more than FAT16 for your application if you don't plan to store more than 2GB of data on a CompactFlash card. After all, many embedded applications only need to store relatively small amounts of data. However CompactFlash cards with capacities greater than 256MB are typically supplied pre-formatted with FAT32. Also Windows XP will typically format a CompactFlash card with a capacity greater than 32MB as FAT32 by default. This is because FAT32 uses larger volumes more efficiently than FAT16 and is also less susceptible to a single point of failure due to the use of a backup copy of critical data structures in the boot record. Therefore if you use a driver that only supports FAT16 for your application your users will need to find a PC with a CompactFlash adaptor to re-format larger capacity cards to be FAT16 before they can be used with your device. You also run the risk of increased technical support demands from users who haven't read your instructions or don't understand how to format a card as FAT16 instead of the default FAT32 and can't work out why their new CompactFlash card won't work in your device. Using a driver that supports FAT16 and FAT32 doesn't result in a large amount of additional code space by today's standards, as the two systems are very similar, and it makes life a lot easier for you and your users.

See the 'Layout Of A Compact Flash Card With FAT' section later in this manual for detailed information of the FAT16 and FAT32 filing system.

COMPACTFLASH MEMORY CARD FAT16/ FAT32 DRIVER

INTRODUCTION

Using a CompactFlash card in your embedded device with the FAT filing system allows you to very easily read and write multiple files and exchange this data with other embedded devices and PC's. Apart from the convenience of such a powerful and flexible filing system, being able to read and write PC compatible files can add huge benefits to your product. However writing a CompactFlash FAT filing system driver is a complex and daunting task. This driver removes that complexity for you and allows you to read and write files with ease.

This driver has been specifically designed from the ground up for embedded applications using 8, 16 or 32 bit processors or microcontrollers. Whilst the code has been kept as small as possible, it hasn't been reduced to such a point that the driver becomes difficult to use. Instead great importance has been put on being able to use as many of the standard ANSI-C file system functions as possible and with as many of each of their features as possible.

The CompactFlash card FAT16 / FAT32 driver code has been designed and tested using the Microchip MPLAB C18 ANSI compliant C complier for the Microchip PIC18 8bit series of microcontrollers. Using the driver with other ANSI compliant C compliers and with other processors / microcontrollers should not present significant problems, but you should ensure that you have sufficient programming expertise to carry out any modifications that may be required to the source code. Embedded-code.com source code is written to be very easy to understand by programmers of all levels. The code is very highly commented with no lazy programming techniques. All function, variable and constant names are fully descriptive to help you modify and expand the code with ease.

The CompactFlash card FAT16 / FAT32 driver and associated files are provided under a licence agreement. Please see 'www.embedded-code.com\licence.php' or email 'licence@embedded-code.com' for full details.

The remainder of this manual provides a wealth of technical information about the driver as well as useful guides to get you going. We welcome any feedback on this manual and the driver to feedback@embedded-code.com.

As with any development project you should ensure that backup copies are made of any files stored on a CompactFlash card that is used with the driver until you have completed your development and thoroughly tested the operation of the driver in your application.

FEATURES

Designed for both FAT16 and FAT32 formatted CompactFlash cards with an 8bit hardware interface to a microcontroller or processor.

Optimised for embedded designs. Only a single 512 data buffer is required for all operations. (It is not possible to write to CompactFlash cards without a 512 byte buffer as sectors have to be read to local memory, modified and written back as a whole).

Intelligent use of the local ram sector buffer. Read and writes of sector data only occur when necessary, avoiding unnecessary and slow repeated read or write operations to the CompactFlash card.

Optimised file delete function for fast deleting of large files. Instead of altering each FAT table entry one at a time, a complete sector of FAT table entries are altered in one operation before writing back to the card, resulting in a large speed improvement.

Provides the following standard ANSI-C functions:

fopen, fseek, ftell, fgetpos, fsetpos, ffs_rewind, fputc, putc, fgetc, getc, fputs, fgets, fwrite, fread, fflush, fclose, remove, rename, clearer, feof and ferror

Standard DOS '*' and '?' wildcard characters may be used in file operations.

Multiple files may be opened at the same time.

DRIVER TECHNICAL OVERVIEW

The data area of CompactFlash memory cards is accessed through the use of a 512 byte sector buffer. (Actually this buffer may be less than 512 bytes and this is supported by the driver, but it is very unlikely you will come across a card that doesn't have 512 bytes per sector). All data read and write operations work through the reading and writing a 512 byte block of sector data. Therefore to modify a single byte, a complete sector of data must be read to local ram, modified and then the complete sector written back to the card.

Other flash memory devices, such as flash memory IC's also basically use the same system whereby a complete block of data must be erased to reset all of the bytes in that block back to 0xFF ready for writing again, as typically flash memory can only write by turning high bits to low, not low to high).

This 512 byte buffer is an issue when it comes to designing a driver to provide fast read and write access. The reason is that as a programmer you want to be able to access individual bytes of a file without worrying about sectors, but you don't want the driver continuously reading and writing 512 bytes of data every time you modify a byte, resulting in painfully slow access. This driver overcomes these problems by only reading and writing when an operation needs to access a byte that is contained in a different sector on the card. Whilst this requires some instances of quite complex driver code, this complexity is worthwhile due to the massive speed improvements this approach provides.

If you want to gain an understanding of exactly how the driver works then this manual contains a thorough description of the layout of FAT based CompactFlash cards. Once you understand this each of the driver functions are relatively easy to understand. However you don't need to do this and if you just want to read and write FAT16 or FAT32 CompactFlash cards then you can skip these in-depth parts of the manual.

Finally you should also note that different CompactFlash memory cards can take different amounts of time to complete internal operations, such as preparing to read or writing a new sector of data. If your application is very time sensitive you may need to consider using some processor RAM memory to act as some sort of FIFO buffer for read and write operations. For example say you are designing a MP3 player that needs to send MP3 file data to a MP3 decoder IC within a certain response time when it requests it. You may find that a slow CompactFlash card might not be able to provide the next byte of data fast enough when it moves from one sector to the next, resulting in your MP3 decoder IC temporarily running out of data. By using some form of circular FIFO RAM buffer in your application you could read data from the CompactFlash as one process, always trying to fill the data buffer so its full, and read data from the buffer to send to the MP3 decoder IC when it requests it as a separate interrupt based process.

SPECIFICATIONS

Code Size

Approximately 13460 program memory words (16 bit) compiling just the driver functions with the Microchip C18 compiler for a PIC18F4620 with all optimisations turned off. This may vary depending on your compiler etc.

Approximately 9080 program memory words (16 bit) compiling the complete PIC18 project PCB sample project (including the driver) using the Microchip C18 compiler with all optimisations turned on.

Variables Memory Space

Approximately 566 bytes of static RAM. This includes a continuous 512 byte buffer that is required by the driver (it is possible to share this buffer with other parts of an application – see the 512 Byte Buffer Define section of this manual).

An additional 22 bytes of static RAM are required for each file that may be opened simultaneously (set by the FFS_FOPEN_MAX define).

The driver requires a moderate amount of variable storage space from the stack for its functions.

CompactFlash Card Mode

The driver accesses a CompactFlash card in common memory mode (not IDE mode).

Files Included In The Project

Driver Source Code Files

The driver source code files:

mem-ffs.c	The FAT16/32 file system driver functions
mem-ffs.h	
mem-cf.c	The lower level CompactFlash card driver functions
mem-cf.h	

Sample Project Source Code Files

The sample project source code files, with a few basic functions ready for you to try and modify as required:

ap-main.c
ap-main.h

The embedded-code.com generic global file

main.h

The Microchip MPLAB C18 compiler project files

cf_demo.cod	
cf_demo.cof	
cf_demo.hex	(The executable code which may be imported into MPLAB and programmed into the PIC without needing to open the whole project, if desired)
cf_demo.lst	
cf_demo.map	
cf_demo.mcp	
cf_demo.mcw	
cf_demo.mptags	
cf_demo.tagsrc	
untitled.mcw	
18f4620i-ffs.lkr	(A *modified version off the microchip standard linker script for the PIC18F4620)*

Notes About Our Source Code Files

How We Organise Our Project Files

There are many different ways to organise your source code and many different opinions on the best method! We have chosen the following as a very good approach that is widely used, well suited to both small and large projects and simple to follow.

Each .c source code file has a matching .h header file. All function and memory definitions are made in the header file. The .c source code file only contains functions. The header file is separated into distinct sections to make it easy to find things you are looking for. The function and data memory definition sections are split up to allow the defining of local (this source code file only) and global (all source code files that include this header file) functions and variables. To use a function or variable from another .c source code file simply include the .h header file.

Variable types BYTE, WORD, SIGNED_WORD, DWORD, SIGNED_DWORD are used to allow easy compatibility with other compilers. Our projects include a 'main.h' global header file which is included in every .c source code file. This file contains the typedef statements mapping these variable types to the compiler specific types. You may prefer to use an alternative method in which case you should modify as required. Our main.h header file also includes project wide global defines.

This is much easier to see in use than to try and explain and a quick look through the included sample project will show you by example.

Please also refer to the resources section of the embedded-code.com web site for additional documentation which may be useful to you.

Modifying Our Project Files

We may issue new versions of our source code files from time to time due to improved functionality, bug fixes, additional device / compiler support, etc. Where possible you should try not to modify our source codes files and instead call the driver functions from other files in your application. Where you need to alter the source code it is a good idea to consider marking areas you have changed with some form of comment marker so that if you need to use an upgraded driver file its as easy as possible to upgrade and still include all of the additions and changes that you have made.

THE DRIVER FUNCTIONS & DEFINES

Pin Defines

`FFS_DATA_BUS_IP`	CompactFlash D7:0 data bus read register
`FFS_DATA_BUS_OP`	CompactFlash D7:0 data bus write register (same as read register if your microcontroller / processor doesn't have separate registers for input and output)
`FFS_DATA_BUS_TO_INPUTS`	Set the data bus pins to inputs
`FFS_DATA_BUS_TO_OUTPUTS`	Set the data bus pins to outputs
`FFS_CE`	The CompactFlash Chip Enable pin (output)
`FFS_WE`	The CompactFlash Write Enable pin (output)
`FFS_OE`	The CompactFlash Output Enable pin (output)
`FFS_REG`	The CompactFlash Register pin (output)
`FFS_RDY`	The CompactFlash Ready pin (input)
`FFS_WAIT`	The CompactFlash Wait pin (input)

The CompactFlash address pins are assigned using several defines to make it easy to use direct microcontroller / processor pins or an external latch IC:-

`FFS_ADDRESS_REGISTER`	The register that should be updated when changing an address pin state (e.g. the port register, or a ram register that gets written to a latch IC).
`FFS_ADDRESS_BIT_0`	The bit of the register that is CompactFlash address pin 0 (must be one of 0x80, 0x40, 0x20, 0x10, 0x08, 0x04, 0x02 or 0x01).
`FFS_ADDRESS_BIT_1`	The bit of the register that is CompactFlash address pin 1.
`FFS_ADDRESS_BIT_2`	The bit of the register that is CompactFlash address pin 2.
`FFS_ADDRESS_FUNCTION`	Optional function to call to output the `FFS_ADDRESS_REGISTER`. Just comment this out if its not required (i.e. if your not using an external latch IC).

The CompactFlash reset pin is assigned using several defines to make it easy to use a direct microcontroller / processor pin or an external latch IC:-

`FFS_RESET_PIN_REGISTER`	The register that should be updated when changing the reset pin state (e.g. the port register, or a ram register that gets written to a latch IC).
`FFS_RESET_PIN_BIT`	The bit of the register that is reset pin (must be one of 0x80, 0x40, 0x20, 0x10, 0x08, 0x04, 0x02 or 0x01).
`FFS_RESET_PIN_FUNCTION`	Optional function to call to output the `FFS_RESET_PIN_REGISTER`. Just comment this out if its not required (i.e. if your not using an external latch IC).

The CompactFlash card detect pin is assigned using several defines to make it easy to use a direct microcontroller / processor pin or an external input buffer IC:-

`FFS_CD_PIN_REGISTER`	The register that should be read when reading the card detect pin state (e.g. the port register, or a ram register that gets read from a buffer IC).
`FFS_CD_PIN_BIT`	The bit of the register that is card detect pin (must be one of 0x80, 0x40, 0x20, 0x10, 0x08, 0x04, 0x02 or 0x01).

FFS_CD_PIN_FUNCTION	Optional function to call to read the FFS_CD_PIN_REGISTER. Just comment this out if its not required (i.e. if your not using an external buffer IC).

512 Byte Buffer Define

FFS_DRIVER_GEN_512_BYTE_BUFFER	The microcontroller / processor ram buffer that is used to buffer a complete sector of CompactFlash data. A define is used as some compilers may have special requirements to create a large data buffer. The driver only accesses the buffer using pointers, in case your compiler requires this. This buffer may also be shared with other functions in your application if you call the ffs_fflush() function for each open file and set ffs_buffer_contains_lba = 0xFFFFFFFF first.

Bus Access Delay Defines

FFS_DELAY_FOR_WAIT_SIGNAL()	Needs to be minimum 35nS. Use one or more null instructions to provide the required delay based on your processor speed. This define may also have additional null instructions to allow data bus signals to stabilise during read or write access. 2 layer PCB's (no ground plane) and PCB's with long track lengths are more likely to require this. If you are experiencing read or write problems try using this define to give a reasonable delay and then drop it later once all is working.
FFS_DELAY_FOR_RDY_SIGNAL()	Needs to be minimum 400nS. Use one or more null instructions to provide the required delay based on your processor speed.

Watchdog Timer Define

CLEAR_WATCHDOG_TIMER	Use this if you have a watchdog timer that needs to be reset for operations that can take a long time. Just comment this out if its not required.

User Options

FFS_FOPEN_MAX	The maximum number of files that may be opened simultaneously (1 - 254). 22 bytes of memory are required per file.

Standard Type And Function Names

For ease of interoperability this driver uses modified version of the standard ANSI-C function names and FILE data types. To avoid conflicting with your compilers stdio.h definitions you can comment out this section and use the modified ffs_ (flash filing system) names in your code. If you want to use the ANSI-C standard names then un-comment this section:-

```
#define     fopen           ffs_fopen
#define     fseek           ffs_fseek
#define     ftell           ffs_ftell
#define     fgetpos         ffs_fgetpos
#define     fsetpos         ffs_fsetpos
#define     rewind          ffs_rewind
#define     fputc           ffs_fputc
#define     fgetc           ffs_fgetc
#define     fputs           ffs_fputs
#define     fgets           ffs_fgets
#define     fwrite          ffs_fwrite
#define     fread           ffs_fread
#define     fflush          ffs_fflush
#define     fclose          ffs_fclose
#define     remove          ffs_remove
#define     rename          ffs_rename
#define     clearerr        ffs_clearerr
#define     feof            ffs_feof
#define     ferror          ffs_ferror
```

```
#define     putc            ffs_putc
#define     getc            ffs_getc

#define     EOF             FFS_EOF
#define     SEEK_SET        FFS_SEEK_SET
#define     SEEK_CUR        FFS_SEEK_CUR
#define     SEEK_END        FFS_SEEK_END
```

Open File

```
FFS_FILE* ffs_fopen (const char *filename, const char *access_mode)
```

This function opens a file for read and or write access.

For ease of use this driver does not differentiate between text and binary mode. You may open a file in either mode (or neither) and all file operations will be exactly the same (basically is if the file was opened in binary mode. LF characters will not be converted to a pair CRLF characters and vice versa. This makes using functions like fseek much simpler and avoids operating system difference issues. (If you are not aware there is no difference between a binary file and a text file – the difference is in how the operating system chooses to handle text files)

`filename`	Only 8 character DOS compatible root directory filenames are allowed. Format is F.E where F may be between 1 and 8 characters and E may be between 1 and 3 characters, null terminated, non-case sensitive. The '*' and '?' wildcard characters may be used.	
`access_mode`	"r"	Open a file for reading. The file must exist.
	"r+"	Open a file for reading and writing. The file must exist.
	"w"	Create an empty file for writing. If a file with the same name already exists its content is erased.
	"w+"	Create an empty file for writing and reading. If a file with the same name already exists its content is erased before it is opened.
	"a"	Append to a file. Write operations append data at the end of the file. The file is created if it doesn't exist.
	"a+"	Open a file for reading and appending. All writing operations are done at the end of the file protecting the previous content from being overwritten. You can reposition (fseek) the pointer to anywhere in the file for reading, but writing operations will move back to the end of file. The file is created if it doesn't exist.
Return value.	If the file has been successfully opened the function will return a pointer to the file. Otherwise a null pointer is returned (0x00).	

Move File Byte Pointer

```
int ffs_fseek (FFS_FILE *file_pointer, long offset, int origin)
```

This function allows you to change the byte location in the file which the next read or write access will address. The function is quite complex as it looks to see if the new location is in the same cluster as the current location to avoid having to read all of the FAT table entries for the file from the file start where possible, which results in a large speed improvement.

`file_pointer`	Pointer to the open file to use.
`origin`	The initial position from where the offset is applied FFS_SEEK_SET (0) Beginning of file FFS_SEEK_CUR (1) Current position of the file pointer FFS_SEEK_END (2) End of file
`offset`	Signed offset from the position set by origin
returns	0 if successful, 1 otherwise

```
int ffs_fsetpos (FFS_FILE *file_pointer, long *position)
```

This function is an alternative to `ffs_seek`. The value used is intended to be file system specific and obtained using the `ffs_getpos` function. However as the type is recommended to be a long and this doesn't provide enough space to store everything needed for the low level file position this function calls the `ffs_fseek` function.

Get The Current Position In The File

```
long ffs_ftell (FFS_FILE *file_pointer)
```

This function returns the current position within the file (the next byte that will be read or written).

```
int ffs_fgetpos (FFS_FILE *file_pointer, long *position)
```

This function is an alternative to `ffs_tell`. The value returned is intended to be file system specific and only to be used with fsetpos. However as the position type is recommended to be a long and this doesn't provide enough space to store everything needed for the low level file position this function calls the `ffs_tell` function.

Returns	0 if successful, 1 otherwise

Set File Byte Pointer To Start Of File

```
void ffs_rewind (FFS_FILE *file_pointer)
```

The file byte pointer is set to the first byte of the file and the file access error flag is cleared if it has been set.

`file_pointer`	Pointer to the open file to use.

Write Byte To File

```
int ffs_fputc (int data, FFS_FILE *file_pointer)
```
or
```
ffs_putc(int data, FFS_FILE *file_pointer)
```

`file_pointer`	Pointer to the open file to use.
`data`	The data byte to write which is converted to a byte before writing (the int type is specified by ANSI-C)
Returns	If there are no errors the written character is returned. If an error occurs FFS_EOF is returned.

Read Byte From File

```
int ffs_fgetc (FFS_FILE *file_pointer)
```
or
```
int ffs_getc (FFS_FILE *file_pointer)
```

`file_pointer`	Pointer to the open file to use.
Returns	The byte read is returned as an int value (int type is specified by ANSI-C). If the End Of File has been reached or there has been an error reading FFS_EOF is returned.

Write String To File

```
int ffs_fputs (const char *string, FFS_FILE *file_pointer)
```
or
```
int ffs_fputs_char (char *string, FFS_FILE *file_pointer)
```

This function writes a string to the file until a null termination is reached. The null termination is not written to the file. If a new line character (\n) is required it should be included at the end of the string

The alternative `ffs_fputs_char` function is not part of the ANSI-C standard but may be needed writing a string from ram with compilers that won't deal with converting the ram string to a constant string.

Returns	Non-negative value if successful. If an error occurs FFS_EOF is returned.

Read String From File

```
char* ffs_fgets (char *string, int length, FFS_FILE *file_pointer)
```

This function reads characters from file and stores them into the specified buffer until a newline (\n) or EOF character is read or (length - 1) characters have been read. A newline character (\n) is not discarded. A null termination is added to the string

Returns	Pointer to the buffer if successful. A null pointer (0x00) if there is an error of the end-of-file is reached (use ffs_ferror or ffs_feof to check what happened).

Write Data Block To File

```
int ffs_fwrite (const void *buffer, int size, int count, FFS_FILE *file_pointer)
```

Writes `count` number of items, each one with a size of `size` bytes, from the specified `buffer`.
No translation occurs for files opened in text mode. The total number of bytes to be written is (`size` x `count`).

Returns	The number of full items (not bytes) successfully written. This may be less than the requested number if an error occurred.

(For a very fast method of reading complete sectors at a time see the 'Using The Driver In A Project' section later in this manual).

Read Data Block From File

```
int ffs_fread (void *buffer, int size, int count, FFS_FILE *file_pointer)
```

Reads `count` number of items each one with a size of `size` bytes from the file to the specified `buffer`.
Total amount of bytes read is (`size` x `count`).

Returns	The number of items (not bytes) read is returned. If this number differs from the requested amount (`count`) an error has occurred or the End Of File has been reached (use ffs_ferror or ffs_feof to check what happened).

Store Any Unwritten Data To The Card

int ffs_fflush (FFS_FILE *file_pointer)

Write any data that is currently held in microcontroller / processor ram that is waiting to be written to the card. Update the file filesize value if it has changed.

This function does not need to be called by your application, but may be called if your application opens a file for a long period of time to avoid data loss if your device suddenly looses power.

Returns	0 if successful, 1 otherwise

Close File

```
int ffs_fclose (FFS_FILE *file_pointer)
```

Closes an open file, saving any unsaved data to the card and updating the file filesize value if it has changed.

Returns	0 if successful, 1 otherwise

Delete File
```
int ffs_remove (const char *filename)
```

This function is optimised to avoid unnecessary read and writes of the FAT table to greatly improve its speed.

Returns	0 if the file is successfully deleted, 1 if there was an error (the file doesn't exist or can't be deleted as its currently open.

Rename File
```
int ffs_rename (const char *old_filename, const char *new_filename)
```

Return value	0 if the file is successfully renamed, 1 if there was and error (the file doesn't exist or can't be renamed as its currently open)

Clear Error & End Of File Flags
```
void ffs_clearerr (FFS_FILE *file_pointer)
```

Has End Of File Been Reached
```
int ffs_feof (FFS_FILE *file_pointer)
```

Has An Error Occurred During File Access
```
int ffs_ferror (FFS_FILE *file_pointer)
```

Is A Compact Flash Card Inserted And Available
```
BYTE ffs_is_card_available (void)
```

Do Background Tasks
```
void ffs_process (void)
```

This function needs to be called regularly from your applications main loop to detect a new card being inserted so that it can be initialised ready for access.

THE DRIVER SUB FUNCTIONS

These functions are used by the driver but should not be used by your application.

Find File
```
DWORD ffs_find_file (const char *filename, DWORD *file_size, BYTE *attribute_byte,
                     DWORD *directory_entry_sector,
                     BYTE *directory_entry_within_sector,
                     BYTE *read_file_name, BYTE *read_file_extension)
```

This function searches for a specified filename. If wildcard characters are used then the first file that matches with the standard and wildcard characters will be found.

`filename`	Only 8 character DOS compatible root directory filenames are allowed. Format is F.E where F may be between 1 and 8 characters and E may be between 1 and 3 characters, null terminated. The '*' and '?' wildcard characters are allowed.
`*file_size`	Pointer where the file size (bytes) will be written to.
`*attribute_byte`	Pointer where the attribute byte will be written to.
`*directory_entry_sector`	Pointer where the sector number that contains the files directory entry will be written to.
`*directory_entry_within_sector`	

	Pointer where the file directory entry number within the sector that contains the file will be written to.
*read_file_name	Pointer to a 8 character buffer where the filename read from the directory entry will be written to (this may be needed if using this function with wildcard characters)
*read_file_extension	Pointer to a 3 character buffer where the filename extension read from the directory entry will be written to (this may be needed if using this function with wildcard characters)
Returns	The file start cluster number (0xFFFFFFFF = file not found)

Convert File Name To Dos Filename

```
BYTE ffs_convert_filename_to_dos (const char *source_filename, BYTE *dos_filename,
                                  BYTE *dos_extension)
```

Used by functions to convert the application supplied filename to a driver specific DOS type filename. The source_filename is a case insensitive string with between 1 and 8 filename characters, a period (full stop) character, between 1 and 3 extension characters and a terminating null.

Returns	1 if the filename contained any wildcard characters, 0 if not (this allow calling functions to detect invalid names if they are creating a new file)

Read Next Directory Entry

```
BYTE ffs_read_next_directory_entry (BYTE *file_name, BYTE *file_extension,
                                    BYTE *attribute_byte, DWORD *file_size,
                                    DWORD *cluster_number,
                                    BYTE start_from_beginning,
                                    DWORD *directory_entry_sector,
                                    BYTE *directory_entry_within_sector)
```

*file_name	Pointer where the 8 character array filename will be written to.
*file_extension	Pointer where the 3 character array filename extension will be written to.
*attribute_byte	Pointer where the file attribute byte will be written to.
*file_size	Pointer where the file size will be written to.
*cluster_number	Pointer where the start cluster for the file will be written to.
start_from_beginning	Set to cause routine to start from 1st directory entry (this must be set if the drivers data buffer has been modified since the last call)
*directory_entry_sector	Pointer where the sector number that contains the files directory entry will be written to.
*directory_entry_within_sector	Pointer where the file directory entry number within the sector that contains the file will be written to.
Returns	1 if a file entry was found, 0 if not (marks the end of the directory

Overwrite The Last Directory File Name

```
void ffs_overwrite_last_directory_entry (BYTE *file_name, BYTE *file_extension,
                                         BYTE *attribute_byte, DWORD *file_size
                                         DWORD *cluster_number)
```

*file_name	Pointer to an 8 character filename (must be DOS compatible - uppercase and any trailing unused characters set to 0x20)
*file_extension	Pointer to 3 character filename extension (must be DOS compatible - uppercase and any trailing unused characters set to 0x20)
*attribute_byte	Pointer to the file attribute byte
*file_size	Pointer to the file size
*cluster_number	Pointer to the start cluster number for the file

Get The Start Cluster Number For A File

```
DWORD get_file_start_cluster(FFS_FILE *file_pointer)
```

Returns the cluster number of the start of the file. Further cluster numbers are read from the FAT table.

Create A New File

```
BYTE ffs_create_new_file (const char *file_name, DWORD *write_file_start_cluster,
                          DWORD *directory_entry_sector,
                          BYTE *directory_entry_within_sector)
```

*file_name	Pointer to an 8 character filename
*write_file_start_cluster	The cluster number that contains the start of the file.
`*directory_entry_sector`	Pointer where the sector number that contains the files directory entry will be written to.
`*directory_entry_within_sector`	Pointer where the file directory entry number within the sector that contains the file will be written to.
Return value	1 if successful, 0 if not

Find Next Free Cluster In FAT Table

```
DWORD ffs_get_next_free_cluster (void)
```

Find the next available free cluster from the FAT table. The last found free cluster number is stored to help speed up successive calls to this function.

Returns	The cluster number, or 0xFFFFFFFF if no free cluster found (card is full)

Get Next Cluster Value From FAT Table

```
DWORD ffs_get_next_cluster_no (DWORD current_cluster)
```

This function looks up the `current_cluster` number in the FAT table and returns the FAT table entry which will be the next cluster number or the end of file marker.

Modify Cluster Value In FAT Table

```
void ffs_modify_cluster_entry_in_fat (DWORD cluster_to_modify,
                                      DWORD cluster_entry_new_value)
```

The `cluster_to_modify` FAT table entry is overwritten with `cluster_entry_new_value`.

Read Sector To Buffer

```
void ffs_read_sector_to_buffer (DWORD sector_lba)
```

Reads a sector of data (usually 512 bytes) to the microcontroller / processor ram buffer.

`sector_lba`	The ‘Logical Block Address’ / sector number to read.

Write Sector From Buffer

```
void ffs_write_sector_from_buffer (DWORD sector_lba)
```

Write a sector of data (usually 512 bytes) from the microcontroller / processor ram buffer.

`sector_lba`	The ‘Logical Block Address’ / sector number to read.

Is CompactFlash Card Present

```
BYTE ffs_is_card_present (void)
```

Returns	1 if present, 0 if not

Set CompactFlash Card Reset Pin
```
void ffs_card_reset_pin (BYTE pin_state)
```

Set CompactFlash Card Address
```
void ffs_set_address (BYTE address)
```

address	The low 3 bits are the address to set

Write Byte To CompactFlash Card
```
BYTE ffs_write_byte (BYTE data)
```

Read Word From CompactFlash Card
```
WORD ffs_read_word (void)
```

Read Byte From CompactFlash Card
```
BYTE ffs_read_byte (void)
```

USING THE DRIVER IN A PROJECT

General Requirements

Add the mem-ffs.c, mem-ffs.h, mem-cf.c and mem.cf.h files to your project. Check the definitions in the mem-ffs.h and mem-cf.h file for the microcontroller / processor you are using and your hardware connections. In each .c file in your application that will use the driver functions include the 'mem-fffs.h' file.

You will need to provide some form of timer for the driver. Typically this can be done in your applications general heartbeat timer if you have one. Do the following every 10mS:-

```
//----- FAT FILING SYSTEM DRIVER TIMER -----
if (ffs_10ms_timer)
      ffs_10ms_timer--;
```

If you do not have a matching timer then using a time base that is slightly greater than 10mS is fine.

You will need to periodically call the drivers background processing function. Typically this can be done as part of your applications main loop. This function looks to see if a CompactFlash card has been inserted or removed and updates the driver appropriately. Add the following call:-

```
//----- PROCESS FAT FILING SYSTEM -----
ffs_process();
```

Checking If A CompactFlash Card Is Available

The following example checks to see if a CompactFlash card is available to use:-

```
//IS A FAT FORMATTED COMPACTFLASH CARD INSERTED AND READY TO USE?
if (ffs_card_ok)
{

}
```

CompactFlash Card Operations

The included sample application contains several examples of using the driver.

Characters That May Be Used In DOS Compatible File Names

Upper case letters A-Z (lowercase will be modified to uppercase).
Numbers 0-9
Space (though trailing spaces are considered to be padding and not a part of the file name)
! # $ % & ( ) - @ ^ _ ` { } ~ '
Values 128-255

Directories

This driver supports reading and writing of files in a CompactFlash cards root directory only.

Partitions

This driver does not support multiple partitions. It will access the first partition of a CompactFlash card. Other partitions will not be damaged, but they cannot be accessed.

Long Filenames

This driver does not support long file names. Adding long filename support would use additional code space which is not desirable in many embedded applications, and is also subject to patent / licence restrictions as Microsoft holds patents for the long filename specification.

Working With Multiple Files

You to open multiple files at the same time and perform any operation on any of these files at any time. However all read and write operations involve reading a complete 512 byte block of data from the CompactFlash card and storing the complete block back to the card if any of the data has been modified before moving onto another block of data. The driver deals with this block requirement in an intelligent way, only reading and writing a block when it has to. If working on more than one file best speed will be achieved by working on one file as much as possible before working on another file. This is because each time you swap to a different file the driver has to save or dump the block of data currently being written or read and then load the data block being written or read for the

other file. Therefore if doing an operation such as copying data from one file to another try and copy as much data as possible to processor ram before starting writing it to the other file. You don't have to, but doing this will significantly increase the speed of your application.

Ensure Data Is Saved For Write Operations

Files may be opened and kept open indefinitely. However you should try and carry out file write operations in one process and close the file again when it is not required in case your product should loose power. If power is lost while a file is open any data that has been written since the last close of the file may be lost, as the current file size value may not have been written back to directory entry for the file. Whilst the data may have already been stored to the CompactFlash card, without the file size value the next time the file is accessed by the driver or another device the data will effectively not exist and the sectors that contain it will be lost on the CompactFlash card (until it is formatted or a disk repair utility is run). In theory the file size value could be updated every time a new block of data is written to the card, however the driver does not do this as it would significantly slow down bulk write operations. If you need to keep a file open for a long period of time then you should periodically call the ffs_fflush function to ensure that the most recent data is saved.

Reading & Writing A Text File

.txt files are as simple as it gets. They are simply comprised of ASCII bytes with a CR (carriage return) & LF (line feed) character at the end of each line of text.

In addition to being a great way of storing and retrieving configuration and operating data for your product, writing text files can be a really useful way of debugging complex problems with an application, by being able to write large quantities of text and then analysing this with any standard text application on a PC. In addition, if your designing a product that may experience problems in certain installations it is typically quite a simple matter to write some code to provide logging of the products operation, such as communications sent and received, to a .txt file on a CompactFlash card which a user can then email you for remote analysis.

Reading & Writing A Spreadsheet File

.csv files are a great way of reading and writing spreadsheet data. They are exactly the same as a text file, except that the comma ',' character is used to mark moving on to the next column. Every time the CF and LF characters are used the next row is started.

.csv files may be directly read and written by Microsoft Excel™.

Fast Reading Of Bulk File Data

The ANSI-C fread function is provided to allow blocks of data to be read but this can be too slow for some applications. This is because of the overhead the C library functions require which is fine and very useful on systems with enough processor power so it doesn't notice, but can waste huge amounts of clock cycles in speed sensitive embedded applications. The following is a simple method that will allow complete sectors (512 bytes) to be read as a data block, used by your application as required and then the next sector read.

Open a file for reading using fopen as normal and then use the fgetc function to read the first byte. In reading the first byte the driver will actually read the first sector of file data into the drivers sector buffer FFS_DRIVER_GEN_512_BYTE_BUFFER. Subsequent calls to the fgetc or other read functions will simply read data from this buffer, but with all of the background checks the driver has to do for each byte read. Instead you can simply access the buffer directly in your application. When you are ready to read the next sector do the following:-

```
your_file_name->current_byte_within_file += 511;
your_file_name->current_byte += 511;
```

That's it. In modifying the 2 above values you reposition the drivers internal processes into thinking that it last accessed the last byte in the current sector. To load the next sector call the fgetc function again and repeat the process. When using this method just bear in mind that you will need to detect the end of file yourself as the last sector read for a file will contain unused data bytes unless the file size is an exact multiple of 512 bytes.

Fast Writing Of Bulk File Data

This can be achieved in the same was as fast reading of bulk data above. Use the fputc function to write the first byte of a new sector. Then write the rest of the data directly to the buffer. When you are ready to write the next sector do the following:-

```
your_file_name->current_byte_within_file += 511;
your_file_name->current_byte += 511;
your_file_name->file_size += 511;
```

In modifying the 3 above values you reposition the drivers internal processes into thinking that it last wrote to the last byte in the current sector. To write the next sector call the fputc function again and repeat the process.

Using CompactFlash Cards For Firmware Updates.

A CompactFlash card may be used to allow new firmware files to be read off a card and programmed into your devices memory. You could use a standard raw .hex format or your own encrypted format. Remember that if reading the file directly off the card and into program memory you will need to allow sufficient boot loader program memory space for the CompactFlash driver. If space is at a premium the driver could be 'hacked' down to the bare bones of just reading files with no writing or file re-positioning capabilities to reduce its size.

Deleting Files

Deleting a single file

```
const char filename_1[] = {"test.txt"};

ffs_remove(filename_1);
```

Deleting all files in the root directory:-

```
const char filename_all[] = {"*.*"};

while (ffs_remove(filename_all) == 0)
      ;
```

Searching In The Directory

There is no function that directly provides this, as its not provided by the standard ANSI-C functions. However, a relatively simple way of achieving this is to add a global variable to the driver that is usually zero, or add an additional variable to the `ffs_find_file function` declaration. In the `ffs_find_file` function use this variable so that if it is greater than zero the function does not return when it finds a matching file, but instead decrements the value and looks for the next match. When used with wildcard characters in the file name this allows you to find each matching file in turn, by setting the variable to zero and then every time the function returns with a cluster number for a match you set it to the last value +1, continuing until the functions returns with the not found value.

Disk Viewing & Editing Utilities

If you want to be able to view the contents of a CompactFlash card on your PC, which can be very useful when debugging or just learning about how disks are structured, then the WinHex application is very good. This is available from http://www.x-ways.net.

COMPACTFLASH AND FAT LICENSING

The implementation and use of the FAT file system and CompactFlash specification may require a license from various entities, including, but not limited to Microsoft® Corporation, IBM and the CompactFlash Association. It is your responsibility to obtain information regarding any applicable licensing requirements.

Microsoft offers licensing for the use of its FAT filing system on a per unit sold basis. However it is generally viewed that this only applies to applications that implement the patented long file name system (LFN). It is our understanding that if long filenames are not used then no licence fee is due, however you should ascertain if you agree with this view yourself (to our knowledge Microsoft have not stated this but others have determined this based on original releases of the FAT standard by Microsoft).

IBM patents may also apply to technology supporting extended attributes within the file system.

We have checked with the CompactFlash Association and have been told that providing a CompactFlash card interface in a product does not require a licence from their association. If you use the CompactFlash logo trademark on your product or in your literature then they ask that you indicate that they are trademarks of the CompactFlash Association.

ADDITIONAL INFORMATION

What is CompactFlash, CF Type I, CF Type II and CF I/O?

The only difference between CF Type I and CF Type II cards is the card thickness. Type I cards are 3.3 mm thick and Type II cards are 5mm thick. A Type I card will operate in a Type I or Type II slot. A Type II card will only fit in a Type II slot. The electrical interfaces are identical. CompactFlash memory is predominantly available as Type I cards.

Where can I get a free copy of the CompactFlash Specification?

http://www.compactflash.org/specdl1.htm.

SAMPLE PROJECT

A sample project is included which is designed to be used with the project PCB module available from embedded-code.com. The project is ready to be used with the Microchip MPLAB IDE and the Microchip C18 compiler.

When run the 2 LED's on the project PCB operate as follows:-

Red LED indicates that PCB is powered

Green LED indicates that a CompactFlash card is inserted and is ready for use.

The 2 buttons on the project PCB trigger 2 different operations:-

Left edge switch	When pressed all files in the root directory are deleted, and a new file called test.txt is created containing example test data. The red LED blinks to confirm the operation.
Middle switch	When pressed a new Excel compatible spreadsheet file called test.csv is created containing test data from the test.txt file if it is present on the CompactFlash card. The green LED blinks to confirm the operation.

The project may be used as a starting point to write a new application or just as a reference for including the driver in your own project. A description of each of the sample project files is given in the 'Files Included In The Project' section of this manual.

Note that this project uses a modified version off the microchip standard linker script for the PIC18F4620. This is required as the C18 compiler does not support data buffers over 256 bytes without a modification to the linker script to define a larger bank of microcontroller ram. A 512 byte buffer is required by the driver.

TROUBLESHOOTING

If you are experiencing problems using the driver in your project the following tips may help:-

Double check IO pin definitions in the driver header file.

Verify with a scope that all of the control and data pins to the CompactFlash card are working correctly.

Add additional null execution steps to the FFS_DELAY_FOR_WAIT_SIGNAL define in the mem-cf.h file in case more time is required for signals to stabilise on your PCB. This is more likely to be an issue for 2 layer PCB's (no ground plane) with long tack lengths.

Check that no other device on the data bus is outputting while the driver is trying to communicate with the CompactFlash card.

Single step through the initialise new card part of the ffs_process function. There are several points at which the driver verifies the correct value is returned by the CompactFlash card and if the correct value is not being returned this may point to the cause of a problem.

Try using a different CompactFlash card made by a different manufacturer. We have occasionally come across faulty cards or cards that do not properly conform to the CompactFlash standard, even from reputable manufacturers.

If you're using output latches for some of the control pins, instead of pins connected directly to your processor, check your output latch function restores the previous output on the data bus when it exits, to avoid destroying the data the driver function is writing to a CompactFlash card.

Check that your microcontroller is not resetting due to a watchdog timer timeout. Read and write operations to CompactFlash cards can sometimes take time to complete that may exceeded your watchdog timer setting?

Check that you have enough stack space allocated. This driver uses a moderate amount of ram from the stack and if your application is already using large amounts of the stack before calling driver functions this may be causing a stack overrun?

PROJECT PCB MODULE

A PCB module is available from embedded-code.com which the CompactFlash driver is already configured for. It may be used as a development board to evaluate the driver, or as OEM (other end manufacturer) module to build into your own equipment.

PIC18 8bit PCB Module

FEATURES

PIC Microcontroller

Device

PIC18F4620 powered at 5V

Memory

64K bytes / 32K single word instructions of flash program memory.
3986 bytes of RAM data memory
1K bytes of eeprom data memory
(Note that when using an in-circuit debugger a small amount of program and RAM memory is not available).

Oscillator Speed

40MHz (10 million instructions per second).

Programming and in-circuit debugging

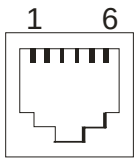
Several debuggers/programmers are available for the Microchip PIC18 series. We recommend the Microchip ICD2.

A 5 pin 'SIL' programming header is provided for programming and in-circuit debugging:

SIL 5	Function
1	MCLR/Vpp
2	Vdd
3	Gnd
4	PGD
5	PGC

A special link cable is available from embedded-code.com to connect the Microchip ICD2 debugger to our project PCB's, or if you wish to make you own:

SIL 5	Function	ICD2 RJ12
1	MCLR/Vpp	6
2	Vdd	5
3	Gnd	4
4	PGD	3
5	PGC	2



(Socket)

Special Notes

If working with a particular PIC device for the first time it is a good idea to check the Microchip 'errata' document for the device which will list any known issues and suggested workarounds.

The latest data sheet for this PIC microcontroller may be found on the Microchip web site at http://www.microchip.com.

Disabling The PIC Microcontroller

If you want to use the PCB module with an alternative processor / microcontroller, or want to connect it as a slave board to another of our Project PCB Modules the PIC microcontroller may be disabled by simply linking pins 1 and 3 on the 5 pin programming header (pin 1 is indicated by a square pad and 2 arrows on the silkscreen). This forces the PIC microcontroller into a reset state and all of its IO pins are set to high impedance inputs.

Note that the PIC microcontroller may be configured to disable the MCLR input which would stop this disabling method working. However the PCB module is supplied with the MCLR pin enabled and our sample projects set the pin as enabled.

RS232 Port

The PCB includes a RS232 driver IC for linking to a PC or other RS232 devices. The PIC microcontroller only provides one USART peripheral so a jumper is provided to allow selection of the RS232 or the RS485 receive signal to be connected to the microcontroller.

Making a RS232 Serial Cable To Connect The Module To A PC

D15 line male		D9 line female	Function
3	>	5	Ground
4	>	2	TX > RX
5	>	3	RX < TX

(If your PC application needs to use hardware flow control / handshaking then link pins 4>6 and pins 7>8 on the D9 connector).

RS422 / RS485 Port

The PCB includes a 2 wire bi-directional RS485 driver IC, suitable for RS422 or RS485 communications. The PIC microcontroller only provides one USART peripheral so a jumper is provided to allow selection of the RS232 or the RS485 receive signal to be connected to the microcontroller.

If you have not used a RS422 or RS485 interface before you should search the web for details of the requirements of this type of bus. The main requirements are that the cable connection must be 'daisy chain' (i.e. from device to device in one long line, with no 'Y' splits, and that twisted pair screen cable should be used if connecting more than a very short distance. The cable type is important and it is the twisting of the pair that carries the 'D-' and 'D+' data signals that provides the excellent interference rejection of this type of interface (much more so than the cable screen in fact).

Resistor footprints are provided for a terminate resistor and bus pull resistors which may be fitted if required. Normally a RS422 or RS495 bus is terminated at each end using a 120ohm resistor.

In applications where multiple devices transmit on the bus at different times you may wish to avoid the bus giving a bad low signal when no device is driving it by fitting pull up and pull down resistors. We recommend fitting 750R pull up and pull down resistors on just one device, typically the bus 'master' device if you have one, and 56K pull up and pull down resistors on all other devices. The device at each end of the bus should then use a 130R terminate resistor. These values are not part of any specification and you may find others recommend different values, but we have found these values to work very well in applications with fast data rates and long cable lengths.

I2C Port

The PIC microcontroller has a built in I2C port which you may use or simply use these pins as additional IO pins if required. Note that if using an I2C bus there should be pull up resistors fitted at one point on the bus and the PCB includes 0805 resistor footprints to allow these to be fitted if needed. The I2C bus may be used to connect local I2C devices, or to connect to other equipment or PCB modules using a short cable link.

DC Power
A 2.5mm mini power connector is provided to power the PCB. Note that a power supply is not supplied. A suitable DC power supply should be used with an output voltage of between 9 and 12V. An unregulated DC power supply may be used.

Voltage Regulator
The PCB voltage regulator may be used to power additional electronics. The IC is rated up to 800mA total load although you should check that the IC does not become too hot with additional load connected. If it does reduce the load or reduce the input supply voltage to reduce the heat output.

Switches
2 push buttons are provided for use in your application.

LEDs
1 red and 1 green LED are provided for use in your application. The red LED is next to left edge switch and the green LED is next to middle switch.

Stripboard Prototyping Area
This PCB module includes a stripboard prototyping area for you to add additional electronics if required. Note that the pads are connected in lines on the bottom layer of the PCB in the same way as standard stripboard.

PIC Microcontroller Spare Pins
There are 3 spare PIC pins which are connected to pads next to the stripboard prototyping area. These may be configured as analog inputs if required.

D Connector Spare Pins
The D connector has 6 spare pins which are connected to pads next to the stripboard prototyping area.

Development Connection Header
A SIL header type connection is provided on the PCB containing all of the connections made to the CompactFlash memory card. This may be used when testing signals or to connect an alternative microcontroller or processor, or to connect additional electronics to the data bus.

Running Current
With no CompactFlash card inserted the PCB module draws approximately 60mA. Standard CompactFlash memory cards may draw up to an additional 75mA average current.

Enclosure
A high quality machined enclosure is also available.

LAYOUT OF A COMPACTFLASH CARD WITH FAT

Note – this section of the manual is for information only. You do not need to read and understand this large and in depth section to use the driver! However you may want to if you wish to gain an understanding of disk access, the FAT filing system and how this driver works.

Terms used for hard disks and therefore CompactFlash memory cards

Remember when understanding these terms that hard disks uses multiple disks of magnetic material with a read/write head for each side of each disk. Bytes are read from and written to a disks surface in circular paths.

Track

The circular track on one surface of a disk (numbered 0 - #). This is not usually referred to.

Cylinder

All of the tracks in the same position on all of the surfaces (numbered 0 - #). This is not usually referred to other than when determining the parameters of a disk during initialisation.

Head

Each side of a disk has a read / write head (numbered 0 - #). This is not usually referred to other than when determining the parameters of a disk during initialisation.

Sector

This is the fundamental unit of disk mapping - all reading and writing to disks is carried out in sectors. A sector is usually 512 bytes in size, but can be 128 – 1024 bytes.
(Numbered as 1 - # (0 is reserved for identification purposes)).

Cluster

A cluster is a specified group of sectors. It is clusters that are the addressing unit when reading and writing files using the FAT system (i.e. a directory will point to a particular file using the cluster number that contains the start of the file). A cluster may only be used by one file, and large files will use multiple clusters to hold their data. A disk with a large cluster size (lots of sectors per cluster) will mean that disk space is wasted as any unused bytes after the end of a file in its final cluster will not be available for anything else. A disk with a small cluster size means less wastage. However, a small cluster size means a larger FAT table as a FAT table contains an entry for every cluster on a disk (or in the partition if the disk is partitioned), hence the need to FAT32 instead of FAT16 for larger volumes.

The valid range is 1 – 64 sectors per cluster. The first cluster that may be used is number 2 (clusters 0 & 1 are reserved).

The FAT filing system was developed for DOS and DOS thinks of a disk as a linear object, not as it is actually constructed. This means that DOS treats the sectors of a disk as a sequential list of sectors, from the first on the disk to the last. Whilst this made things more complex when writing drivers for hard disks, it makes things easier when dealing with modern flash memory cards as these are linear memory objects.

Byte Ordering

The FAT file system uses 'little endian'. That is that the first byte read is the least significant byte of a large value, the next byte read is more significant than the last and so on. For example this is how a 32bit value would be stored (with the bit numbers shown):-

```
byte[3] 3 3 2 2 2 2 2 2              //This is the last byte read from the disk
        1 0 9 8 7 6 5 4

byte[2] 2 2 2 2 1 1 1 1
        3 2 1 0 9 8 7 6

byte[1] 1 1 1 1 1 1 0 0
        5 4 3 2 1 0 9 8

byte[0] 0 0 0 0 0 0 0 0              //This is the first byte read from the disk
        7 6 5 4 3 2 1 0
```

Disk Information Block

This block of data is not part of the disk space, but is read from a Compact Flash Card using the 'Identify Drive' command before accessing the disk. See the following section for an in depth description.

No Start Address	255 bytes	'Identify Drive' command drive parameter information block.

The following show how the different sections of a disk are organised for FAT16 and FAT32, looking at the disk as a linear memory object (which is how it is addressed). See the following sections for an in depth description of each block.

The Layout of a FAT16 Volume

Start Address	Size	Contents	
0x00000000	512 bytes	Master Boot Record (Amongst other things this specifies the address of each of the main partitions).	
Partition Start Address + 0	512 bytes	Partition 1	The Boot Record. Located in the first sector of a partition.
Partition Start Address + 512	As specified in the Boot Record		FAT table 1
Partition Start Address + 512 + (Size of FAT Table x (FAT table # - 1))	As specified in the Boot Record		FAT table # (specified by 'Number of Copies of FAT' in master boot record. A value of 2 is normal)
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT)	As specified in the Boot Record		Root directory
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT) + Size of Root Directory	Calculated from the Master Boot Record Total Partition Size		Data area for files and other directories. (This area occupies the remainder of the disk, or the space to the start of the next partition).

Then follows further partitions if present:-

Start Address	Size	Contents	
Partition Start Address + 0	512 bytes	Partition 2	The Boot Record. Located in the first sector of a partition.
Partition Start Address + 512	As specified in the Boot Record		FAT table 1
Partition Start Address + 512 + (Size of FAT Table x (FAT table # - 1))	As specified in the Boot Record		FAT table # (specified by 'Number of Copies of FAT' in master boot record. A value of 2 is normal)
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT)	As specified in the Boot Record		Root directory
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT) + Size of Root Directory	Calculated from the Master Boot Record Total Partition Size		Data area for files and other directories. (This area occupies the remainder of the disk, or the space to the start of the next partition).

Repeated for each partition

Note - Shaded cells may repeat or not be present at all.

The Layout of a FAT32 Volume

This is basically the same as for a FAT16 volume, but without the root directory included (and with each block using a different amount of space).

Start Address	Size	Contents	
0x00000000	512 bytes	Master Boot Record (Amongst other things this specifies the address of each of the main partitions).	
Partition Start Address + 0	512 bytes	Partition 1	The Boot Record. Located in the first sector of a partition.
Partition Start Address + 512	As specified in the Boot Record		FAT table 1
Partition Start Address + 512 + (Size of FAT Table x (FAT table # - 1))	As specified in the Boot Record		FAT table # (specified by 'Number of Copies of FAT' in master boot record. A value of 2 is normal)
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT)	Calculated from the Master Boot Record Total Partition Size		Data area for files and other directories. (This area occupies the remainder of the disk, or the space to the start of the next partition).

Then if there is more than 1 partition, the additional partitions follow:-

Start Address	Size	Contents	
Partition Start Address + 0	512 bytes	Partition 2	The Boot Record. Located in the first sector of a partition.
Partition Start Address + 512	As specified in the Boot Record		FAT table 1
Partition Start Address + 512 + (Size of FAT Table x (FAT table # - 1))	As specified in the Boot Record		FAT table # (specified by 'Number of Copies of FAT' in master boot record. A value of 2 is normal)
Partition Start Address + 512 + (Size of FAT Table x Number of Copies of FAT)	Calculated from the Master Boot Record Total Partition Size		Data area for files and other directories. (This area occupies the remainder of the disk, or the space to the start of the next partition).

Repeated for each partition

Note - Shaded cells may repeat or not be present at all.

COMPACTFLASH IDENTIFY DRIVE INSTRUCTION

When initialising a new CompactFlash card the 'Identify Drive' command is used to determine the cards setup. Note that this is not part of the disk space, but is drive specific data. This command returns the following data:-

Word		Value
0	0x00	= 0x848A . General configuration word which indicates that this is a CompactFlash storage card
1	0x01	Default number of cylinders
2	0x02	Reserved (0x0000)
3	0x03	Default number of heads (0x00## where # is the value)
4	0x04	Number of unformatted bytes per track (0x#### where # is the value)
5	0x05	Number of unformatted bytes per sector (0x#### where # is the value)
6	0x06	Default number of sectors per track (0x#### where # is the value)
7	0x07	Number of sectors per card (Word 7 = most significant word, Word 8 = least significant word)
8	0x08	(0x######## where # is the value)
9	0x09	Vendor Unique
10	0x0A	20 bytes of serial number in ASCII (right justified and padded with spaces (0x20))
||	||	
19	0x13	
20	0x14	Buffer type (0x#### where # is the value)
21	0x15	Buffer size in 512 byte increments (0x#### where # is the value)
22	0x16	# of ECC bytes passed on Read/Write Long Commands (= 0x0004)
23	0x17	8 bytes of firmware revision in ASCII. (Big Endian)
||	||	
26	0x1A	
27	0x1B	40 bytes of model number in ASCII (Left Justified, Big Endian)
||	||	
46	0x2E	
47	0x2F	Maximum number of sectors on Read/Write Multiple command. (0x#### where # is the value)
48	0x30	Double Word not supported (= 0x0000, double word transfers not possible)
49	0x31	Capabilities:- Bit 13 Standby Timer (1 = Standby timer is supported (defined by the IDLE command), 0 = Standby timer operation is defined by the vendor) Bit 11 IORDY Support (1 = device supports IORDY operation, 0 = device may support IORDY operation) Bit 9 LBA support (CompactFlash storage cards support LBA mode addressing) Bit 8 DMA Support (Should be set to 0 as DMA mode is not supported)
50	0x32	Reserved (= 0x0000)
51	0x33	PIO data transfer cycle timing mode (0x0#00 where # is the value)
52	0x34	DMA data transfer cycle timing mode (= 0x0000)
53	0x35	Translation parameters are valid (= 0x0001)
54	0x36	Current numbers of cylinders (0x#### where # is the value)
55	0x37	Current numbers of heads (0x#### where # is the value)
56	0x38	Current sectors per track (0x#### where # is the value)
57	0x39	Current capacity in sectors (LBAs)(Word 57 = LSW, Word 58 = MSW)
58	0x3A	(0x######## where # is the value)
59	0x3B	Multiple sector setting (0x010# where # is the value)
60	0x3C	Total number of sectors addressable in LBA Mode
61	0x3D	(0x######## where # is the value)
62	0x3E	Reserved (138 bytes)
||	||	
127	0x7F	
128	0x80	Security status (0x#### where # is the value)
129	0x81	Vendor unique bytes (64 bytes)
||	||	
159	0x9F	

160	0xA0	Power requirement description (0x#### where # is the value) Bit 15 VLD (1 = this word contains a valid power requirement description) Bit 14 RSV (This bit is reserved and must be 0) Bit 13 -XP (1 = the CompactFlash Storage Card does not have Power Level 1 commands, 0 = has Power Level 1 commands_ Bit 12 -XE (1 = Power Level 1 commands are disabled, 0 - Power Level 1 commands are enabled) Bit 0-11 Maximum current. This field contains the CompactFlash Storage Card's maximum current in mA.
161	0xA1	Reserved
||	||	
255	0xFF	

This driver only reads the first section of this data to retrieve essential disk setup information and the rest is dumped. However you may want to modify the driver to include reading of additional data such as the 'Power Requirement Description' etc.

THE MASTER BOOT RECORD

The first sector of a hard disk is set aside for the Master Boot Record. This is operating system independent. It is located on the first Sector of the disk, at Cylinder 0, Head 0, Sector 1. It contains the partition table, which defines the different sections of your hard drive and if this section of a disk is corrupted it can mean that the disk is dead!

Note – if trying to view the master boot record using PC disk viewing software ensure that you have selected the correct section of the disk. Some software will show you the contents of the first partition by default, not the first sector containing the master boot record.

<table>
<tr><th colspan="2">Byte (0x00000000 + #)</th><th colspan="3">Value</th></tr>
<tr><td>0</td><td>0x0000</td><td colspan="3" rowspan="3">446 bytes of boot up executable code and data.</td></tr>
<tr><td>||</td><td>||</td></tr>
<tr><td>445</td><td>0x01BD</td></tr>
<tr><td>446</td><td>0x01BE</td><td rowspan="16">Partition 1</td><td>Offset 0x00</td><td>Current State of Partition (00h=Inactive, 80h=Active)</td></tr>
<tr><td>447</td><td>0x01BF</td><td>Offset 0x01</td><td>Beginning of Partition – Head</td></tr>
<tr><td>448</td><td>0x01C0</td><td>Offset 0x02</td><td>Beginning of Partition – Cylinder/Sector</td></tr>
<tr><td>449</td><td>0x01C1</td><td>Offset 0x03</td><td>
<table>
<tr><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="8">Cylinder Bits 7 to 0</td><td colspan="2">Cylinder Bits 9+8</td><td colspan="6">Sector Bits 5 to 0</td></tr>
</table>
</td></tr>
<tr><td>450</td><td>0x01C2</td><td>Offset 0x04</td><td>Type of Partition:
0x00 Unknown or Nothing
0x01 12-bit FAT
0x04 16-bit FAT (Partition Smaller than 32MB)
0x05 Extended MS-DOS Partition
0x06 16-bit FAT (Partition Larger than 32MB)
0x0B 32-bit FAT (Partition Up to 2048GB)
0x0C Same as 0x0B, but uses LBA 0x13 extensions
0x0E Same as 0x06, but uses LBA 0x13 extensions
0x0F Same as 0x05, but uses LBA 0x13 extensions
The above values relate to Microsoft operating systems – there are others.
LBA = Logical Block Addressing which uses the Int 0x13 extensions built into newer BIOS's to access data above the 8GB barrier, or to access strictly in LBA mode, instead of CHS (Cylinder, Head, Sector).</td></tr>
<tr><td>451</td><td>0x01C3</td><td>Offset 0x05</td><td>End of Partition – Head</td></tr>
<tr><td>452</td><td>0x01C4</td><td>Offset 0x06</td><td>End of Partition – Cylinder/Sector</td></tr>
<tr><td>453</td><td>0x01C5</td><td>Offset 0x07</td><td>
<table>
<tr><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="8">Cylinder Bits 7 to 0</td><td colspan="2">Cylinder Bits 9+8</td><td colspan="6">Sector Bits 5 to 0</td></tr>
</table>
</td></tr>
<tr><td>454</td><td>0x01C6</td><td>Offset 0x08</td><td rowspan="4">Number of sectors between the master boot record and the first sector in the partition.</td></tr>
<tr><td>455</td><td>0x01C7</td><td>Offset 0x09</td></tr>
<tr><td>456</td><td>0x01C8</td><td>Offset 0x0A</td></tr>
<tr><td>457</td><td>0x01C9</td><td>Offset 0x0B</td></tr>
<tr><td>458</td><td>0x01CA</td><td>Offset 0x0C</td><td rowspan="4">Number of sectors in the partition</td></tr>
<tr><td>459</td><td>0x01CB</td><td>Offset 0x0D</td></tr>
<tr><td>460</td><td>0x01CC</td><td>Offset 0x0E</td></tr>
<tr><td>461</td><td>0x01CD</td><td>Offset 0x0F</td></tr>
</table>

462	0x01CE	Partition 2	Offset 0x00	Current State of Partition (00h=Inactive, 80h=Active)
463	0x01CF		Offset 0x01	Beginning of Partition - Head
464	0x01D0		Offset 0x02	Beginning of Partition - Cylinder/Sector
465	0x01D1		Offset 0x03	(Format as per partition 1)
466	0x01D2		Offset 0x04	Type of Partition (Format as per partition 1)
467	0x01D3		Offset 0x05	End of Partition - Head
468	0x01D4		Offset 0x06	End of Partition - Cylinder/Sector
469	0x01D5		Offset 0x07	(Format as per partition 1)
470	0x01D6		Offset 0x08	Number of sectors between the master boot record and the first
471	0x01D7		Offset 0x09	sector in the partition.
472	0x01D8		Offset 0x0A	
473	0x01D9		Offset 0x0B	
474	0x01DA		Offset 0x0C	Number of sectors in the partition
475	0x01DB		Offset 0x0D	
476	0x01DC		Offset 0x0E	
477	0x01DD		Offset 0x0F	
478	0x01DE	Partition 3	Offset 0x00	Current State of Partition (00h=Inactive, 80h=Active)
479	0x01DF		Offset 0x01	Beginning of Partition - Head
480	0x01E0		Offset 0x02	Beginning of Partition - Cylinder/Sector
481	0x01E1		Offset 0x03	(Format as per partition 1)
482	0x01E2		Offset 0x04	Type of Partition (Format as per partition 1)
483	0x01E3		Offset 0x05	End of Partition - Head
484	0x01E4		Offset 0x06	End of Partition - Cylinder/Sector
485	0x01E5		Offset 0x07	(Format as per partition 1)
486	0x01E6		Offset 0x08	Number of sectors between the master boot record and the first
487	0x01E7		Offset 0x09	sector in the partition.
488	0x01E8		Offset 0x0A	
489	0x01E9		Offset 0x0B	
490	0x01EA		Offset 0x0C	Number of sectors in the partition
491	0x01EB		Offset 0x0D	
492	0x01EC		Offset 0x0E	
493	0x01ED		Offset 0x0F	
494	0x01EE	Partition 4	Offset 0x00	Current State of Partition (00h=Inactive, 80h=Active)
495	0x01EF		Offset 0x01	Beginning of Partition - Head
496	0x01F0		Offset 0x02	Beginning of Partition - Cylinder/Sector
497	0x01F1		Offset 0x03	(Format as per partition 1)
498	0x01F2		Offset 0x04	Type of Partition (Format as per partition 1)
499	0x01F3		Offset 0x05	End of Partition - Head
500	0x01F4		Offset 0x06	End of Partition - Cylinder/Sector
501	0x01F5		Offset 0x07	(Format as per partition 1)
502	0x01F6		Offset 0x08	Number of sectors between the master boot record and the first
503	0x01F7		Offset 0x09	sector in the partition.
504	0x01F8		Offset 0x0A	
505	0x01F9		Offset 0x0B	
506	0x01FA		Offset 0x0C	Number of sectors in the partition
507	0x01FB		Offset 0x0D	
508	0x01FC		Offset 0x0E	
509	0x01FD		Offset 0x0F	
510	0x01FE	Boot signature (= 0xAA55)		
511	0x01FF			

THE BOOT RECORD

The first sector of a partition contains a boot record. There are differences between the FAT16 and FAT32 boot records.

(Greyed out FAT32 entries indicate that the contents is the same as for FAT16)

FAT16

Offset	Description
0x0000	Jump Code + NOP
0x0001	
0x0002	
0x0003	8 byte OEM Name
||	
0x000A	
0x000B	Bytes Per Sector
0x000C	
0x000D	Sectors Per Cluster (Restricted to powers of 2 (1, 2, 4, 8, 16, 32…))
0x000E	Reserved Sectors
0x000F	
0x0010	Number of Copies of FAT. (A value of 2 is recommended – values other than 2 are possible by are not recommended by Microsoft)
0x0011	Maximum Root Directory Entries
0x0012	
0x0013	Number of Sectors in Partition Smaller than 32MB
0x0014	
0x0015	Media Descriptor (F8h for Hard Disks)
0x0016	Sectors Per FAT
0x0017	
0x0018	Sectors Per Track
0x0019	
0x001A	Number of Heads
0x001B	
0x001C	Number of Hidden Sectors in Partition
0x001D	
0x001E	
0x001F	
0x0020	Number of Sectors in Partition
0x0021	
0x0022	
0x0023	

FAT32

Offset	Description
0x0000	Jump Code + NOP
0x0001	
0x0002	
0x0003	8 byte OEM Name
||	
0x000A	
0x000B	Bytes Per Sector
0x000C	
0x000D	Sectors Per Cluster (Restricted to powers of 2 (1, 2, 4, 8, 16, 32…))
0x000E	Reserved Sectors
0x000F	
0x0010	Number of Copies of FAT. (A value of 2 is recommended – values other than 2 are possible by are not recommended by Microsoft)
0x0011	Maximum Root Directory Entries (not
0x0012	applicable for FAT32)
0x0013	Number of Sectors in Partition Smaller
0x0014	than 32MB (not applicable for FAT32)
0x0015	Media Descriptor (F8h for Hard Disks)
0x0016	Sectors Per FAT (not applicable for
0x0017	FAT32 – bigger field below)
0x0018	Sectors Per Track
0x0019	
0x001A	Number of Heads
0x001B	
0x001C	Number of Hidden Sectors in Partition
0x001D	
0x001E	
0x001F	
0x0020	Number of Sectors in Partition
0x0021	
0x0022	
0x0023	

From this point the boot records are not the same – continued on next page...

0x0024	Logical Drive Number of Partition
0x0025	
0x0026	Extended Signature (29h)
0x0027	Serial Number of Partition
0x0028	
0x0029	
0x002A	
0x002B	11 bytes of volume name of the partition
||	
0x0035	
0x0036	FAT Name (FAT16)
0x003E	448 bytes of executable code and data
||	
0x01FD	
0x01FE	Boot signature (= 0xAA55)
0x01FF	

0x0024	Number of Sectors Per FAT
0x0025	
0x0026	
0x0027	
0x0028	Flags: 15:8 Reserved Bit 7 1 = FAT Mirroring is Disabled, only 1 FAT is active as specified in bits 3:0 0 = FAT Mirroring is Enabled into all FATs 6:4 Reserved Bits 3:0 Number of active FAT (0-#). Only valid if mirroring disabled.
0x0029	
0x002A	Version of FAT32 Drive (high byte = major version, low byte = minor version)
0x002B	
0x002C	Cluster Number of the Start of the Root Directory (Usually 2, but not required to be)
0x002D	
0x002E	
0x002F	
0x0030	Sector Number of the File System Information Sector (Referenced from the start of the partition)
0x0031	
0x0032	Sector Number of the Backup Boot Sector (Referenced from the start of the partition)
0x0033	
0x0034	Reserved (12 bytes)
||	
0x003F	
0x0040	Logical Drive Number of Partition
0x0041	Unused
0x0042	Extended Signature (29h)
0x0043	Serial Number of Partition
0x0044	
0x0045	
0x0046	
0x0047	11 byte volume name of the partition
||	
0x0051	
0x0052	8 byte FAT Name (FAT32)
||	
0x0059	
0x005A	420 bytes of executable code and data
||	
0x01FD	
0x01FE	Boot Signature (= 0xAA55)
0x01FF	

THE FAT TABLES

The FAT table (whether FAT16 or FAT32) contains an entry for every cluster on the disk (or partition if the disk is partitioned). Each entry is either 16 bits in size for FAT16, or 32bits in size for FAT32. The contents of an entry may be as follows:-

FAT16 Table Entry Values:-

0x0000	The cluster is free.
0x0001	Reserved
0x0002 – 0xFFF0	This cluster is used. The value indicates the next cluster number for the file.
0xFFF7	Cluster is bad
0xFFF8 – 0xFFFF	EOC (End Of Clusterchain) (typically you should use 0xFFFF)

FAT32 Table Entry Values:-

0x#0000000	The cluster is free.
0x0001	Reserved
0x0002 – 0xFFF0	This cluster is used. The value indicates the next cluster number for the file.
0x#FFFFFF7	Cluster is bad
0x#FFFFFF8 – 0x#FFFFFFF	EOC (End Of Clusterchain) (typically you should use 0x#FFFFFFF

(The top 4 bits are reserved and will not necessarily be zero. They must be ignored when reading a cluster number but maintained when writing a new value to an entry)

When a file is stored the first available free cluster is found from the FAT table and stored in the files directory entry (see later in this manual). The file is written to the cluster. If it doesn't fit within the cluster then the next free cluster is found and the new cluster number is written in the previous clusters FAT table entry. This continues until the last cluster that is required for the file (which may be the first cluster if the file will fit within one cluster). The EOC marker is written to the FAT tables for the last cluster to indicate that no further clusters are used.

Therefore when reading a file the start cluster number is determined from the files entry in the directory the file is located in. Then the FAT table is used to find the next cluster that holds the next block of the files data, then the next etc. Whilst the EOC marker indicates that a cluster is the last cluster used to store a file, the exact file size is stored in the files directory entry so that the last used byte number of the file can be determined.

FAT16 FAT Table

Byte (Partition Start Address + 512 + #)		FAT Entry	Value
0	0x0000	1	Reserved. Contains the media type value in the low 8 bits and all other bits are set to 1
1	0x0001		
2	0x0002	2	Reserved – set on format to the EOC marker. The top 2 bits may be used as 'dirty volume' flags: Bit 15 1 = volume is 'clean'. 0 = volume is 'dirty' (the file system driver did not complete its last task properly and it would be good idea to run a disk checking program. Bit 14 1 =no disk read/write errors were encountered. 0 = the file system driver encountered a disk I/O error on the volume the last time it was used, which indicates that some sectors may have gone bad on the volume. It would be a good idea to run a disk checking program.
3	0x0003		
4	0x0004	3	The FAT entry for the 1st cluster in the data area of the disk / partition
5	0x0005		
6	0x0006	4	The FAT entry for the 2nd cluster in the data area of the disk / partition
7	0x0007		
||	||		
#	0x####	#	The FAT entry for the last cluster in the data area of the disk / partition
#	0x####		

FAT32 FAT Table

Byte (Partition Start Address + 512 + #)		FAT Entry	Value
0	0x0000	1	Reserved. Contains the media type value in the low 8 bits and all other bits are set to 1
1	0x0001		
2	0x0002		
3	0x0003		
4	0x0004	2	Reserved – set on format to the EOC marker. The top 2 bits may be used as 'dirty volume' flags: Bit 27 1 = volume is 'clean'. 0 = volume is 'dirty' (the file system driver did not complete its last task properly and it would be good idea to run a disk checking program. Bit 26 1 =no disk read/write errors were encountered. 0 = the file system driver encountered a disk I/O error on the volume the last time it was used, which indicates that some sectors may have gone bad on the volume. It would be a good idea to run a disk checking program.
5	0x0005		
6	0x0006		
7	0x0007		
8	0x0008	3	The FAT entry for the 1st cluster in the data area of the disk / partition
9	0x0009		
10	0x000A		
11	0x000B		
12	0x000C	4	The FAT entry for the 2nd cluster in the data area of the disk / partition
13	0x000D		
14	0x000E		
15	0x000F		
||	||		
#	0x####	#	The FAT entry for the last cluster in the data area of the disk / partition
#	0x####		
#	0x####		
#	0x####		

FAT16 uses 2 FAT tables, one after the other, and FAT32 uses up to 4 FAT tables. This provides a backup in case of corruption of one of the tables. If you change the contents of the FAT table, ensure that all copies are updated (checking for FAT32 to see which tables should be updated).

Location & Size

The first FAT table starts straight after the Boot Record. Therefore the start address of the first FAT table:

= Start address of partition + No of reserved sectors

Each additional FAT table follows straight on after the last. The number of FAT tables is recommended to be 2 due to old systems that assume a value of 2. However the number of FAT tables does not have to be 2 and for flash drives where a backup of the FAT table is redundant only a single table may be used. It is also possible to have more than 2 FAT tables.

ROOT DIRECTORY & OTHER DIRECTORIES

A FAT directory is simply a 'file' containing a linear list of 32 byte entries. The only special directory, which must always be present, is the root directory. For FAT16 volumes the root directory is located in a fixed location on the disk immediately following the last FAT and is a fixed size in sectors as specified in the Boot Record.

For FAT16 the first sector of the root directory is sector number relative to the first sector of the FAT volume:

For FAT32 the root directory can be of variable size and is a cluster chain just like any other directory. The first cluster of the root directory is specified in the Boot Record.

Each directory entry is 32 bytes and formatted as follows:

<table>
<tr><th colspan="2">Byte</th><th>Value</th></tr>
<tr><td>0</td><td>0x00</td><td rowspan="8">Name
(The 8 character filename)</td></tr>
<tr><td>1</td><td>0x01</td></tr>
<tr><td>2</td><td>0x02</td></tr>
<tr><td>3</td><td>0x03</td></tr>
<tr><td>4</td><td>0x04</td></tr>
<tr><td>5</td><td>0x05</td></tr>
<tr><td>6</td><td>0x06</td></tr>
<tr><td>7</td><td>0x07</td></tr>
<tr><td>8</td><td>0x08</td><td rowspan="3">Extension
(The 3 character filename extension)</td></tr>
<tr><td>9</td><td>0x09</td></tr>
<tr><td>10</td><td>0x0A</td></tr>
<tr><td>11</td><td>0x0B</td><td>Attributes
<table>
<tr><td>Bit:</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>Value:</td><td>0</td><td>0</td><td>Archive</td><td>Directory</td><td>Volume Label</td><td>System</td><td>Hidden</td><td>Read Only</td></tr>
</table></td></tr>
<tr><td>12</td><td>0x0C</td><td>NT
(Reserved for WindowsNT always 0)</td></tr>
<tr><td>13</td><td>0x0D</td><td>Created time – mS (0 if not used)</td></tr>
<tr><td>14</td><td>0x0E</td><td rowspan="2">Created time - hour and minute (0 if not used)</td></tr>
<tr><td>15</td><td>0x0F</td></tr>
<tr><td>16</td><td>0x10</td><td rowspan="2">Created date (0 if not used)</td></tr>
<tr><td>17</td><td>0x11</td></tr>
<tr><td>18</td><td>0x12</td><td rowspan="2">Last accessed date (0 if not used)</td></tr>
<tr><td>19</td><td>0x13</td></tr>
<tr><td>20</td><td>0x14</td><td rowspan="2">Extended Attribute
(reserved for OS/2, always 0)
High word of cluster for FAT32 volumes</td></tr>
<tr><td>21</td><td>0x15</td></tr>
<tr><td>22</td><td>0x16</td><td rowspan="2">Time of last write to file</td></tr>
<tr><td>23</td><td>0x17</td></tr>
<tr><td>24</td><td>0x18</td><td rowspan="2">Date of last write to file</td></tr>
<tr><td>25</td><td>0x19</td></tr>
<tr><td>26</td><td>0x1A</td><td rowspan="2">Start cluster (referenced from the start of the data area of the volume)</td></tr>
<tr><td>27</td><td>0x1B</td></tr>
<tr><td>28</td><td>0x1C</td><td rowspan="4">File size</td></tr>
<tr><td>29</td><td>0x1D</td></tr>
<tr><td>30</td><td>0x1E</td></tr>
<tr><td>31</td><td>0x1F</td></tr>
</table>

(Shaded bytes we're unused in the original DOS specification and may still be left unused if desired)

Special Markers

If the first byte of a directory entry is 0xE5 then the entry has been erased. If the first byte is 0x00 then the entry has never been used (this can be used to detect the end of the table as all following entries will also be 0x00).

Location & Size

For FAT16 the root directory is located directly after the 2nd FAT table:

= Start address of partition + No of reserved sectors + (Number of FAT tables x FAT table size)

Its size is specified by the boot record:

= maximum number of root directory entries x 32 bytes per entry

The data area starts straight after the root directory. The only difference between the root folder and any other folders is that the root folder is at a specified location and has a fixed number of entries.

For FAT32 the root directory can be of variable size and is a cluster chain, just like any other directory is. The first cluster of the root directory on a FAT32 volume is stored in the sector specified in the boot record.

For both FAT16 and FAT23, unlike other directories, the root directory itself does not have any date or time stamps, does not have a file name (other than the implied file name "\"), and does not contain "." and ".." files as the first two directory entries in the directory. The only other special aspect of the root directory is that it is the only directory on the FAT volume for which it is valid to have a file that has only the 'Volume ID' attribute bit set.

Date and Time Formats

If date and time are not supported then they should be written as zero. Bytes 22 – 25, time of last write and date of last write, must be supported according to the FAT specification but if a device has no real time clock then this isn't possible.

Date field

A 16-bit field that is a date relative to 01/01/1980:-

Bits 15:9	Count of years from 1980, valid range 0 – 127 (=1980–2107).
Bits 8:5	Month of year, valid range 1–12 (1 = January)
Bits 4:0	Day of month, valid range 1-31

Time Format.

A 16-bit field with a valid range from Midnight 00:00:00 to 23:59:58:-

Bits 15:11	Hours, valid range 0 – 23
Bits 10:5	Minutes, valid range 0 – 59
Bits 4:0	2-second count, valid range 0–29 (= 0 – 58 seconds)

DATA AREA

The remainder of the volume is the data area, which may contain files and directories. It is this area that the FAT tables relate to.

Start Address

For FAT16 the start address of the data area is:-

Start address of partition + Number of reserved sectors + (Number of FAT tables x FAT table size) + Number of root directory sectors

For FAT32 the start address of the data area is:-

Start address of partition + Number of reserved sectors + (Number of FAT tables x FAT table size)

For a given cluster number in the FAT table, the start address of that sector is:-

data area start address + ((FAT table cluster number – 2) x sectors per cluster)

Because sectors per cluster is restricted to powers of 2 (1, 2, 4, 8, 16, 32…), division and multiplication by sectors per cluster can actually be performed via shift operations which is often faster than multiply or divide instructions

FAT32 File System Information Sector

(Not applicable to FAT16)

The partition boot record specifies the sector that contains this information block, which can be utilised by a FAT driver to speed up write operations.

Byte (Sector Start + #)		Value
0	0x0000	Signature = 0x41615252. This validates that this is a File System Information Sector.
1	0x0001	
2	0x0002	
3	0x0003	
4	0x0004	480 reserved bytes
||	||	
483	0x01E3	
484	0x01E4	Signature = 0x61417272. Another signature that is more localized in the sector to the location of the fields that are used.
485	0x01E5	
486	0x01E6	
487	0x01E7	
488	0x01E8	Number of Free Clusters on the volume. Set to 0xFFFFFFFF if unknown and needs computing. This should be range checked at least to make sure it is <= volume cluster count.
489	0x01E9	
490	0x01EA	
491	0x01EB	
492	0x01EC	It indicates the cluster number at which the driver should start looking for free clusters – it is a hint for the FAT driver. Because a FAT32 FAT is large, it can be rather time consuming if there are a lot of allocated clusters at the start of the FAT and the driver starts looking for a free cluster starting at cluster 2. Typically this value is set to the last cluster number that the driver allocated. If the value is 0xFFFFFFFF, then there is no hint and the driver should start looking at cluster 2. Any other value can be used, but should be checked first to make sure it is a valid cluster number for the volume.
493	0x01ED	
494	0x01EE	
495	0x01EF	
496	0x01F0	12 reserved bytes
||	||	
507	0x01FB	
508	0x01FC	Trailing signature = 0x000055AA Used to validate that this is a File System Information Sector.
509	0x01FD	
510	0x01FE	
511	0x01FF	

SUPPORT

Please visit the support section of the embedded-code.com web site if you have any queries regarding this driver. Please note that our support covers the use of this driver with the reference designs in this manual. Where possible we will try to help solve any problems if the code is used with other devices or compilers, but given the huge number of devices and compilers available we are unable to guarantee 'out of the box' compatibility. If you plan to use the source code with a different processor, microcontroller and/or compiler you should ensure that you have sufficient programming expertise to carry out any modifications that may be required to the source code.

If you do encounter issues using the driver with other compilers or devices and are able to give us details of the issue you encountered we will try and include changes or notes across our range of drivers to help other programmers avoid similar issues in the future. Please email any such issues discovered to support@embedded-code.com

REVISION HISTORY

V1.00

Original release

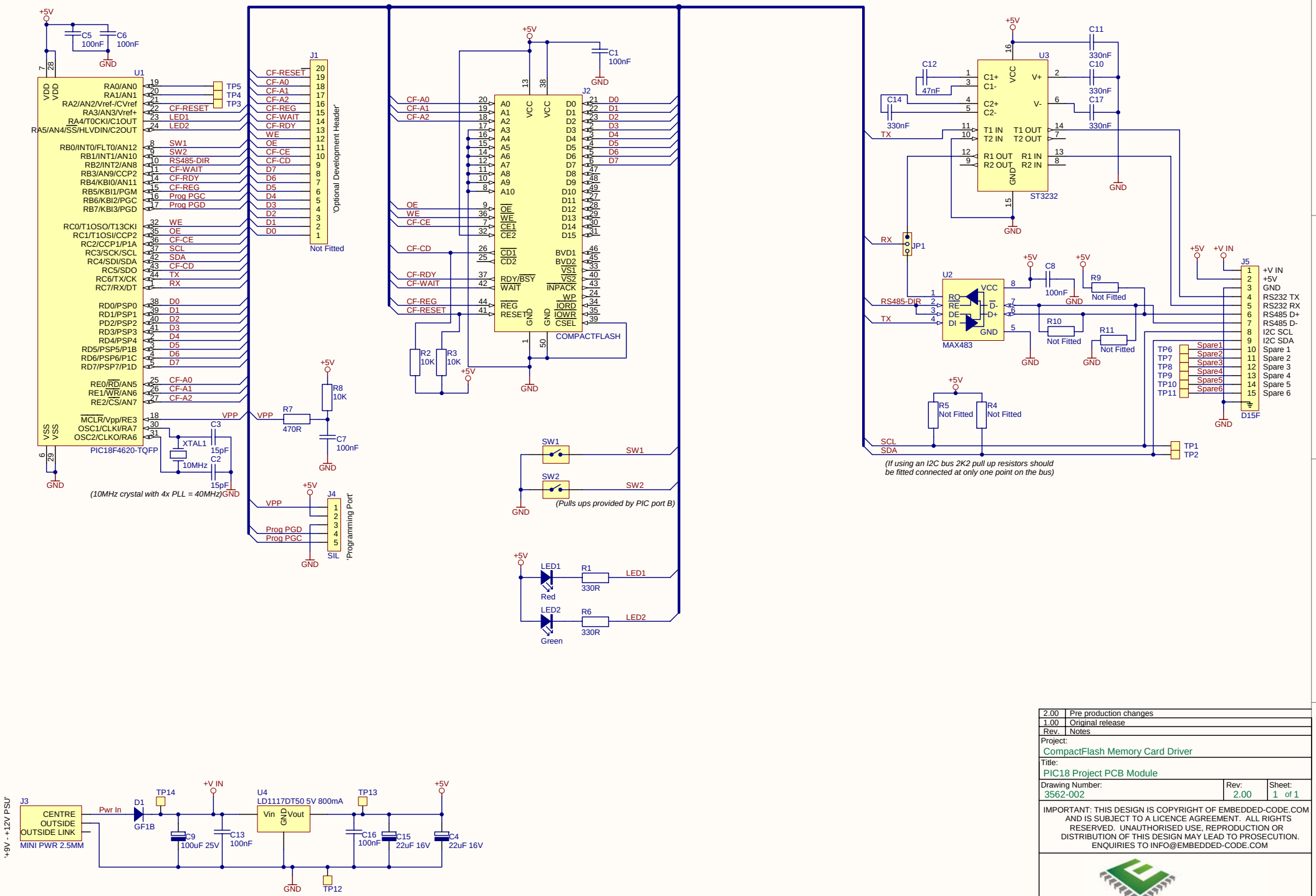
V1.01

Minor modifications for V1.02 firmware.

V1.02

Added sections on ‘Fast Reading Of Bulk File Data’ and ‘Fast Writing Of Bulk File Data’.
Added ‘Searching In The Directory’ section to demonstrate how it is possible to search in the root directory for files.

Web: www.embedded-code.com
Email: info@embedded-code.com



2.00	Pre production changes
1.00	Original release
Rev.	Notes

Project: CompactFlash Memory Card Driver

Title: PIC18 Project PCB Module

Drawing Number: 3562-002 | Rev: 2.00 | Sheet: 1 of 1

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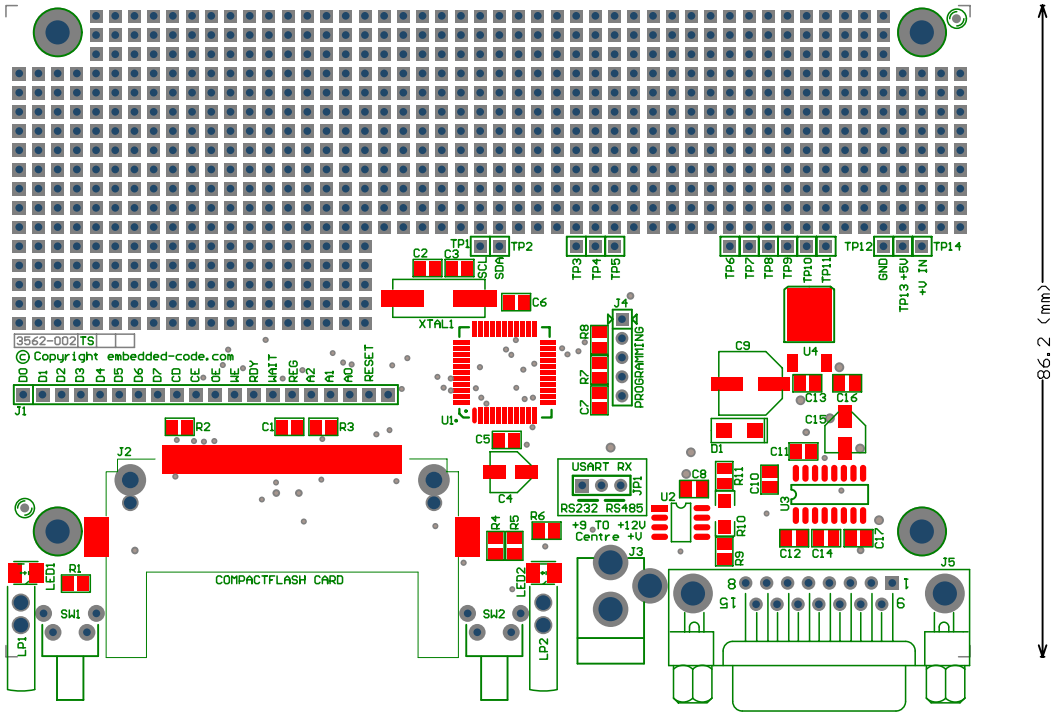

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Layers Shown:	TopOverlay
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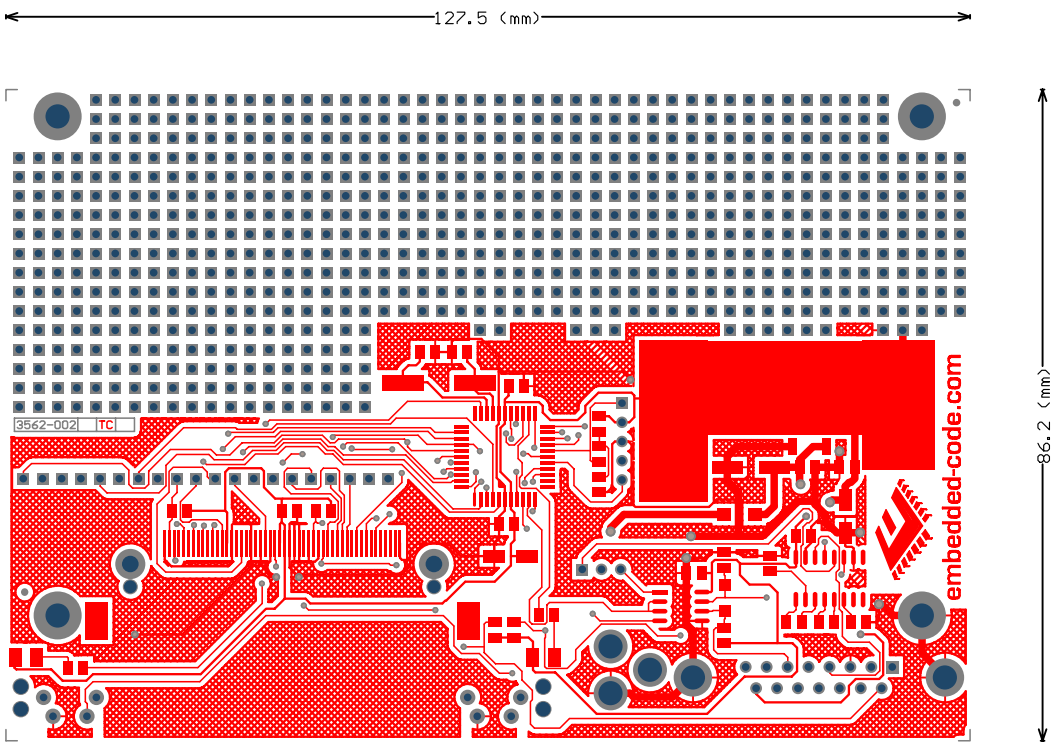

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Ref: 3562-002
Layers Shown: TopLayer
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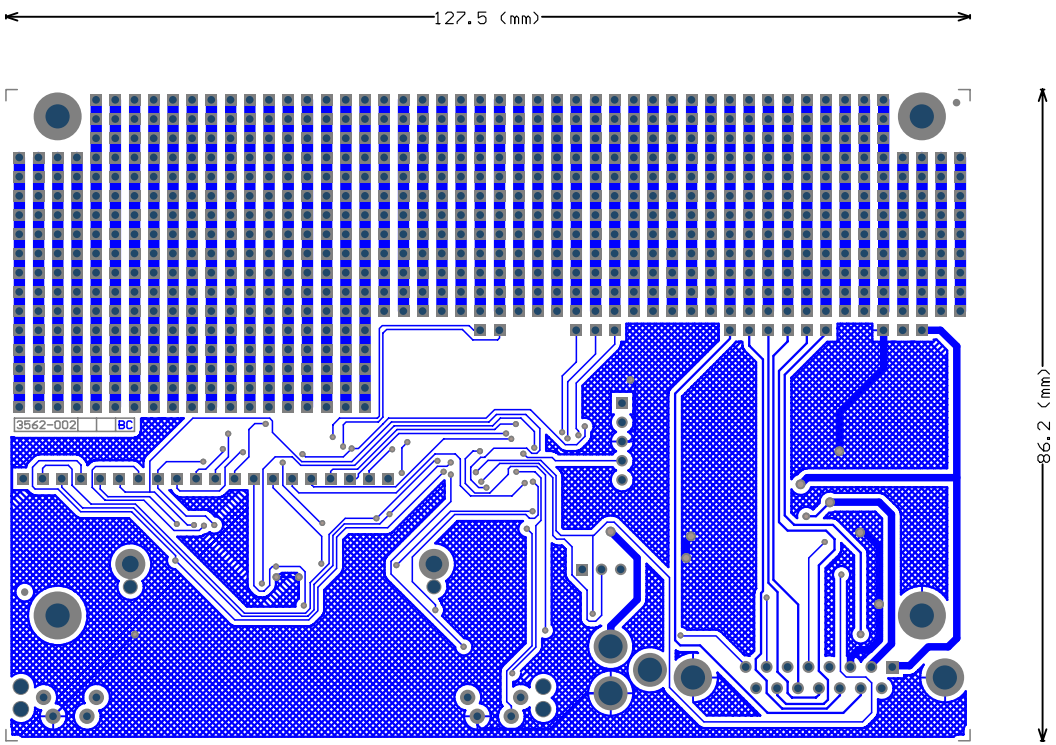

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Layers Shown: BottomLayer
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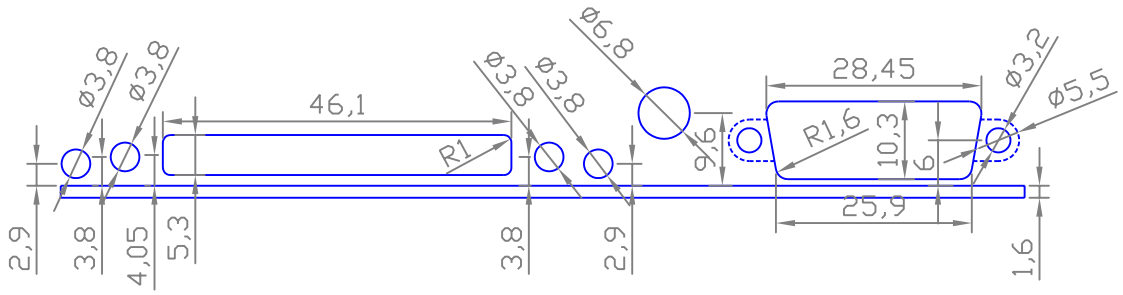
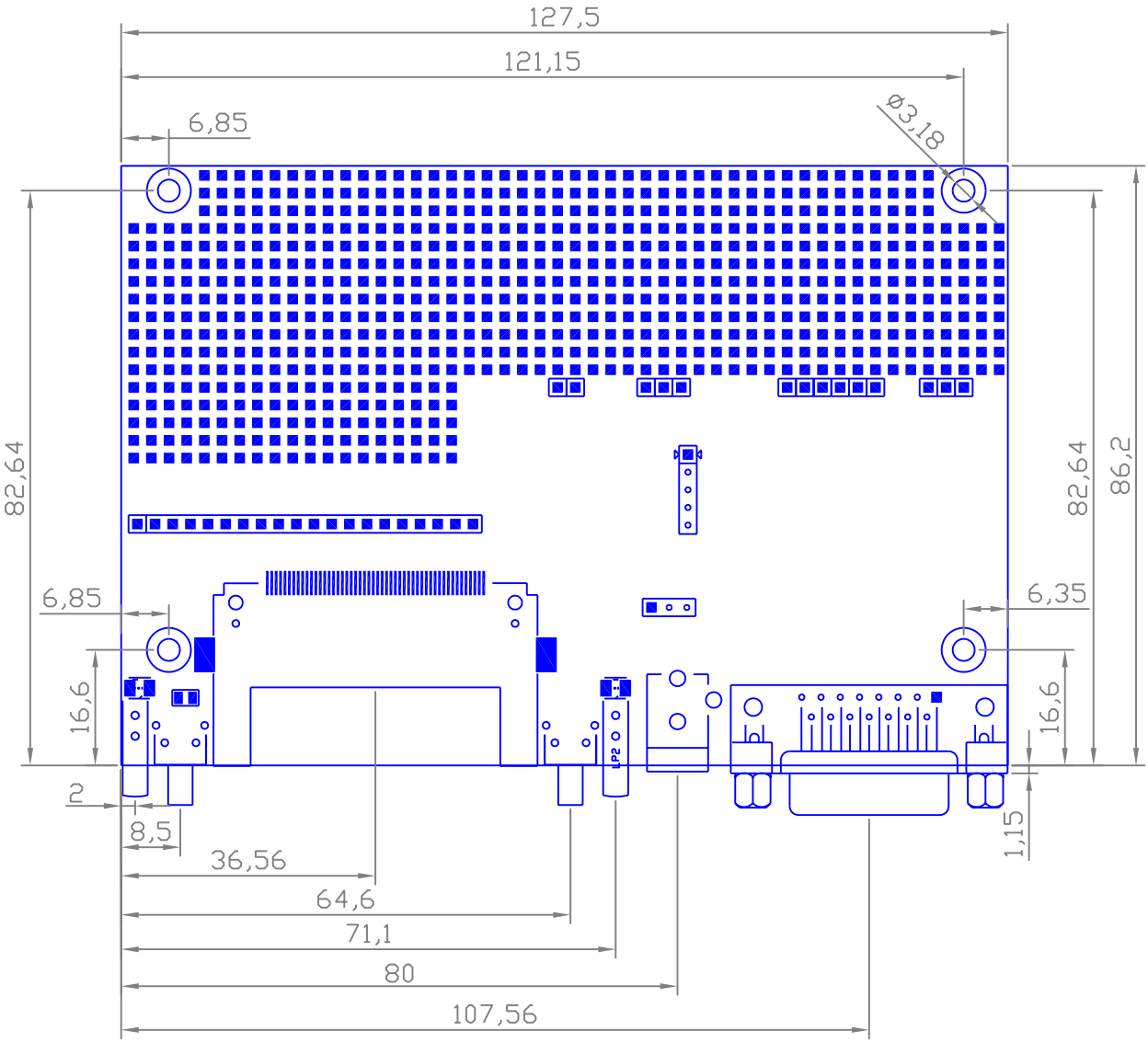
Side view showing suggested panel cutout dimensions



Plan view



Title: COMPACT FLASH MEMORY CARD DRIVER PIC18 PROJECT PCB MODULE
Sheet: MECHANICAL DRAWING
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