Restoration Report

IBM 3741 Data Station

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You might look at the current project.

Padua, June 2000

Introduction

Out of a collection of 3000 historic machines at the Computer Museum of Padua's old slaughterhouse the authors chose an IBM 3741 Data Station to work with. The choice was made because of the known history of the machine, its relative simplicity and potential usefulness. We knew the machine had been operative when in came into the collection and we had the full original service documentation. With respect to related items like the IBM System 3 its complexity seemed manageable. If we had gotten it to work, it might have served to recover information from 8 inch floppy disks.

While going on we were able to learn much about IBM's philosophy. We gained historic insight in construction tecniques and service staff training. A most striking result was that the service manuals contain very little information as to how the circuits work. In spite of their impressive dimension (over 800 A3 pages) they are limited to replacement rules for entire subassemblies.

The floppy disk drives (model 33FD) are of historic importance: first introduced with the IBM 3740 family, they were the industry standard of which many elements remain in today's omnipresent 3 1/2 inch floppy disk technology. We used a nice experimental setup that may be used in any computer exhibition to explain principles of magnetic storage.

Machine description

The Data Station's purpose was the manipulation of disk contents. Characters entered on the keyboard were written directly to the disk. Function keys allowed to select track and sector manually. The position and current content were displayed on the screen. The Data Station was not a computer. It was not programmable, had no DOS (Disk Operating System) and no freely adressable memory. The IBM 3741 standard version had one 8" floppy disk drive, a CRT (Cathodic Ray Tube = Screen) able to display 6 lines of 40 characters and a keyboard. It was highly modular: one could add a second disk drive, a printer, a serial modem, and a memory extension from 2 kb to 8 kb. According to the magazine *COMPUTERWOCHE*, no. 36, 1975 the monthly rent for a fully equipped system was DM 1500,-

> ***IBM-Baby 3741***
> *MÜNCHEN - Die Modelle 3 und 4 des IBM-Systems 3741 werden zunehmend als Stand-alone-Computer eingesetzt. Ursprünglich als Datenerfassungsgerät mit Diskette angeboten, reden neuere IBM-Prospekte von der "Datenverarbeitungsstation" 3741. Mit 8 K Bytes und Anschluß eines Matrixdruckers kostet das IBM-Kleinsystem rund 1500 Mark Monatsmiete. Das System /32 beginnt erst bei 2230 Mark monatlich. os*

State of our machine

Our specimen was delivered on 18 August 1977 and features an Italian keyboard layout. The machine at Padua has two disk drives and a serial modem built in. 2 kb of RAM are installed.

Faults

The problem is easy to explain: when we switched it on, the drive motors hummed and there was a burnt smell but nothing else happened.

Strategy and Error Maps

Our first strategy was to follow the original maintenance manual, much as the IBM service staff might have done twenty years ago. The documentation is devided two parts: error maps that allow a tecnician with little understanding to replace the faulty part and drawings to locate them. In most cases, electrical testing is limited to supply voltage checks.

As an example, look at Error Map 4-6. You normally get here when the buzzer either remains silent or is always on (as in our case when the reset process later gave out). Note the tolerances!

MAP 4-6 –

– This MAP helps you locate problems in the audio feedback device.

Can you make the machine fail?

Y N

- When the failure is intermittent, perform the following steps, one on each call, until the problem is fixed.
- Record the date of each step.

When operating the 3741, does the display suddenly go blank but comes on again in about 10 seconds and the keyboard locks up? –

– Frequent intermittent keyboard lockups with or without a flashing screen and with or without error codes can be caused by arcing in the CRT. You cannot reset these lockups by pressing RESET. On machines with the keyboard PC board at EC 310084 or EC 309728, reset these lockups by pressing REP. On machines with the keyboard PC board at EC 309786, reset these lockups by powering down and then up.

A CRT high voltage converter with excessive high voltage output or a defective CRT can cause CRT arcing. A CRT causing these intermittent problems more than once a week should be replaced.

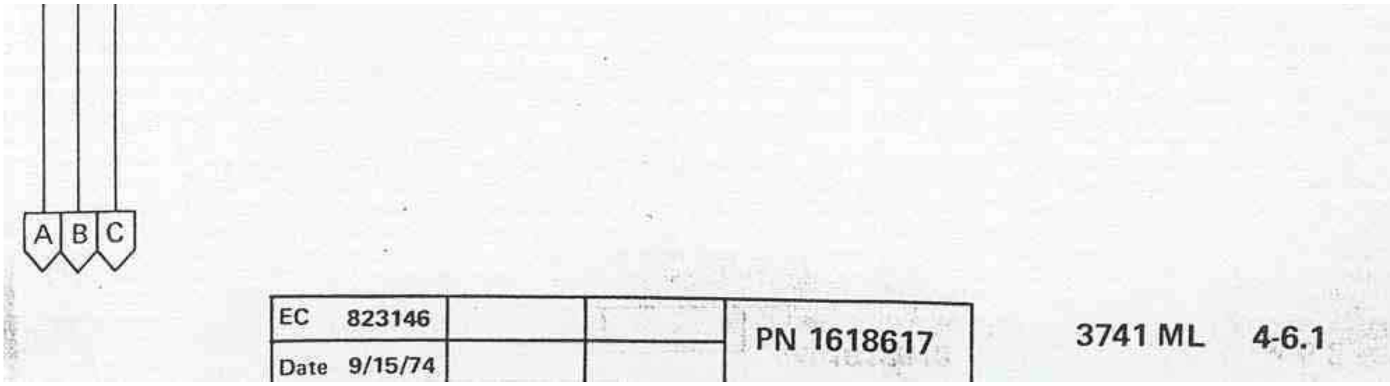
Note: When the 3741 is first installed, the CRT can arc once or twice. This is not unusual after shipping and handling.

Y N

- Vibrate the machine to cause the failure.
- Check the room temperature and the humidity and compare them to the installation procedure, page 16-1.
- Measure the voltages at the keyboard with respect to frame ground (407L):

Vdc	Pin	Limits
+5.0	B09	4.7 to 5.5
+8.5	D03	8.0 to 9.4
Ground	D08	0
-5.0	D06	4.6 to 5.4

- Power down.
- Clean the key module flyplates (407D) and pad area (407K) of the keyboard PC board (407G) with a lint-free cloth (PN 2108930). –
  – Dampen the lint-free cloth with water or alcohol (PN 2200200).
- Reinstall the all keys unit (407A) after all the flyplates (407D) are dry.
- Verify the fix.
  DATE: [| |]
- Power down.
- Reseat both ends of the keyboard signal cable (407H, 504).
- Verify the fix.
  DATE: [| |]
- Power down.
- Replace the audio feedback device (407J).
- Verify the fix.
  DATE: [| |]
- Power down.
- Replace the keyboard PC board (407G).
- Verify the fix.
  DATE: [| |]



IBM customers must not have been very demanding: in Map 5-1.2 it reads

> *Do extra characters still appear when the diskette is loaded?*
> *If this symptom is a customer complaint, replace the failing PC board. This symptom does not affect machine functions.*

Service-friendly

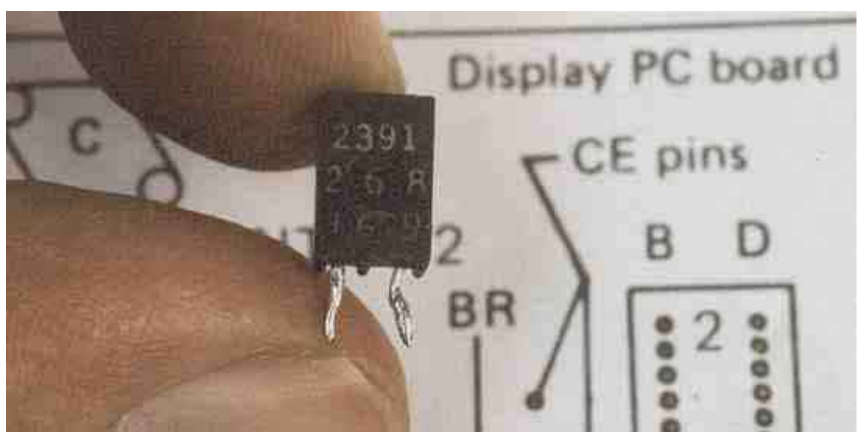
Most remarkable is the service-friendlyness. All parts of the machine are easily accessible and usually one or two screws allow to take out subassemblies. We were impressed by the possibility to hang the disk drives into special brackets on the rear side for service access. In the picture, you also see the electric oven whose resistance wires we used to test the power supply at maximal load.

Blown Electrolytic Capacitors

We found the 8.5V and the 12V fuses blown. Before powering up again, we detached everything from the main board. One by one we reinstalled the components, finding that hooking up the CRT blew the fuses again.

CRT repair

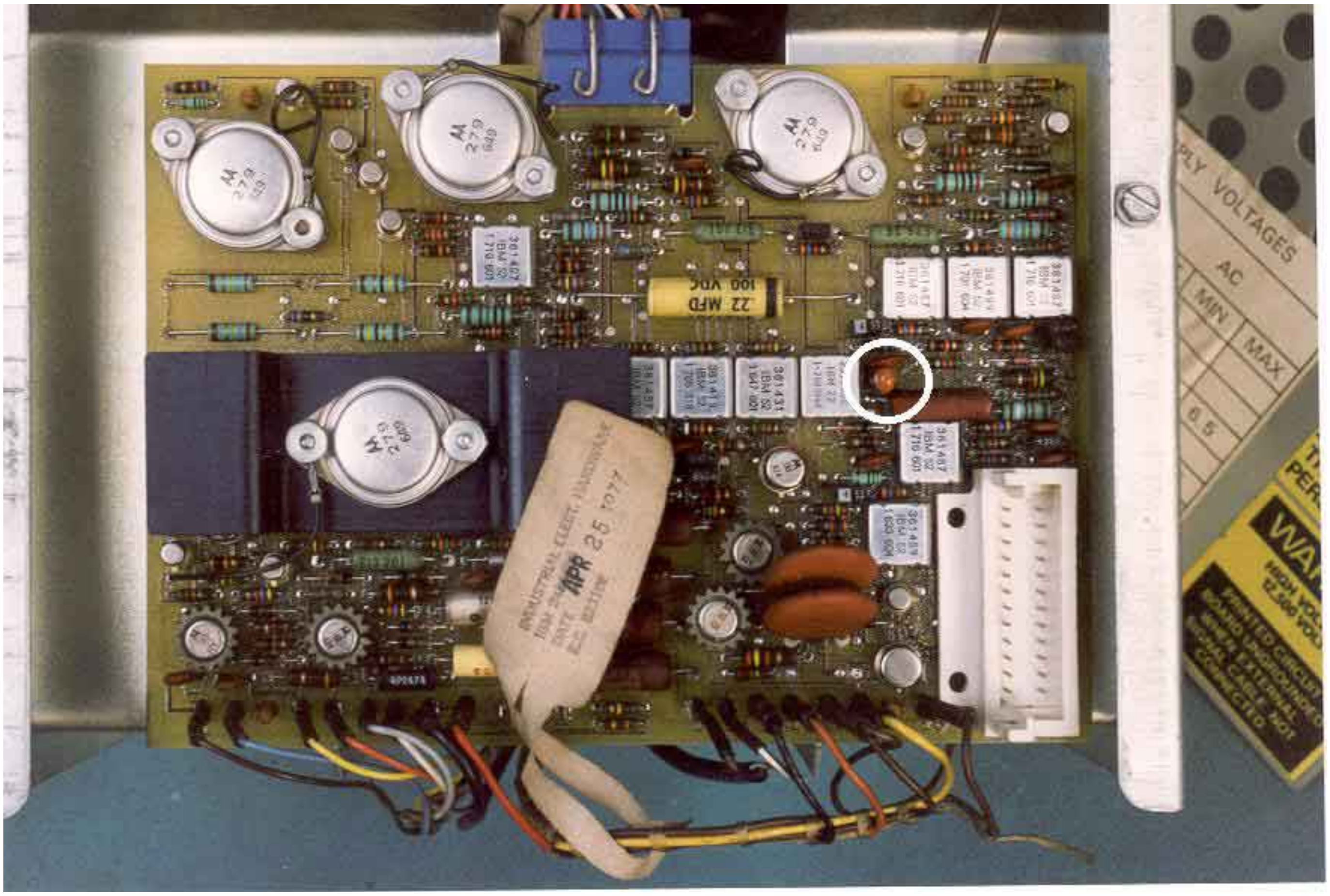
It must have been because Francesco and Martin both wanted to measure everything themselves that we found nothing. No shortcut, that is. That was on 17 June, 2000. We found an identical CRT in an IBM 5320 (System 32) and tried it. Same result, fuse blown. After excessive testing of the power supply which we drove to full load using heating wires we found that OK. So finally Martin measured again, this time finding a shortcut from the 12V line in the CRT unit to ground, tracing it down to an electrolytic capacitor.



Electrolytic capacitors age. Especially the ones that IBM used (non standard, of course) don't stand 12 Volts any more after 23 years. So when we turned on the machine, we short-circuited both CRTs. The reason that we blew only one capacitor and that we found it is that it was used as a power line bypass, with the full potential across it. Capacitors from timing circuits often are exposed to less voltage. Of course nobody had ever seen a capacitor like that (or have you?), and we could neither measure the capacity any more nor guess it from the stamped code (2391 268 1629). I heard that even the IBM Pensioneers Club does not have access to IBM's internal conversion charts.

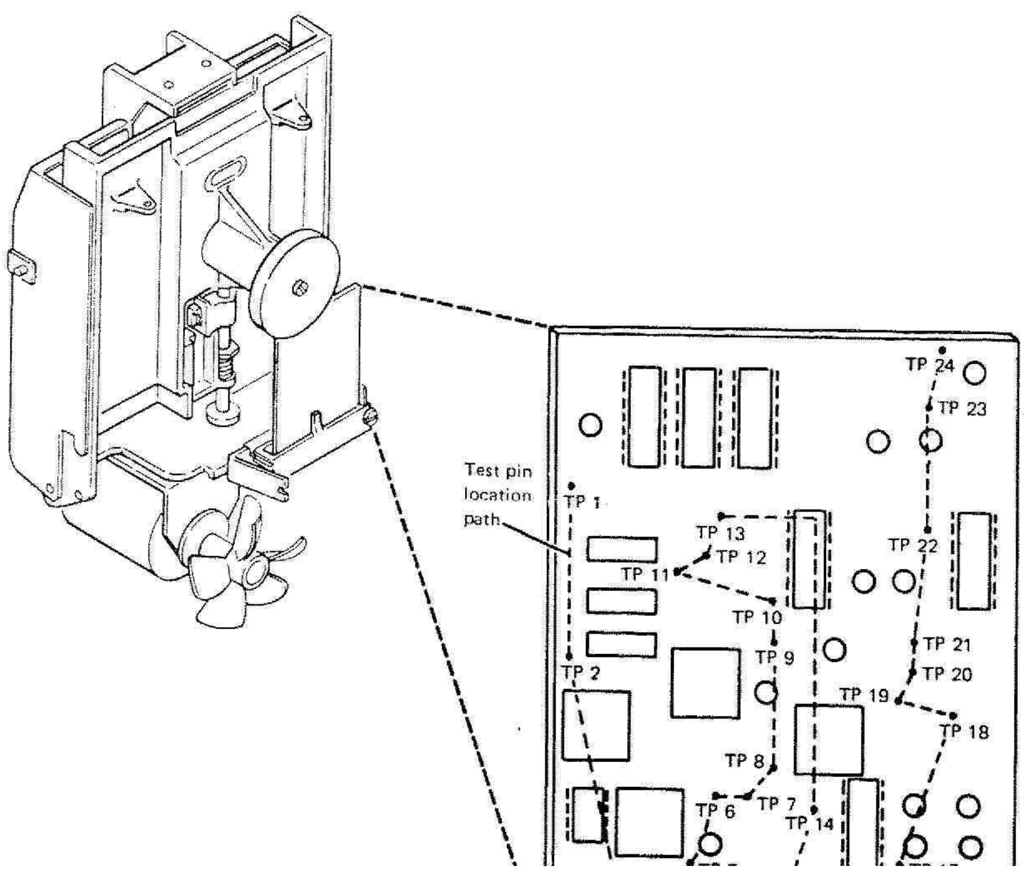
> **Addendum 17. Dec. 2000** I learned from Henk Stegeman, who owns an IBM 3741 himself and is lucky to have pieces of the 'internal use only' documentation, that IBM P/N 2391268 is a tantaal, 6.8 µF, 20Volt.

Normally, the CRT should work without bypass capacitors. To be on the safe side we put a 10µF 16V tantalum capacitor (white circle). On 20 June 2000 at 18:15, we turned it all on and... 25 seconds later we saw the status line appear on the screen. It worked!

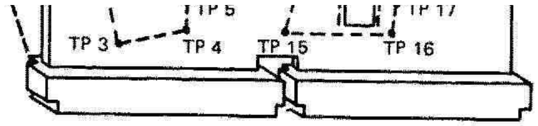


Disk drive repair

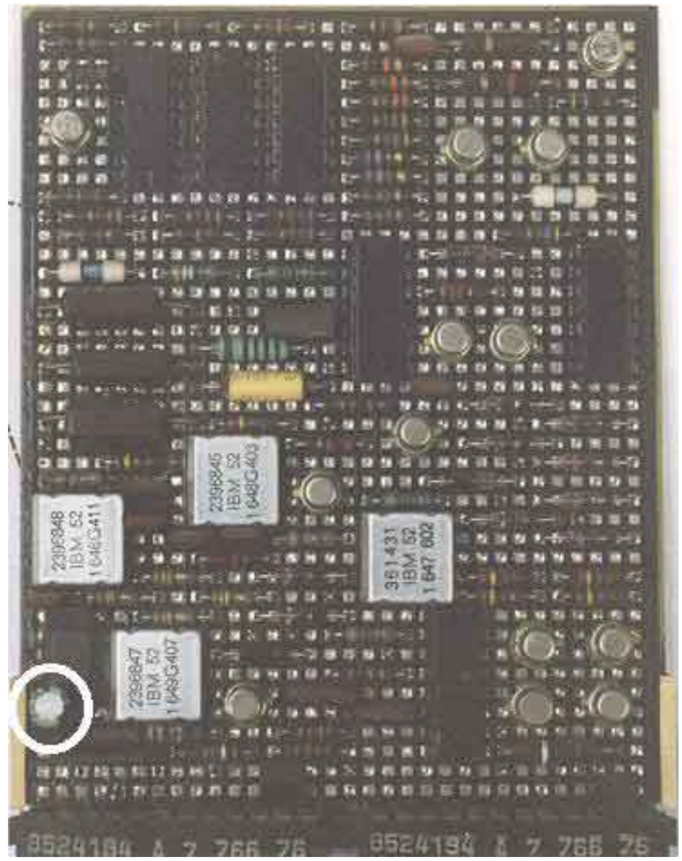
When we inserted a diskette, we heard the head load magnet click and saw an error code appear. Note that one-sided drives have a magnet-actuated pressure pad opposite the head. Obviously something was wrong. Same problem? This time, the manual held useful information: some test points (TP) on the File Control Card (FC card). That's a big name for a little electronics!



FC Card Test Point	Test Pin Name
TP 1	+24 volts
TP 2	+ Index
TP 3	+ File data
TP 4	+ Access 2
TP 5	-5 volts
TP 6	+ Access 3
TP 7	+ Access 1
TP 8	Phototransistor
TP 9	+ Write data
TP 10	+ Head engage
TP 11	+ Low current
TP 12	+ Write gate
None	+ Erase gate
TP 13	Preamp TP 2
TP 14	Preamp TP 1
TP 15	+ Access 0
TP 16	LED current
TP 17	Ground
TP 18	- MC-0
TP 19	- MC-3
TP 20	- MC-2
TP 21	- MC-1
TP 22	- Head load
TP 23	+5 volts



TP 24	Erase current
None	Head A
None	Head B



We found that 24V at TP 1 were missing, even though they were present at the main board. Moreover, the corresponding capacitor (!) was short-circuited. So that's where the burnt smell came from a week ago! Instead of blowing the 8A fuse in the 24V line, some circuit traces on the printed boards had burnt. They are much thinner than the fuse and extremely difficult to find and repair. A clear design flaw by IBM.

Luckily, we could borrow a 33FD drive FC card from an IBM 2502 Punch Card Reader, that's why we keep junk. We soldered out the critical capacitor **before** power-on this time. It had some 700 nF (code 2414 883 L646), so we chose new 1 µF electrolytic capacitors for replacement (sponsored by Grundig). I don't know how the capacity may have changed with age.

After re-installation the supply voltages remained constant, but we still could not read from disk.

General Note

Obviously, a constant power supply voltage with no oscillations or spikes is important for any circuit's function. At high frequencies the power supply's feedback regulator may not cope, so it helps to reduce line impedance. To achieve this, power supply leads are bypassed to ground throughout a circuit, using a combination of ceramic (0.01-0.1 µF) and electrolytic (1-10 µF) capacitors.

In computer restoration we deal with digital circuits where many logic lines may switch simultaneously. A digital output, for example, that drives three address decoders, sees an input capacitance of up to 50pF, depending on the chips and their connections. If the transition happens in 0.6ns, the current will be 40mA. With a wiring inductance of 5nH/cm we easily arrive at a spike of half a Volt on the power or ground line when the chip's lead is long. (see Horowitz, Hill, *The Art of Electronics*, 2nd Ed., ch. 9.12) The faster the edge transitions are and the more lines are switched, the more important are functioning bypass capacitors.

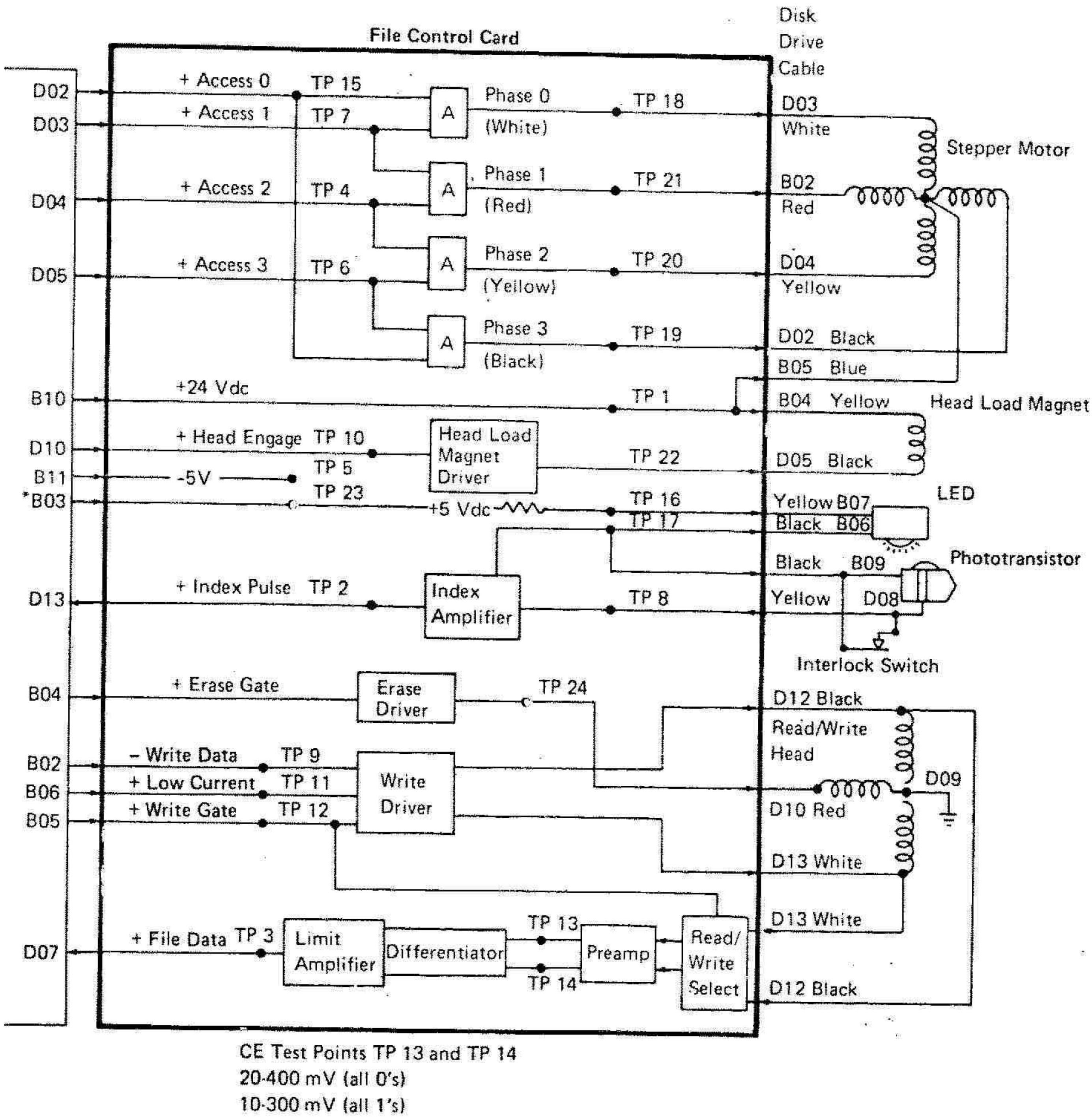
8" Floppy Disk Drive 33FD

None of our drives could read anything. We had three file control cards that were supposed to work, so we devised an experimental setup to judge which one delivered the best signals. In the end, we could observe clearly the data format on the oscilloscope screen. It was a very impressive demonstration of what remains largely miraculous even to most experts. We hope to give a good guideline here for the creation of similar displays.

Tecnical Description

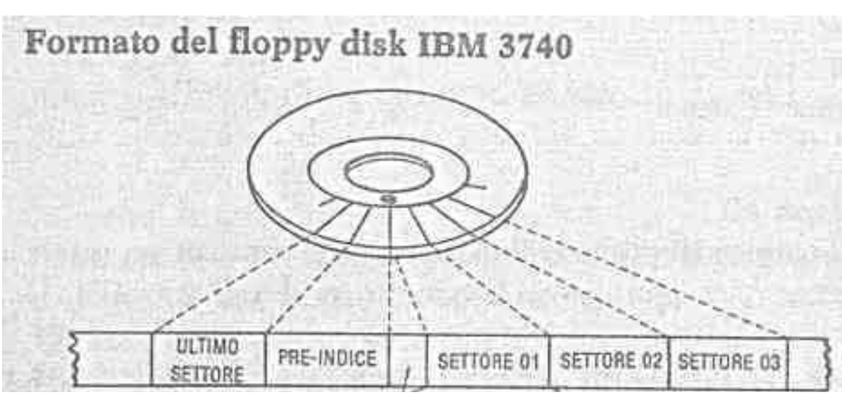
The 33FD drive is very simple. The fan and disk motor turns all the time. Disk speed is 360 rpm +/- 1.5 %. If a floppy diskette is entered, a magnet-driven pad presses the disk against the read/write head.

The disk is divided into 77 tracks, numbered from 00 at the outside to 76 at the center. They are addressed by movement of the head, effected by a unipolar stepper motor. 90° turn of the screw correspond to 1 track. It is notable that at least two defective tracks can be marked and will be left out automatically, so there are always 75 working tracks. The angular beginning of the tracks is marked by an index hole in the disk which is optically recognized. This is all the FC card does, and with the diagram from the manual, the individual functions can be traced to the test points.



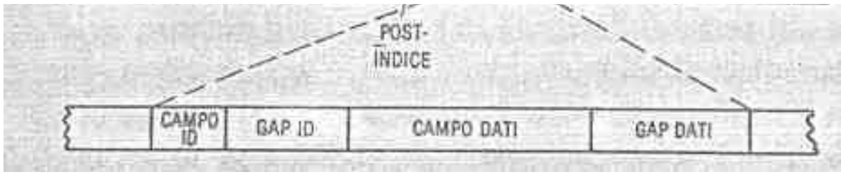
Data Format

Each track is divided into 26 sectors, containing 128 bytes of data each (in our case). The first sector after the index hole is no. 01, the following ones are not necessarily numbered sequentially. Each sector consists of an ID field, followed by a gap, followed by a data field and another gap. Every field is preceeded by six zeroed bytes that are part of the gap.



Note the relation between sector sequence and index hole as shown in the graph. We were able to observe directly ID and data fields and gaps. The gap lengths are:

gap	length (byte)
post-index	22
ID	17
data	33
pre-index	ca. 230, depends on physical track length



The following format details cannot be observed directly but are included for completeness:

Bit Representation

Mainly there were two recording formats: single density or FM (frequency modulation) as used in the IBM 3740 standard, and double density or MFM (modulated frequency modulation), introduced by the IBM System 34 standard.

In our case, every bit cell is 4 µs long and has a clock pulse at the beginning. To represent logical 1, another pulse is set at the middle of the cell. In the case of zero, there is nothing until the next cell's clock. For double density, a reduction of cell length to 2 µs is achieved by writing the clock pulse only if both the preceding and the actual cell are logical 0.

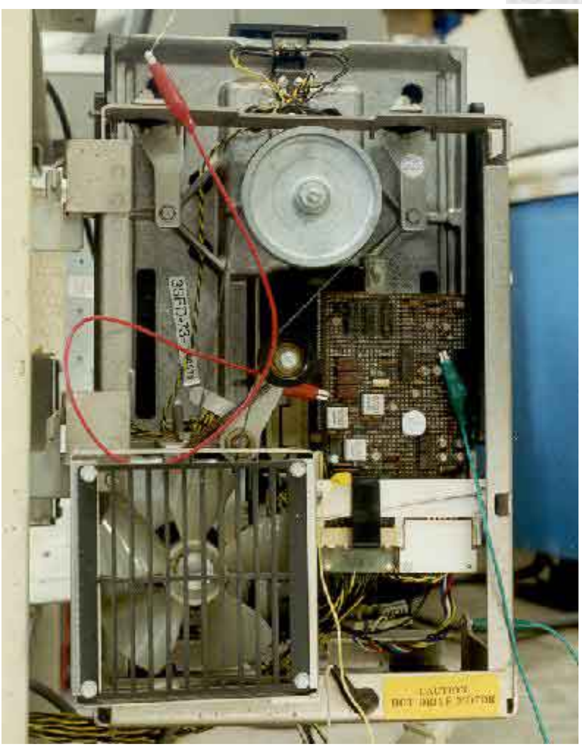
ID field

The ID field consists of a specific one-byte address mark and six more bytes. They contain the track no., the disk side no., the sector no. and a code for the sector length (00, 01, 02 for 128, 256, 512 Byte). Bad tracks are marked by setting these Bytes to FF. At the end the ID field contains MSB and LSB of the data checksum.

Data field

In the data field, the address mark is followed directly by the specified number of data bytes. Then for the checksum 16 bit of cyclic resonance code (CRC) are generated. It is the result of the polynomial $x^{16}+x^{12}+x^5+1$ and contains all bytes from the data and ID fields.

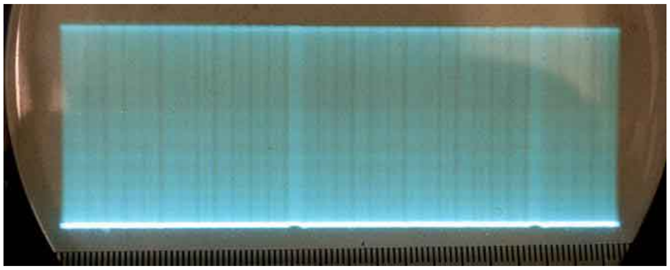
Experimental Setup

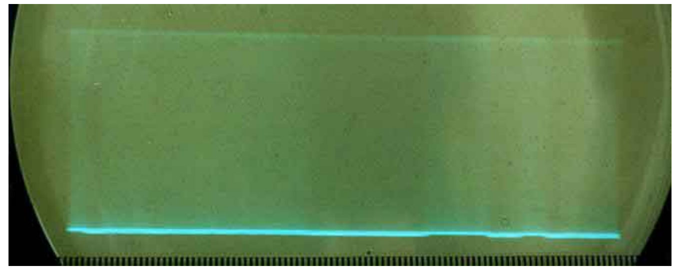


With a rather simple installation the confusing data format can be displayed very clearly. At TP 3, the FC card of the drive provides the digital data of about 1V Amplitude (yellow wire). All we had to is to display it on an oscilloscope. To hold the sectors in place on our screen, we used as external trigger the prepared pulse at TP 2 which contains the optical information from the diskette index hole (red wire). In order to get nice signals, the head load magnet had to be switched on, we connected TP 22 to frame ground (green wire).

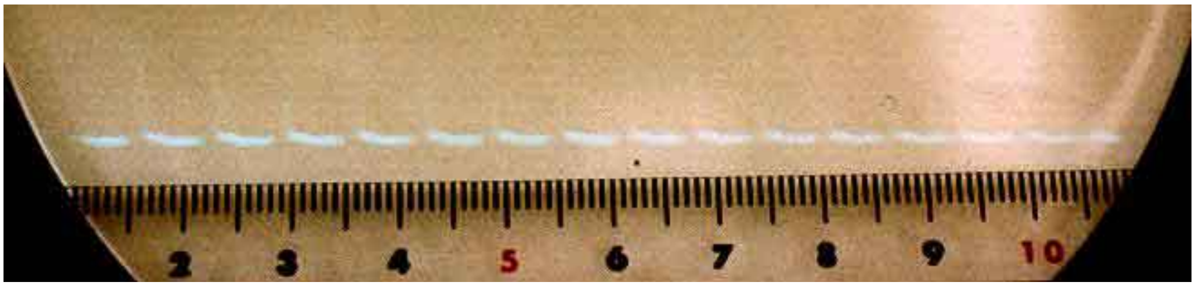
There is one problem: because of the relatively low disk speed, we get only 60 Hz for our signal. On modern high speed oscilloscopes the screen is sometimes not phosphorescent enough to give sufficient brightness at low frequencies. Of course Francesco had a historic 15 MHz oscilloscope with tubes!

Here it is! What you see is a bit more than one track, the gaps between sectors showing as dark vertical lines (left picture). If we zoom onto one sector, we loose a lot of brightness. The data gap of the first and the ID gap of the following sector can yet be seen (to the right).



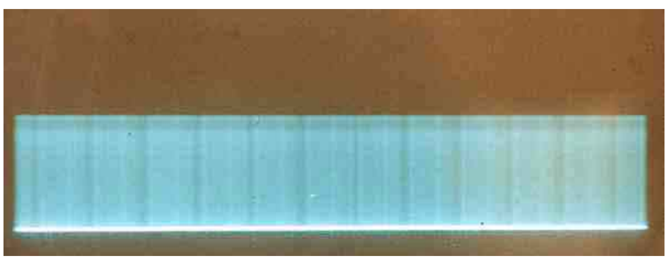


How far can this go? We don't expect to see single bits. The brightness would be insufficient, and also the index pulse trigger is probably not precise enough to synchronize the 4 µs cells. But let's try. The next image represents about one tenth of a sector, with the timescale set to 8 µs /cm. Indeed, we see a periodic signal with ten periods on 6.4 cm, corresponding to 5.1 µs each. Are these bit cells or not ?!

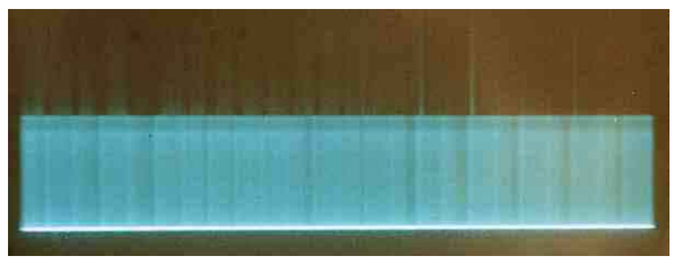


Checking Head Adjustment

We can use this setup to check the head adjustment. First we get a nice clear image of some sectors (on the left), then we turn the stepper motor by hand. At 90°, we should reach the next track, so we expect somehing to happen in between. And rightly so! At a very narrow angular range (+/- 4°) around 45° we see interference patterns (spikes) from the information on neighbouring tracks (on the right). This means that the head adjustment is rather uncritical. It is normally achieved by simple mechanical means, but this also seems an efficient way.



Head position adjusted



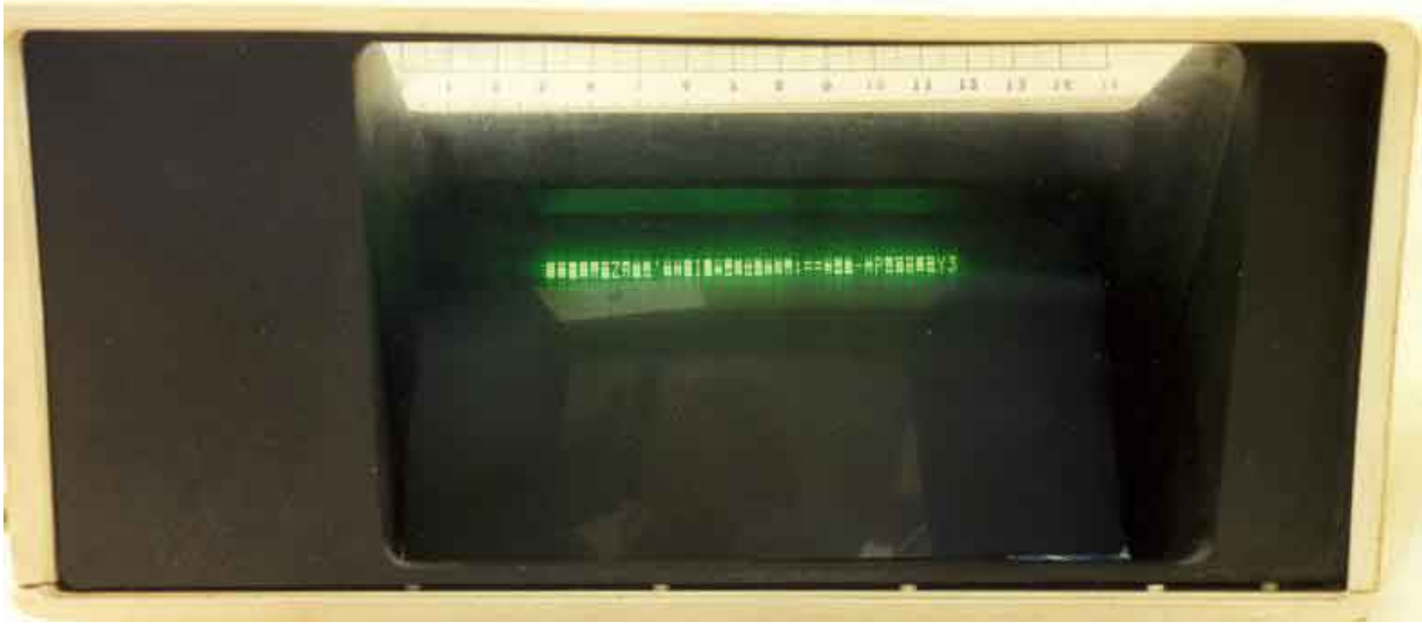
Head between two tracks

Results

Apart from the amusement and the feeling of having understood something we were able to see differences in signal quality by the different circuit boards we had for our drives. For final assembly, we chose the nicest. Also, we were reassured that the head adjustment would not be a problem.

Conclusion

Finally, we were able to repair the CRT and floppy disk drive. Did the whole thing work then? No! Somehow we had ruined the main circuit board in the process, it would not carry out the reset procedure anymore. The keyboard kept on buzzing, the drive stepper motor didn't seek track zero and the screen showed this (the ruler laid in front of it):



What did we learn? The next time one plans to power up an IBM machine after over 20 years, it's advisable to

a) disconnect everything from the power supply at first and to proceed step by step and
b) solder out a bypass capacitor from the supply lines, at least at 12V and 24V, and try it at some overvoltage. (After measuring its capacity.)

The Team

Martin Wölz

Silvia Basaldella, Francesco Piva

We had a great time and hope to have given some ideas. You might look at the current project.