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

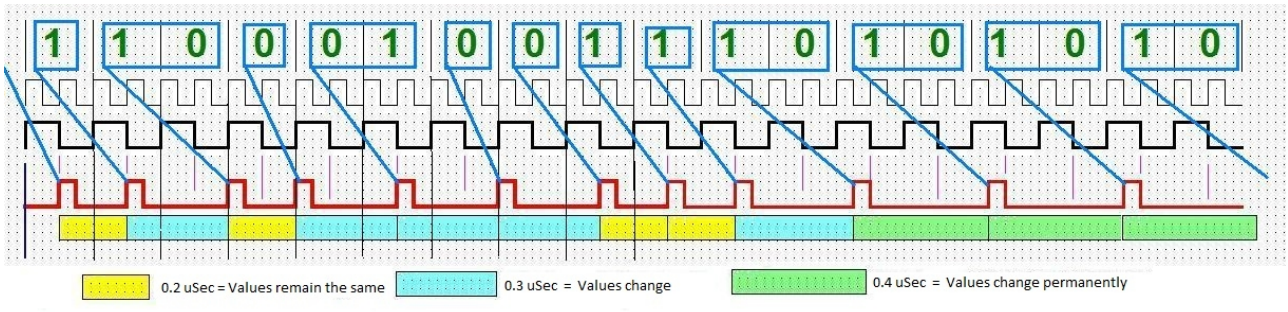
References:

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

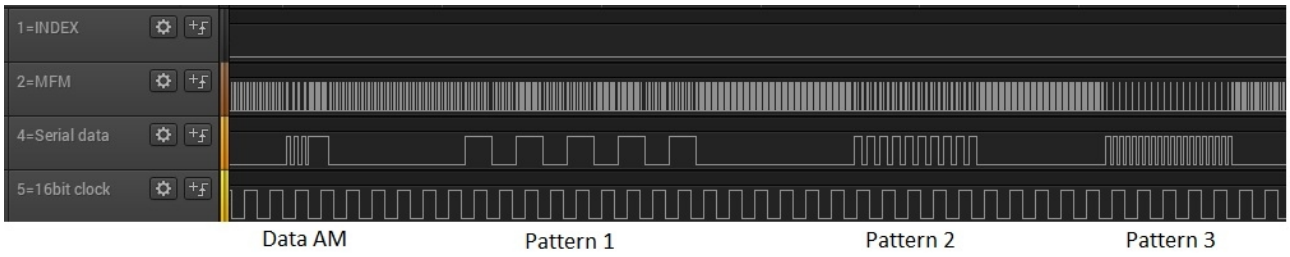
Requirements :
During development, I had chosen a method to write a well-defined pattern on the disk. This method was very helpful for the RL01 / RL02 emulator development, so I did use this method in the development of the MFM disk emulator as well.
Abstract, used Pattern:

```
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$(36) \ NEXT I          // 0x43, 0x92, 0xDC
48 FOR I=1 TO 5 \ A$=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$(128) \ NEXT I                           // 1000 0000 = 0x80
68 FOR I=1 TO 5 \ A$=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                           // 0111 1111 = 0x7F
98 FOR I=1 TO 5 \ A$=A$+CHR$(0) \ NEXT I
510 A$=A$+CHR$(10)+CHR$(13)
520 A$=A$+"STELL DIR VOR ES IST KRIEG UND KEINER GEHT HIN"
525 A$=A$+CHR$(10)+CHR$(13)
540 A$=A$+"  IMAGINE IT IS WAR AND NOBODY GOAS THERE  "
545 A$=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-LENGTH: ";LEN(A$)                                // Should be 255
640 FOR I=1 TO 125 \ B$=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-LENGTH: ";LEN(B$)                                // Should be 255
699 goto 800
700 OPEN "DU0:PATT4.TXT" FOR OUTPUT AS FILE #1
720 FOR I=1 TO 5000
730 PRINT #1,A$;
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



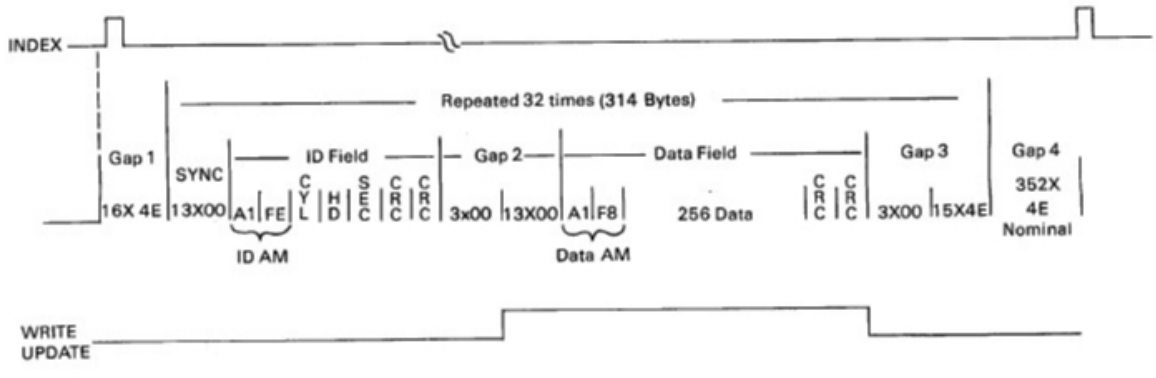
The folder software /READC/contains the program readc. This program reads a cylinder and a track with head 1 and saves the data to the SD card. Then you can view the file with a HEX editor. Here is an example where you can find the Pattern 1 to 3 again:

```
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.

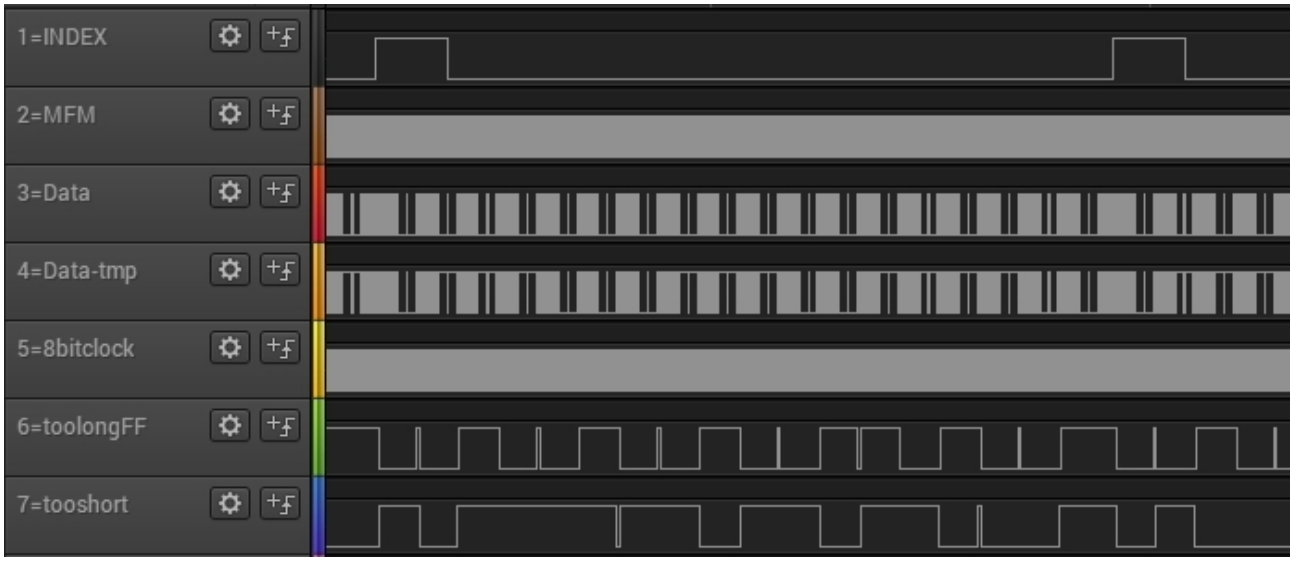
Even the same manufacturer, for example, DEC. There were different formats used . A disk , formatted with the RQDX-1 controller Disk could not be used in a RQDX-3 environment.

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:

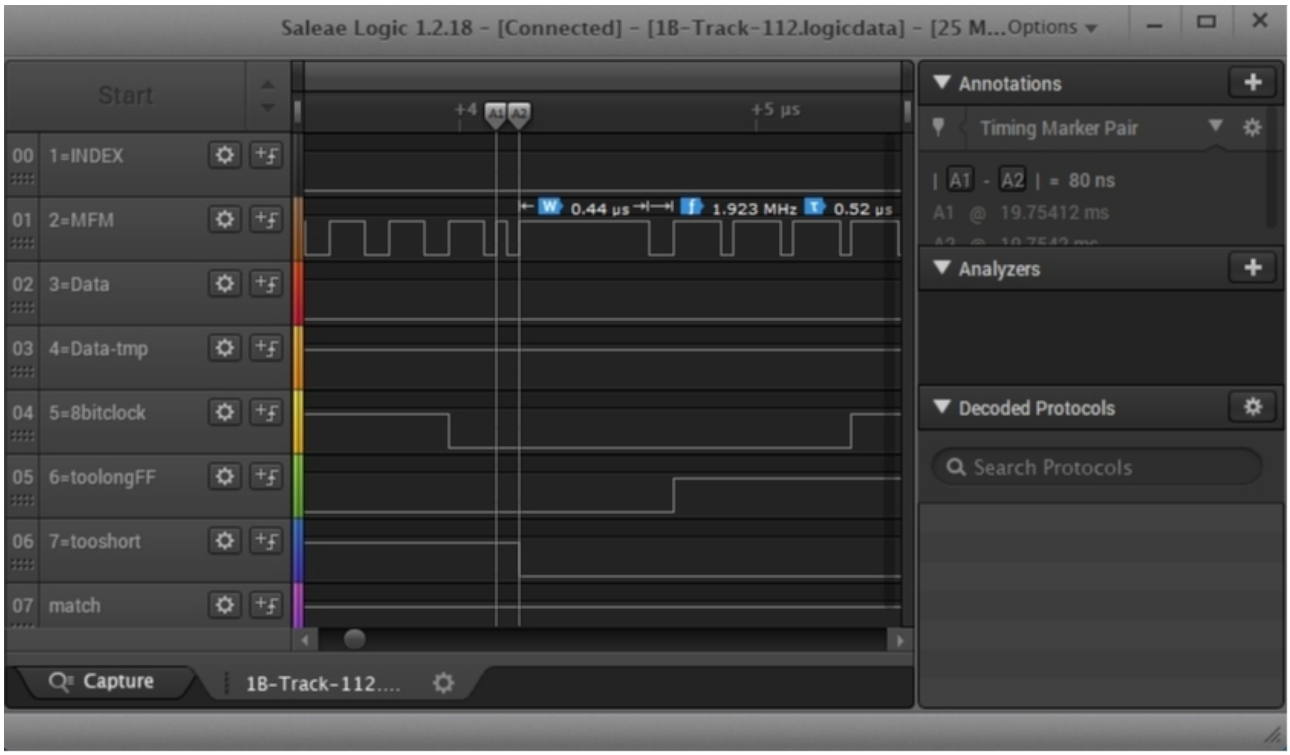


The MFM decoder (MFM-disk_Emulator_SoC/my_Verilogs/MFM_gap_DECODER_V1_0.v) is able to detect too short and too long MFM gaps. If a wrong gap is detected, then a flipflop is switching. Usually the following times are correct :

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.

I don't know exactly how to handle this cylcles. At the moment, I switch the data to low on a too long cycle detection. Important to know : I could not see this peculiar symptom in the PC environment (My problem: At the moment, I don't have any PC related reference hardware).

The way for a solution:
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**. But unfortunately each manufacturer has always used a different data AM pattern.

Solution:

The MFM_gap_DECODER_V1_0.v will trigger on detection of a Data AM pattern. These decoder makes real-time MFM-decoding with serial and 8 bit parallel output and will allign it to byte boundary after detecting the 16 bit Data AM pattern . With these possibilities a .img file can be created in real-time to be also compatible with the SIMH project.

Handicap:

For each manufacturer, you have to analyze it individually to get the proper Data AM pattern. I can not do that alone! Any hint and help is welcome

Note: It is intended to create for each disk-type its own configuration file. This can be modified with any standard editor.

To verify the detection of a Data AM pattern, use the program soc_mfm_beta/MFM/readc.
Exmple:

```
root@socfpga:~/MFM# ./readc


            ***** MFM-DISK   READER  @ Soc/HPS *****
         READ one Cylinder+Track and save it to SD card
             DE10-Nano ST-506/412/225   Beta Version
        ***********************************************
              (c) Reinhard Heuberger WWW.PDP11GY.COM

              >>>>>> DEBUG-MODE = ON <<<<<<
              >>>> Device Type = ST506 <<<<
      ****************************************
      *************** +Test-Mode *************
      ****************************************

      Anzahl der Cylinder: 153
      Drive_select #0  DRV_SLCTD = LOW
      Drive_select #1  DRV_SLCTD = LOW
      Drive_select #2  DRV_SLCTD = HIGH
      READY =      HIGH
      SEEK_cmplt = HIGH
      TRACK_0 =    LOW
      DRV_SLCTD =  HIGH
      Drive = ready
      Drive is NOT @ home
    Drive positioned to home

       Cylinder - nummer eingeben:  112

       Trigger DataAM , (4Hex, like A5F8)  :A5F8

   Cylinder: 112 ,Trigger DataAM: lsb : 0xA5  msb: 0xF8

      ************ Step to Cylinder 112  done ***********

         Select Head 1 … 2 … 3 … 4

 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 529  Nr.: 1  Gap: 530
 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 1312  Nr.: 2  Gap: 783
 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 1882  Nr.: 3  Gap: 570
 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 2453  Nr.: 4  Gap: 571
 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 3024  Nr.: 5  Gap: 571
.
.
.
 found: DataAM_msb 0xA5  DataAM_lsb 0xF8  @ 41303  Nr.: 66  Gap: 571

      Save track@head1 data-image to SD-Card into file:  ST506-Track-image_112.img

      Save 1 cylinder data to SD-Card into file:  ST506-cylinder_112.mfm

      *********** Select Head 1 and loop **********

      Save 1 track@head1 data to SD-Card into file:  ST506-Track_head1_112.mfm


  Press RESET/Button-1 for exit, Reconfig/Button-2 for restart
^C
```

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

Any hint and help is welcome

Would be nice if someone can get Data AM pattern and disk data from another vendor.
Maybe you can also find the data in the source listing of the low level format program or use the method with the test-pattern and a HEX edit as explained on page 2 and 3 .
If there is no other way, unfortunately the data has to be recorded with a logic analyzer.

Logic analyser connections:
8 test pins are configured from the Arduino Uno R3 Expansion Header . See DE10-Nano user manual, chapter 3.6.3.

Arduino_IO2 PIN_AG10	Arduino IO2 = **Test_1**
Arduino_IO3 PIN_AG9	Arduino IO3 = **Test_2**
Arduino_IO4 PIN_U14	Arduino IO4 = **Test_3**
Arduino_IO5 PIN_U13	Arduino IO5 = **Test_4**
Arduino_IO6 PIN_AG8	Arduino IO6 = **Test_5**
Arduino_IO7 PIN_AH8	Arduino IO7 = **Test_6**
Arduino_IO8 PIN_AF17	Arduino IO8 = **Test_7**
Arduino_IO9 PIN_AE15	Arduino IO9 = **Test_8**

For comments and questions, please contact me.
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