MFM - Disks
issues, infos , problems

Background:
The ST506-Interface was designed in 1982 by the company Seagate for their 5 ¼-inch drive ST506 (5.4 MB) , ST412 (10.1 MB) and ST225(20.4 MB) and every well-known computer manufacturer was using this technology. The ST506-Interface is working based on the MFM(Modified Frequency Modulation) recording method:

But:

Each manufacturer did have its own implementation according to the slogan :
Be 100% incompatible with any other manufacturer

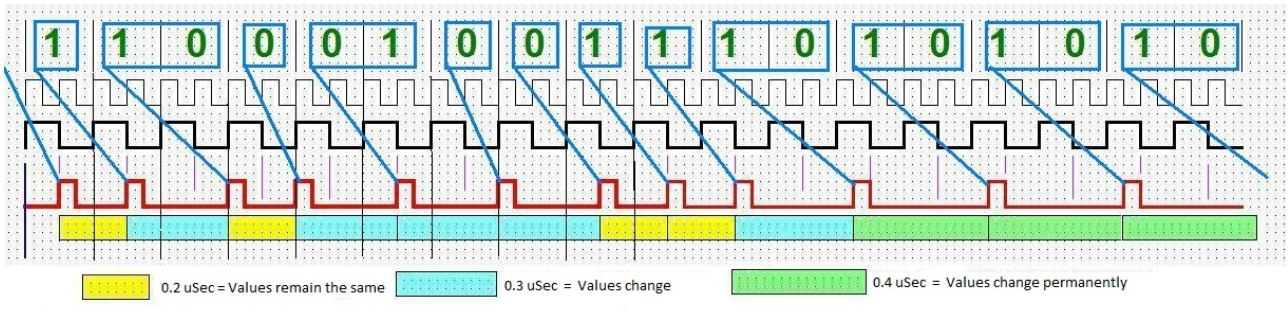
References:

https://github.com/pdp11gy/SoC-HPS-based-MFM-disk-emulator
Download and unzip the file MFM-disk_Emulator_SoC.zip

http://www.pdp11gy.com/

http://www.minuszerodegrees.net/manuals/Seagate/Seagate%20ST506%20-%20Service%20Manual%20-%20May82.pdf

MFM timing overview



The MFM transfer bandwidth is defined as 5 MHz = 0.2 uSec. The FPGA clock is running at 80 MHz, = 0,0125 uSec. which is 16 times higher. This was necessary to prevent a chitter, primarily with the MFM Encoder, also implemented in the same way at the RL RL01 / RL02 emulator project. The entire design runs synchronously in real time based on the 80MHz clock. Since the design runs in real time, MFM decoding can be done “on the fly”. It’s a real time design, based on FPGA CyclonV

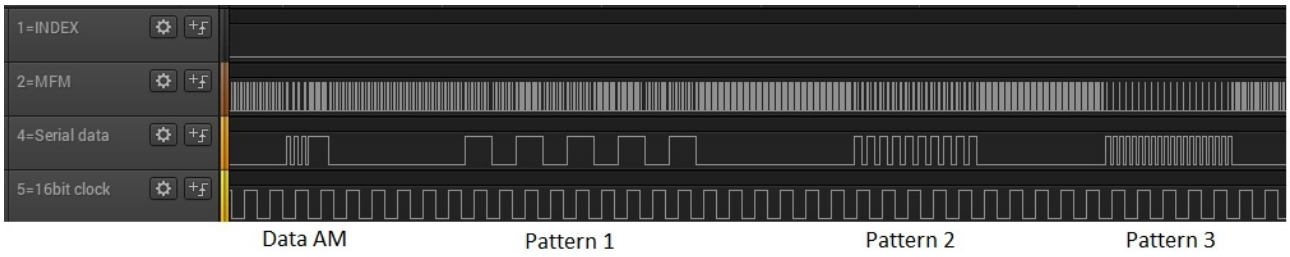
Requirements :
During development, I had chosen a method to write a well-defined pattern on the disk. This method was very helpful for the RL01 / RL02 emulator development, so I did use this method in the development of the MFM disk emulator as well.
Abstract, used Pattern:

```
1)   DEC 00 255 , HEX 00 FF , BIN  0000 0000 FFFF FFFF
     test change from short to long cycle
2)   DEC 51 ,     HEX 33 ,    BIN  0011 0011
     test long cycle to long cycle
3)   DEC 85 ,     HEX 55 ,    BIN  0101 0101
     test verylong to verylong cycle
```

I used a RT-11 basic (from 1985) program as follow and copied the output file to a MFM disk.

```
5 A$="" \ B$="" \ PRINT "GENERATE TEST-PATTERN"
6 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
11 FOR I=1 TO 5 \ A$=A$+CHR$(255)+CHR$(0) \ NEXT I                    Pattern 1
18 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
21 FOR I=1 TO 5 \ A$=A$+CHR$(51) \ NEXT I                             Pattern 2
28 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
31 FOR I=1 TO 5 \ A$=A$+CHR$(85) \ NEXT I                             Pattern 3
38 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
41 FOR I=1 TO 3 \ A$=A$+CHR$(73)+CHR$(146)+CHR$(36) \ NEXT I
48 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
51 FOR I=1 TO 3 \ A$=A$+CHR$(35)+CHR$(145)+CHR$(220) \ NEXT I
58 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
61 FOR I=1 TO 10 \ A$=A$+CHR$(128) \ NEXT I
68 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
71 FOR I=1 TO 3 \ A$=A$+CHR$(231)+CHR$(156)+CHR$(243) \ NEXT I
78 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
81 FOR I=1 TO 3 \ A$=A$+CHR$(99)+CHR$(140)+CHR$(241) \ NEXT I
91 FOR I=1 TO 10 \ A$=A$+CHR$(127) \ NEXT I
98 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
510 A$=A$+CHR$(10)+CHR$(13)
520 A$=A$+"  MFM-DISK EMULATOR, (C) REINHARD HEUBERGER  "
525 A$=A$+CHR$(10)+CHR$(13)
540 A$=A$+"      SOC/HPS VERSION  WWW.PDP11GY.COM      "
545 A$=A$+CHR$(10)+CHR$(13)
550 PRINT "A-STRING-LAENGE: ";LEN(A$)
610 FOR I=1 TO 19
620 A$=A$+CHR$(255)+CHR$(0)
630 NEXT I
635 A$=A$+CHR$(0)
636 PRINT "A$ STRING-LAENGE: ";LEN(A$)
640 FOR I=1 TO 125 \ B$=B$+CHR$(0) \ NEXT I
642 B$=B$+CHR$(255)+CHR$(255)+CHR$(0)+CHR$(0)+CHR$(255)+CHR$(255)
650 FOR I=132 TO 254 \ B$=B$+CHR$(0) \ NEXT I
660 B$=B$+CHR$(0)
691 PRINT "B$ STRING-LAENGE: ";LEN(B$)
699 goto 800
700 OPEN "DU0:PATT4.TXT" FOR OUTPUT AS FILE #1
720 FOR I=1 TO 5000
730 PRINT #1,A$;
731 PRINT #1,CHR$(0);
740 PRINT #1,B$;
741 PRINT #1,CHR$(0);
750 NEXT I
760 CLOSE #1
770 PRINT "DONE"
800 END
```

Of course you can also implement the program in C (see my source code), but at these time it did not exist. The following figure shows the timing from pattern 1 to 3 and Data AM



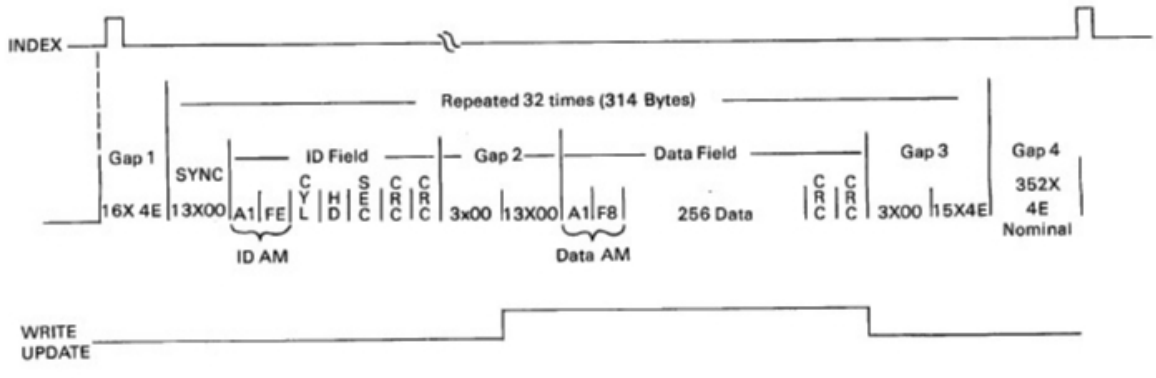
The folder software /READC/contains the program readc. This program reads a cylinder and a track with head 1 and saves the data to the SD card. Then you can view the file with a HEX editor. Here is an example where you can find the Pattern 1 to 3 again:

```
00009F30  12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12  ................
00009F40  12 12 12 12 12 12 12 12 12 12 12 12 12 12 41 21  ..............A!
00009F50  E4 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24  ä$$$$$$$$$$$$$$$$
00009F60  3F FF FF FF FF FF FF FF FF FF FF FF FF FF CA 80  ?ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÊ€
00009F70  21 F3 FF 25 2F 3F FF FF FF 00 00 00 00 00 00 00  !óÿ%/?ÿÿÿ.......
00009F80  00 00 00 00 00 00 A5 F8 00 00 00 00 00 FF 00 FF  ......¥ø.....ÿ.ÿ
00009F90  00 FF 00 FF 00 FF 00 00 00 00 00 00 33 33 33 33  .ÿ.ÿ.ÿ......3333
00009FA0  33 00 00 00 00 00 55 55 55 55 55 00 00 00 00 00  3.....UUUUU.....
00009FB0  49 92 24 49 92 24 49 92 24 00 00 00 00 00 23 91  I'$I'$I'$.....#'
00009FC0  DC 23 91 DC 23 91 DC 00 00 00 00 00 80 80 80 80  Ü#'Ü#'Ü.....€€€€
00009FD0  80 80 80 80 80 80 00 00 00 00 00 E7 9C F3 E7 9C  €€€€€€.....çœóçœ
00009FE0  F3 E7 9C F3 00 00 00 00 00 63 8C F1 63 8C F1 63  óçœó.....cŒñcŒñc
00009FF0  8C F1 7F 7F 7F 7F 7F 7F 7F 7F 7F 7F 00 00 00 00  Œñ..............
0000A000  00 0A 0D 20 20 4D 46 4D 2D 44 49 53 4B 20 45 4D  ...  MFM-DISK EM
0000A010  55 4C 41 54 4F 52 2C 20 28 43 29 20 52 45 49 4E  ULATOR, (C) REIN
0000A020  48 41 52 44 20 48 45 55 42 45 52 47 45 52 20 20  HARD HEUBERGER
0000A030  0A 0D 20 20 20 20 20 20 53 4F 43 2F 48 50 53 20  ..       SOC/HPS
0000A040  56 45 52 53 49 4F 4E 20 20 57 57 57 2E 50 44 50  VERSION  WWW.PDP
0000A050  31 31 47 59 2E 43 4F 4D 20 20 20 20 20 20 0A 0D  11GY.COM      ..
0000A060  FF 00 FF 00 FF 00 FF 00 FF 00 FF 00 FF 00 FF 00  ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.
0000A070  FF 00 FF 00 FF 00 FF 00 FF 00 FF 00 FF 00 FF 00  ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.ÿ.
0000A080  FF 00 FF 00 FF 00 00 00 00 00 00 00 00 00 00 00  ÿ.ÿ.ÿ...........
0000A090  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0A0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0B0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0C0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0D0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A0F0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A100  00 00 00 00 00 FF FF 00 00 FF FF 00 00 00 00 00  .....ÿÿ..ÿÿ.....
0000A110  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A120  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A130  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A140  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A150  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A160  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000A170  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

Very important is the field **data AM** (A5 F8 @ 9F86). That's the section now where open points/questions begin.

With reference to the SEAGATE ST-506 Manual, the disk format is Pre-configured as in the following picture:

FIGURE 20
TRACK FORMAT AS SHIPPED



NOTES:

1. Nominal Track Capacity = 10416 Bytes
2. Total Data Bytes/Track = 256 x 32 = 8,192
3. Sector interleave factor is 4. Sequential ID Fields are sector numbered 0, 8, 16, 24, 1, 9, 17, 25, 2, 10, 18, 26,...etc.
4. Data Fields contain the bit pattern 0000 as shipped
5. CRC Fire Code $=x^{16}+x^{12}+x^{5}+1$
6. Bit 7 of Head Byte ID Field equals 1 in a defective sector (Cylinder Ø is error free)
7. Bit 5 of Head Byte reserved for numbering cylinders greater than 256
8. Bit 6 of Head Byte reserved for numbering cylinders greater than 512

Capacity

```
Nominal Track Capacity:                =    10416 ( Byte )

Total Data Bytes/Track = 256   x 32 =     8192
 SYNC = 13x00           =  13   x 32 =      416
 ID AM = 2 Byte         =   2   x 32 =       64
 CYL/HD/SEC = 3 Byte    =   3   x 32 =       96
 Header-CRC = 2 Byte    =   2   x 32 =       64
 Gap2 3 + 13 = 16Byte   =  16   x 32 =      512
 Data AM = 2 Byte       =   2   x 32 =       64
 Data-CRC = 2 Byte      =   2   x 32 =       64
 Gap3 1of2 = 3x00       =   3   x 32 =       96
 Gap3 2of2 = 15x4E      =  15   x 32 =      480
                         ----------------------+-----------------
                SECTOR: 314      TRACK: 10048 |  CYLINDER: 40192
 Einmalig dazu:  Gap1  16x4E      =         16 |              64
                 Gap4 352x4E      =        352 |            1408
                                 ---------------+-----------------
                    ( Byte )           10416 |           41664
                     ( Bit )           83328 |          333312
                    ( Word )            5208 |           20832
                    ========================+=================
```

Understanding and analysis

The interface and the corresponding signals were described in detail by the company Seagate and were widely respected. It looks quite different at data and timing format. Everything here is incompatible. Each manufacturer has guaranteed implemented his own track and data format which was genarated with their own low-level format program. The following differences exist:

>> CRC algorithm is different, such as different preset value.
>> Track format: ID AM differently.
>> Track format: DATA AM differently.
>> SYNC character differently.

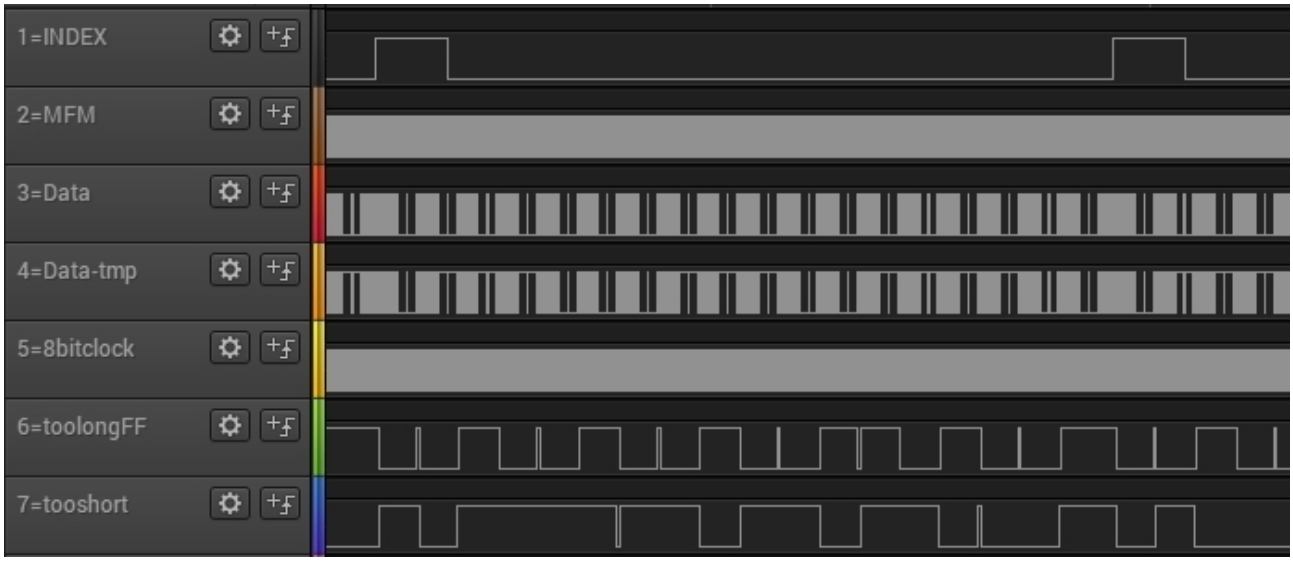
Even the same manufacturer, for example, DEC. There were different formats used . A disk , formatted with the RQDX-1 controller Disk could not be used in a RQDX-3 environment.

Problems

At the moment I am only able to work reasonably with a PDP-11/23 / RQDX-1 and RD51. The RQDX-3 is broken, my Schneider PC is broken and my ST225 disk is also broken. (I hope to get my SANYO PC up and running soon).

In a PDP-11/23 /RQDX-1 environment, I found strange things concernig the timing outside the data field. I found too short and too long MFM gaps.

Example, logic analyser:

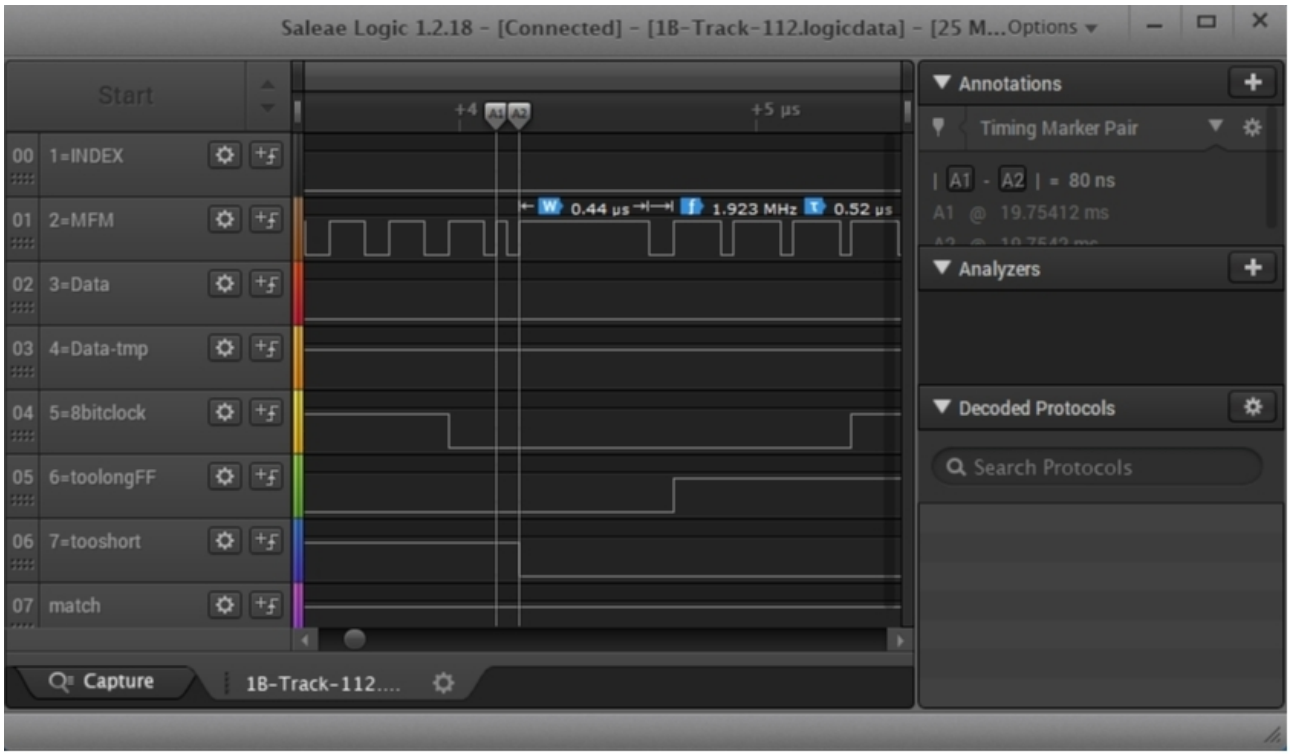


The MFM decoder (MFM-disk_Emulator_SoC/my_Verilogs/MFM_gap_DECODER_V1_0.v) is able to detect too short and too long MFM gaps. If a wrong gap is detected, then a flipflop is switching. Usually the following times are correct :

short = 0,2 uSec
long = 0.3 uSec
verylong = 0.4 uSec

There may be small deviations but in this case too short MFM gaps with 80nSec and too long MFM gaps with 0.52 or 0.72 uSec could be found.
This symptom confuses the timing with the result that the data FlipFlop sometimes tilts uncontrolled. Thus the data are wrong and the boundaries of the byte counter are also no longer correct .

Sometimes a too long cycle comes direct after a too short cycle like in following picture:



Note : The symptom is not visible in the data field.

The indicator for data field is the end of the **data AM** (A5 F8) . So you can find the beginning of the data in the sector. The MFM_gap_DECODER_V1_0.v is able tot detect the data AM. But unfortunately each manufacturer has always used a different format. So you have to analyze this individually for each manufacturer. **I can not do that alone** !

Info: I could not see the too long/too short symptom on a disk in a Schneider PC

Any hint and help is welcome

For comments and questions, please contact me.
Reinhard Heuberger
INFO@pdp11gy.com