LM80C DOS

DISK OPERATING SYSTEM

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REFERENCE MANUAL

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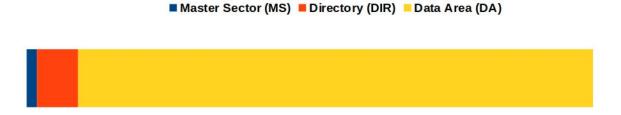
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1. The LM80C DOS

The **LM80C DOS** is a *Disk Operating System* integrated into the firmware of the LM80C 64K Color Computer that serves as an interface to let the user access for input/output operations to a mass storage device. The devices used as mass storage are common Compact Flash (CF) cards (from now on, "disk" will be used in this document as a synonym for CF card). CF cards have been chosen because they can operate in 8-bit mode: this is important when having to interface them with the Z80 CPU, since this microprocessor has an 8-bit data bus that can be directly connected to such memories. Moreover, they are relatively cheap and large enough to store an obscenely amount of files, if compared to floppy disks of the time. CF cards can be driven in both IDE and LBA modes: the latter is the one used on LM80C Color Computers. In LBA (Logical Block Addressing) each sector of the card can be addressed by setting up its sector number through the card's registers.

1.1 How the disk is formatted

The LM80C DOS formats (initializes) a disk by dividing its space in 3 main areas:

1. Master Sector (MS)

2. Directory (DIR)

3. Data Area (DA)

1.2 The Master Sector

The **Master Sector** (MS) is what in other DOSs is often called the MSB, or Master Boot Sector. It is always located at sector #0 of the disk and contains specific details on how the disk has been formatted and several other info on the disk itself, like its name, its geometry, the starting addresses of the directory and of the DA. The MS contains the following data (addresses are in hexadecimal format):

Address	Contents
$000-$008	"LM80C DOS" ← DOS name
$009	$00 ← unused
$00A-$00D	"A.BC" (4 bytes) ← version of DOS used to format the disk (i.e.: 1.06)

`$00E`	$00 ← unused
`$00F-$012`	disk size in sectors (4 bytes): value recovered from bytes $00E-$011 of the CF card ID*
`$013-$014`	number of cylinders (2 bytes): value recovered from bytes $002-$003 of the CF card ID*
`$015-$016`	number of cylinders (2 bytes): value recovered from bytes $002-$003 of the CF card ID*
`$017-$018`	number of heads (2 bytes): value recovered from bytes $006-$007 of the CF card ID*
`$019-$01A`	number of allowed files (2 bytes)
`$01B-$01C`	starting sector of the directory (2 bytes) - default $0001
`$01D-$01E`	starting sector of the Data Area (2 bytes)
`$01F`	$00 ← unused
`$020-$02F`	disk name (16 bytes) – unused bytes are filled up with ASCII code 32 ($20), or "space" **
`$030-$033`	disk ID (4 bytes) – one letter, one number, one letter, and one number, randomly generated (chars "A" to "Z" and "0" to "9", ex.: "B1Y7") ← this is the unique disk ID
`$034-$1FD`	$00 ← unused
`$1FE-$1FF`	"80" ($38 $30) ← control signature, it is always set to "80"

*CF card ID: the "Identify Drive" is a command accepted by the CF card that returns some useful details about the card itself.

**disk name: allowed chars are letters from "A" to "Z", numbers from "0" to "9", "space" and "-" (minus symbol).

IMPORTANT: words (2 bytes) and double words (4 bytes) are stored as follow. For single words, the Little Endian format is used: the first byte contains the less significant byte (LSB) while the second byte contains the most significant byte (MSB). For double words, the first couple of bytes contains the MSW (most significant word), stored in Little Endian format, while the second couple contains the LSW (less significant word), also stored in Little Endian format.

I.e., double word:

0007 A800

is stored as follow:

0700 00A8

Here is an example of a Master Sector from a 256 MB CF card:

	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	
$000	4C	4D	38	30	43	20	44	4F	53	00	31	2E	30	30	00	07	LM80C DOS.1.00..
						DOS name & version											
$010	00	00	A8	D4	03	20	00	10	00	50	0F	00	01	F6	00	00	..(T. ...P...v..
		# of sectors		tracks		sectors		heads		files		b. of DIR		b. of DA			
$020	54	45	53	54	44	49	53	4B	20	20	20	20	20	20	20	20	TESTDISK
								disk name									
$030	54	3C	45	3D	00	00	00	00	00	00	00	00	00	00	00	00	T<E.............
		disk ID															
$040	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	....
....																	
$0F0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	38	30	80
															80		

By analyzing such data we can get some useful informations. We can see that the DOS version is 1.06, that "TESTDISK" is the disk name, that the directory starts at sector $0001 and that the DA starts at sector $00F6. The number of disk sectors is $0007A800 (501′760). In fact, this value can be found using the following formula, based on the disk geometry, too:

```
# of sectors = cylinders × sectors per cylinder × heads
```

By getting the corresponding values from the table above, that gives the following results:

```
$03D4 × $0020 × $0010 = $007A800 = 501'760
```

To know the real size of a CF card, we multiply this value by the size of a sector. This value is fixed for any CF card, and it's equal to 512 bytes. So, translated in numbers:

```
501'760 × 512 = 256'901'120 bytes = 245 MB
```

This is the formatted space over the nominal size (256 MB): keep in mind that the real capacity of a CF is always lesser than the capacity given by the manufacturer.

1.3 The Directory

The **Directory** is the disk area that is used to store the details about the files saved onto the disk. Every file descriptor is called an **entry**. Files are stored in **blocks**: each block of the disk is 64 KB wide, and each block can only store the data of a single file. Entries are also the file indexes themselves, since each entry in the directory corresponds to a file, so, the 1st entry in the directory corresponds to the 1st file on the disk, the 2nd entry corresponds to the 2nd file, and so on. The size of the directory is calculated when the disk is formatted and it's based on the size of the disk itself. Since a sector of the disk is 512 bytes wide, and since each entry in the directory occupies 32 bytes, we can easily calculate that each sector of the directory contains 16 entries (512/32=16). The

maximum allowed number of files that can be managed by LM80C DOS is 65′536, no matter the size of the CF card used is. So, the maximum number of sectors occupied by the directory is:

```
65'536 / 16 = 4'096
```

To calculate the size of the directory, first we must find the number of sectors available (see 1.1.1), and then divide this number by the number of sectors per block. We've already said that each block is 64 KB wide. Given this value, we now know that each block contains 128 sectors, because:

```
block size in sectors = block size in bytes / bytes per sector
```

So, we have:

```
65'536 / 512 = 128
```

The maximum number of entries in a directory are given by:

```
disk size in sectors / sectors per block
```

For our current example with 501′760 sectors, we can easily find that this disk can contain 3′920 entries because:

```
501'760 / 128 = 3'920
```

1.3.1 A directory entry

Each entry in the directory is composed by 32 bytes, each byte carries specific info, as in the table below (addresses are in hexadecimal format, starting address is arbitrarily set to $00):

Address	Contents
`$00-$0F`	file name (16 bytes) - allowed chars are letters from "A" to "Z", numbers from "0" to "9", space and "-" (minus). Extensions are not supported.
`$10`	type of file: $82: BAS (BASIC file) $81: BIN (binary file) $82: SEQ (sequential file)
`$11`	file attributes (for future use, at the moment NOT supported)
`$12-$13`	entry number (2 bytes)
`$14-$17`	number of 1st sector of the corresponding block (4 bytes)
`$18-$19`	file size in bytes (2 bytes)
`$1A`	file size in sectors (1 byte)
`$1B-$1C`	starting address of the file in the computer memory (used for binary files)
`$1D-$1F`	$00 (reserved for future uses)

The first char of the file name can also have a couple of values with specific meanings:

- a value of $00 means that the entry is empty (never used before) and free for use;

- a value of $7F means that the entry has been deleted and can be re-used or recovered (un-deleted)

Below is an example of an entry of the directory of our sample disk:

	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	
00	4D	41	52	49	4F	20	20	20	20	20	20	20	20	20	20	20	MARIO
							file name										
01	80	00	00	00	00	00	F6	00	37	00	01	07	5E	00	00	00	.........7......
	tp.	attr.	entry #		starting sector				file size		sc.l.	m.addr.					

By looking at the entry's data we can see that:

- the file name is "MARIO" - look at the padding spaces (ASCII $20): they're added to fill up the file name space (see "file name");

- this is a BASIC file (type $80 – see "tp.");

- it has no attributes ($00 – see "attr.");

- its entry number is $0000 (see "entry #");

- the block that stores its data begins at sector $0000-00F6 (see "starting sector")

- its size is $0037 bytes (see "file size"), corresponding to 1 sector; (see "sc.l.")

- the file originally was located in RAM starting at $5E07 (for BASIC files, this address corresponds to the value of $PROGND: see "LM80C Hardware Reference Manual", sect. 4.2, to look for the correct value for your current firmware version).

1.4 File types

The LM80C DOS treats files regarding of their type. There is no support for "extensions", as intended in other DOSs, i.e. no portions of the file name can be introduced by a "." (full stop) or other special character to set the type of the file: instead, the type is hard coded directly by DOS into the corresponding file entry in the directory. When listing files of a disk, the DOS will always print the file type after the file name.

Currently, the following file types are supported and reported when listing the directory:

BAS: BASIC programs ($80)

BIN: binary files ($81)

SEQ: sequential files ($82)

???: unknown (a disk error may have been occurred and ruined the file entry)

1.4.1 BASIC files

A BASIC file (marked as "BAS" when listed) is always loaded into the computer memory starting at address $PROGND, ignoring the memory address stored into the file itself. This is done because if the DOS would look at the address stored into the file, it could load it into an area that is not correctly aligned with the BASIC pointers, i.e. for a different version of the firmware but with the same DOS version. The ability to load & run BASIC programs from different firmware versions is valid only for mono-line programs, since each line of a BASIC program points to the RAM address where the next line is stored: if a program from a different firmware is loaded into memory, executing it will result in serveral faults because each line will point to dis-aligned BASIC lines. This is the reason why the DOS version of the disk is always checked before to operate on it, so that a disk can not be used if the DOS version used to format such disk doesn't match the DOS being executed. Unfortunately, the same control can not be executed on BASIC files being loaded, so it is the user that has to avoid loading a program saved with a different firmware.

When a "BAS" file is saved, the DOS makes also a copy of a specific portion of memory on the disk, so that when the files is loaded up again, it will result as if it was just typed in by the user. The area that is stored starts at `$PROGND` and ends to `($PROGND)`, so that several BASIC pointers are saved together with the program itself. What do those values stand for? Like in assembly, `$PROGND`, stands for the address of that memory cell, while `($PROGND)` stands for the pointer stored into that cell: this pointer is a word and points at the last memory cell occupied by the BASIC program. When the BASIC program is loaded into memory, its bytes will be restored from such address, recovering the exact status of the BASIC environment when the program was saved.

1.4.2 Binary files

The case of Binary ("BIN") files is different. Binary files are particular files which contain a raw copy of a portion of memory. In this case, it is mandatory to force the DOS to load the file respecting the original address of the data (argument ",1" after the `LOAD` statement). It is important that the user knows exactly where to load a "BIN" file into memory because its contents may be copied over a memory area occupied by BASIC or DOS routines, altering the functioning of the computer and, in the worst case, leading to the necessity of an hard reset to restore the original firmware.

1.4.3 Sequential files

Sequential files ("SEQ" type) are files whose data are stored in chronological order as they are saved into them. This means that in order to locate a particular data value, such files must be read starting at the beginning of the file and so on, until the position of the required data is reached. A sequential file can be increased in size by adding additional data at the end of the file ("appending"). This occurs when opening a file already present into the directory: in this case, the DOS will position the data pointer at the end of such file to let the user add other data, otherwise if the file is not present, it will be created from scratch.

While data is written to or read from a file, the DOS keeps in memory the disk sector that is currently reflecting that portion of file in a particular area of the main memory called "buffer". When the user writes to/read from a sequential file, he/she is operating on such buffer, not on the

real sector on the disk. Each writing or reading operation increments a data pointer: when this pointer reaches the end of the buffer, the DOS makes some jobs. If writing data to a file, the DOS save the buffer onto the disk, then clears the buffer and resets the pointer to the first location of it. If reading data from a file, if the file keeps more data then the DOS will load the next sector into the buffer, otherwise an EOF (End-Of-File) error will be raided.

1.5 File entries management

LM80C DOS doesn't make use of file allocation tables, instead it makes use of a simpler mechanism where each directory entry is also the pointer to the file block, so the DOS must scan the entire directory to know which entries are free and which aren't. But, since the disk is very fast, scanning a directory with thousands of entries only requires few seconds. Every time a new file is created, the DOS scans the directory looking for the first usable entry, halting its search at the first match. When listing files, instead, the DOS scans the whole directory to seek for entries.

When a file has been deleted, the user can choose 2 different deleting methods: a quick erase, and a full erase. The first one just marks the file to be deleted by writing the special code $7F in the first char of its name, leaving its data on the disk unchanged. By using the DISK function "U" or by manually changing this value in the sector of the entry, the user can recover the file easily. The second method is more secure but it can not be reverted: not only the entry is completely wiped out but the sectors that were occupied by the file data are erased, too, deleting their bytes permanently.

Each block is assigned to one, and only one, file. Sectors not used in a block can not be assigned to other blocks and remain unused. No more than 65,536 blocks (and even files) can be stored in a disk. Very big disks won't be utilized in their whole capacity. This can appear as a big waste of space but since the Z80 is an old CPU with limited capabilities, this seems to be a good compromise between resources allocated to address the disk and computer memory utilized by DOS to manage them.

1.6 The Data Area

The area used to store the file data is called **Data Area** (DA) and it is divided into blocks of a fixed size: 128 sectors, corresponding to 64 KB (65′536 byte). This is also the maximum size of a file.

The DA follows the directory and occupies the rest of the disk space. The first sector of the DA can be calculated using the following formula:

```
1 + (number of entries / entries per sector)
```

Using our sample disk with 3′920 entries, the DA begins at the following sector:

```
1 + (3′920 / 16) = 246
```

This means that the directory (always starting at sector #1) will occupy 246 sectors, from #1 to #245. The DA will then begins at sector #246.

Every byte of a sector is used to store data. The mechanism to keep trace of where to stop loading data from disk is based on the file size stored in its entry. If a file needs more than 1 sector to store its data, a simple subtraction is done to know how many bytes are in the last sector. To know the amount of bytes of the last sector (indicated as BLS, Bytes of Last Sector) the following formula may be used:

```
BLS = (512 * file size in sectors) – (file size in bytes)
```

These values are recovered from the file entry.

Let's say that a file is 13′512 bytes in size, occupying 27 sectors. With the above formula, we calculate:

```
512 * 27 = 13824 -
           13512=
           -----
             312 => BLS
```

Given that the storing of data starts at address $000, the address of the last byte used to store the data is given by `BLS – 1`. Using the example above:

```
$BLS = 312 - 1 => 311 ($137)
```

This means that bytes from $000 to $137 will contain regular data, while bytes from $138 to the end of the sector will contain garbage values ignored by the DOS.

1.7 The DOS buffers

While doing its jobs, the LM80C DOS exchanges data from the disk to the computer and vice-versa. Since a single sector is 512 bytes wide, the DOS needs a place where to temporary park this stream of bytes because the CPU isn't able to deal with it. To accomplish this, 4 temporary memories called "*buffers*" are used to store data from/to the disk.

- The first buffer is the **I/O Buffer** (Input/Output Buffer). Since it has to store an entire sector, it's 512 bytes wide. The I/O buffer is used to create the 512 bytes that will be stored on the disk, or to park the bytes of a sector when data is read from the disk.

- The second buffer is placed just below the previous one and it's 32 bytes wide. This is the **DOS buffer**, and it's used primary to, but not limited to, store an entire entry of the directory during loading & saving operations.

- The third buffer is 36 bytes wide and it's used as a support buffer to store temporary data used by BIOS routines to read/write data from/to the disk. It's located in the BASIC workspace.

- The fourth and last buffer is 27 bytes wide and it's used by DOS to manage sequential files. This area is located just over the I/O buffer.

1.8 DOS memory occupation

After the boot, and if it's enabled, the DOS is copied (and will reside) in the higher part of the RAM. In order, we find: the DOS code, then the BIOS routines, then the I/O buffers, and finally the DOS jump table.

The beginning of DOS is set at $DOSSTART (currently, $EE1B). The DOS contains the routines to load, save, erase, rename, and list files from/to the disk and the BASIC bindings to execute LOAD, SAVE, ERASE, FILES, and DISK statements.

After the DOS, from location $BIOSSTART ($FCD0 in current firmware 1.19), there is the BIOS (Basic Input Output System), a group of routines used to access the disk (the Compact Flash card) so that the DOS can access it without the need to know the hardware specs of the system under its software layer.

After the BIOS, there are 3 or the 4 I/O buffers. The first one is the DOS buffer: it resides from $FDA0 up to $FDBF, and it's 32 bytes wide. The second one is the I/O buffer: it occupies the space between $FDC0 and $FFBF, or 512 bytes. After it, there is the sequential file buffer from $FFC4 to $FFDE (27 bytes wide)

At the very top of the RAM there is the DOS jump table. This table contains the jumps to the current BASIC routines for the DOS commands. When the DOS is not enabled, the table entries point to the REM routine so that calling the DOS commands has no effect.

```
+--------+   $FFFF          top of RAM
|        |   $FFFD-$FFFF    jump to FILES command
|        |   $FFFA-$FFFC    jump to SAVE command
|        |   $FFF7-$FFF9    jump to LOAD command
|        |   $FFF4-$FFF6    jump to ERASE command
|        |   $FFF1-$FFF3    jump to DISK command
|        |   $FFEE-$FFE0    jump to OPEN command
|        |   $FFEB-$FFED    jump to CLOSE command
|        |   $FFE8-$FFEA    jump to GET function
|        |   $FFE5-$FFE7    jump to PUT command
|        |   $FFE2-$FFE4    jump to EOF function
+--------+   $FFDF-$FFE1    jump to EXIST function
+--------+   $FFDE          top of seq. File buffer
|        |
+--------+   $FDC4          bottom seq. file buffer
|        |   $FFC0-$FFC3    filler
+--------+   $FFBF          top of I/O buffer
|        |
|        |   $FDC0          bottom of I/O buffer
+--------+   $FDBF          top of DOS buffer
|        |
+--------+   $FDA0          bottom of DOS buffer
|        |   $FD9F          top of BIOS
|        |
|        |   $FCD0          bottom of BIOS
+--------+   $FCCF          top of DOS
|        |
```

```
|         |
|         |
+--------+    $EE1B          bottom of DOS
|        |    $EE67          top of string space
|        |    $EE04          bottom of string space (assuming 100 bytes)
+--------+    $EE03          top of stack
|        |
```

2. USEFUL LINKS

Project home page:

https://www.leonardomiliani.com/en/lm80c/

Github repository for source codes and schematics:

https://github.com/leomil72/LM80C

Hackaday page:

https://hackaday.io/project/165246-lm80c-color-computer

LM80C

Color Computer

Enjoy home-brewing computers

Leonardo Miliani