Atari Floppy Disk Copy Protection Based on Key Disk

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Revision 1.0 - November 2011

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2 Presentation

This document is meant to describe most of the ***floppy disk protection mechanisms*** used on the Atari platform. This type of **copy protection** is very old and, with many years of development and the usage of sophisticated floppy disk hardware, has conducted to numerous protection methods frequently referred as **key disk protection**. The key disk protection method has at least two obvious qualities: first, a *key disk* can be simultaneously used as *protection* and *distribution* disk and second, this type of protection is very cheap but nevertheless hard to tamper with. So, key disks have been widely used for protection of Atari programs/games. In order to understand the key disk based protection, one is assumed to have some basic knowledge about FD/FDC data and operation.

Some of the FD protection mechanisms are generic to many platforms while some are directly related to a specific FD Controller used on a specific platform. Therefore, in order to get a general understanding, I have reviewed the FD protections mechanism used on several platforms: Amiga, Commodore C64, PC, Tandy, Atari 8 bits and Atari ST 16 bits (see the references section).

A lot of information about the different copy protection mechanisms presented here has been collected from the Web. Links to the original information / Web sites can be found at the end of this document in the references section.

In order to validate this document, I have analyzed the protections of many original floppy disks using four specific programs that I have developed for this purpose:

- For basic protection analysis I have created a program running on **Atari** called ***Panzer*** (**P**rotection **AN**aly**ZER**) that automatically detects and reports most of the protections (see the protection summary table). This program also provides the capability to analyze and report detailed sectors and tracks information (including track and sector **timing**). For more information please refer to the ***Panzer*** documentation.
- The second program is similar to ***Panzer*** but is running on **PC** and is using **Stream** files produced by the KryoFlux board as input. Due to the detail content of the Stream Images (down to the flux revedrsal level) it is possible to provide much more accurate detections of protections especially those related to timing like the bit cell variation. The program is called ***KFPanzer*** (**K**ryo**F**lux stream based **P**rotection **AN**aly**ZER**). For more information please refer to the ***KFPanzer*** documentation.
- For detailed analysis of *timing information*, I have created a program, called ***Analyze,*** running on Atari and PC. This program reads files produced on an Atari by the ***Discovery Cartridge*** and performs a detailed analysis of the flux reversals read from a diskette. This program takes its root in experiments I have done back in the 80s! The program is now in maintenance mode and is replaced by the ***KFAnalyze*** program presented below.
- The last program reads input **Stream** files generated by the KryoFlux board. The Stream files provide detail information (at the flux reversals level) about Atari FD content (more information in the references section). This program is called ***KFAnalyze*** and is a complete redesign in C++ of the ***Analyze*** program. The heart of this program is a Western Digital WD1772 Floppy Disk Controller emulator. This emulator (that implements a full DPLL data separator) provides functions equivalent to the ***read track***, ***read address***, and ***read sector*** commands directly from the flux reversals read from the input *Stream* files. Therefore it is possible to process the Stream information as if we were reading with an Atari WD1772 FDC but with a lot of extra information especially on timing. For more information please read the ***KFAnalyze*** documentation

Intent of this document is also to provide enough information on the *key disk protection mechanisms* to help in the creation of techniques/programs for **duplication** and/or **preservation** of original Atari diskettes with the following philosophy:

> *A backup/duplication technique should always do the most to ensure the integrity of the resultant copy. The copy produced should operate just like the original and not remove any protection, or modify the program being copied in any way. The backup/duplication technique must do the up most to check that the copy produced is identical to the original.*

Duplication is possible without special HW for many of the protections presented here (many copy programs have been designed for that), but more advanced protections require using dedicated HW like the ***Discovery Cartridge*** or the recently released ***KryoFlux Device.*** Analog copiers, like the ***Blitz*** cable and associated software, can sometime create a working copy of a protected diskette but they **do not fulfill** the above requirements of producing a copy identical to the original.

It is interesting to note than an "**emulator preservation program"** (like Pasti) do *not care as much* about (and sometimes can't detect) the exact underlying protection mechanism used. Such program is mostly interested in storing enough information so that an emulator would be able to emulate the effect of a specific protection. For example this kind of program will detect the presence of fuzzy bytes/bits but it will not care if they are caused by bits in Ambiguous areas, bits rate violation. As a matter of fact finding the exact underlying causes often requires specific hardware like a ***Discovery Cartridge*** or ***KryoFlux device***. I have added, for each of the protection mechanism presented in this document, a section (called ***Preservation:***) that describes a *possible* way of "preserving" the necessary information. Generally, for an emulator, you need to store some or all of the following information for each tracks to preserve:

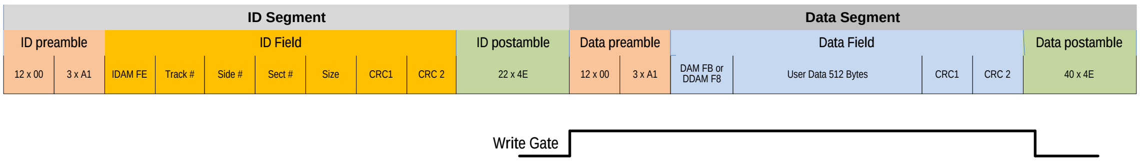
- ✶ The track layout and content
- ✶ The content of all the sectors (even fake ones),
- ✶ Timing information for sector, track, and even bytes
- ✶ Fuzzy bytes information.

I want to thanks to many people on Atari forum for taking time to discuss some of the protections presented here.

3 Terminology used in this document

In the FD literature different terms are often used to designate the same thing! In this document I use the following terminology (a more complete definition is given in the section "Atari Low-level formatting" section):

A **diskette** has two **sides** read by two **heads**. Each side is composed of concentric **tracks**. Each track is made up of several **sectors** (or **records**). Each Sector contains several **fields (**or **blocks)** called: The **Gaps** (GAP1, GAP1a, GAP2, GAP3a, GAP3b, GAP4, and GAP5), the **SYNCH** bytes followed by an **Address Marks** (IAM, IDAM, DAM, and DDAM), the **ID** fields, and of course the **Data** fields.



4 Copy Protection Summary Table

The following table summarizes the copy protections reviewed in this document:

NAME	PZ[1]	KPZ[2]	CAREGORY
Number Of Sector	NOS	NOS	Layout / Track
Sector SiZes	SSZ	SSZ	Layout / Track
Extra Tracks	EXT	EXT	Layout / Track
Missing Tracks	TNF	TNF	Layout / Track
Data Into GAP	[3]	[3]	Layout / Track
Invalid Data in Gap	IDG	IDG	Layout / Track
Invalid Synch-mark Sequence	ISS	ISS	Layout / Track
Track Layout Pattern			Layout / Track
Duplicate Sector Number	DUP	DSN	Layout / Sector
Invalid Sector Number	ISN	ISN	Layout / Sector
Invalid ID Field	IIF	IIF	Layout / Sector
Non Standard IDAM	NSI	NSI	Layout / Sector
Non Standard DAM		NSD	Layout / Sector
Sector with No Data	SND	SND	Layout / Sector
Sector with Bad ID	SBI	SBI	Layout / Sector
Sector with Bad Data	SBD	SBD	Layout / Sector
Data Over Index-pulse	DOI	DOI	Layout / Sector
Data Beyond Index Pulse	DBI	DBI	Layout / Sector
Synch Mark in Data		SID	Layout / Sector
Invalid Track Number	ITN	ITN	Layout / Sector
Sector Within Sector	SWS	SWS	Layout / Sector
Fuzzy bits in Data	FZD	FZD	Fuzzy / Sector
Fuzzy bits in ID	FZI	?	Fuzzy / Sector
Flux rev. in Ambiguous Area	[4]	FAA[4]	Fuzzy / Sector
MFM Timing Violation	[4]	MTV[4]	Fuzzy / Sector
No Flux reversal Area	[4]	NFA[4]	Alteration / Track
Long / Short Sector	LGS/SHS[5]	LGS/SHS[5]	Bit Variation / Sector
Long/Short Track		LGT/SHT	Bit Variation / Track
Intra-sector Bit-rate Variation	IBV	IBV	Bit Variation / Sector
Physical Alteration of Track	?	?	Alteration / Track

Note that several protections' mechanisms can be combined and that some protection always implies other protection (e.g. fuzzy bit always results in CRC error).

[1] Protections detected by ***Panzer*** and reported with the indicated name.
[2] Protections detected by ***KFPanzer*** and reported with the indicated name.
[3] Data into gap is not detected but you should look for it whenever an ISS is found.
[4] Results in Fuzzy bits and therefore reported as FZD or FZI
[5] Reported as LGS is for Long Sector, and SHS is for Short Sector

5 Copy Protection Detail Description

In this section I provide a detailed description of the different protection's mechanisms used in Atari Key disks. The protections have been grouped into four categories. The following taxonomy is used:

- Protections based on Layout
- Protections based on Fuzzy Bits
- Protections based on Bit-rate Variation
- Protections based on Alteration

5.1 *Protections based on Layout*

This category contains all the protections that are based on the layout's modification of one or several track/sector compared to a "standard track" of a "normal diskette".

A "standard track" on an Atari is composed of 9 sectors each with 512 bytes of data sequentially numbered starting with sector 1 until sector 9.

A "normal diskette" has one (i.e. single sided) or two sides (i.e. double sided) and 80 tracks numbered from 0 to 79. A more detailed description of standard and non-standard format can be found in the Atari double density floppy diskette section.

However it is not uncommon to use diskettes with up to 11 sectors and more than 80 tracks as it allows packing more data. A good duplication/imaging program should be able to detect and reproduce all these variants and therefore they are not really considered as protection. A special care should be taken for diskettes with 11 sectors / track as the track timings are in this case extremely tight.

Beyond this basic modification of the layout we also find in this category some very advance protections. Some of them are difficult to detect (so that a copy program would not easily find them) and some of them are difficult to reproduce without special hardware.

5.1.1 Number Of Sectors (NOS)

- **Description**: The standard Atari FD format uses tracks of 9 sectors each containing data blocks of 512 bytes. However many games use 10 or even 11 sectors per tracks just to pack more data on the diskette.
  - Tracks with 11 sectors push several of the parameters that can be handled by the WD1772 FDC close to their limits. This is especially true considering that a 3% rotation's speed variation is by definition possible when reading a diskette. These tracks are therefore often referred as "read only" tracks.
  - Tracks with 12 or more sectors clearly indicate that some "tricks" have been used as 12 real sectors won't fit on a track. Usually these tracks use the Sector within Sector protection.
  - Tracks with less than 9 sectors are not standard and are often combined with sector of size 1024. However alone they are not considered as a protection.
- **Creation**: It is quite easy to format a track with a non-standard number of sectors up to 11. This can be done by sending the appropriate data to the FDC using a ***write-track*** command.
- **Detection**: with a ***read-address*** command.
- **Duplication**: Can easily be done in software for a number of sectors per track up to 11.
- **Preservation**: The preservation file just needs to store the data information for all the sectors of the track using standard ***read-sector*** commands.
- **Examples**: Computer Hits Volume 2 (Beau-Jolly) uses 11 sectors / track, Theme Park Mystery (Image Works) uses 12 sectors / track.

5.1.2 Sector Sizes

- **Description**: Normally all tracks have sectors with a *Data Field* of 512 bytes long. It is possible to create a track with different data field size (usually a mixture of 512 and 1024)[6]. A common example is to have a track with 9 sectors of 512 bytes and a tenth sector with a data field size of 1024 bytes. This is a more reliable approach to increase the overall capacity of a track rather than using 11 sectors of 512 bytes. Non-standard sector size is normally not used as a protection but just to pack more data.
- **Creation**: It is quite easy to format track with mixed sector sizes by sending the appropriate data to the FDC during a ***write-track*** command.
- **Detection**: Can easily be done with a ***read-address*** command.
- **Duplication**: Can easily be done by software.
- **Preservation**: The preservation file just needs to store the data information for all the sectors of the track using standard ***read-sector*** commands.
- **Examples**: Turrican uses tracks with a mixture of sector with 1024 and 512 bytes, Kick Off 2 (Anco Software 1990) uses tracks with mixture of 1024 and 512 bytes sectors.

5.1.3 Duplicate sector

- **Description**: A track where, two or more, sectors use the same sector number. Using blindly a ***read-sector*** command, for this duplicated sector, may return random data values. This is due to the fact that the FDC will access randomly one of these duplicated sectors (with different content) based on current head position. However it is possible to read a specific sector, among the duplicated sectors, by using a ***read-sector*** command delayed by a specific amount of time from the *index pulse*.
- **Creation**: It is quite easy to format a track with duplicate sectors by sending the appropriate data to the FDC during a ***write-track*** command.
- **Detection**: Can easily be done by using a ***read-address*** or a ***read-track*** command.
- **Duplication**: Can easily be done by software.
- **Preservation**: Beyond keeping the standard information for all the sectors it is also necessary to store the presence of duplicate sector.
- **Example**: Night Shift (US Gold) uses a duplicated sector numbered 66. These duplicated sectors also use the no data block protections.

5.1.4 Invalid Sector Number

- **Description**: During the format command any character loaded into the data register of the WD1772 is written to the disk with a normal clock pattern. However the characters $F5 and $F6 are used to write respectively the *Synch Characters* $A1 and $C2 with a missing clock transition. The character $F7 is used to generate two CRC bytes. This implies that it is not possible to create a sector with an ID ranging from 245 through 247 ($F5-$F7). Note that the WD1772 documentation indicates that the sector number should be kept in the range 1 to 240 but in fact any values outside the range indicated above (245-247) works.
- **Creation**: It is **not** possible to create a sector with an ID in the range of 245-247 with the WD1772 FDC and therefore creating such *ID Field* requires a **special hardware**.
- **Detection**: Can easily be done with a ***read-address*** command.
- **Duplication**: Requires special hardware.
- **Preservation**: The sector with an invalid number is read as a normal sector by a ***read-sector*** command and it just needs to be stored in the preservation file like any other standard sector.
- **Example**: Dungeon Master (FTL Inc.) use a sector number of **247** ($F7) on track 0

[6] Note that several of the BIOS calls will **not** work for sectors with size different than 512.

5.1.5 Invalid ID Field

- **Description**: An *ID Field* contains a Track Number, a Side/Head Number, a Sector Number, a Sector Length, and two CRC bytes. During a ***read-sector*** command when an *ID Field* is located on the disk, the WD1772 compares the Track Number of the *ID Field* with its internal Track Register. If there is not a match, the next encountered *ID Field* is read and a comparison is made again. If there is a match, the Sector Number of the *ID Field* is compared with its internal Sector Register. If there is no Sector match, the next encountered *ID Field* is read off the disk and a comparison is made again. If the *ID Field* CRC is correct, the *Data Field* is located and an internal register is loaded with the Sector Length. It is therefore possible to create a track with an invalid ID field. As Invalid Track Number and Invalid Sector Number protections are widely used they are treated separately. Therefore here we will only consider *ID field* with an invalid Side/Head Number (i.e. not equal to 0 or 1) or an invalid Sector Length (i.e. not in range 0-3). TO BE VERIFIED: (not sure of the behavior of FDC with invalid sector length or Side #)
- **Creation**: It is possible to write invalid values for the Side Number and/or for Sector Length of an *ID Field* by sending the appropriate data to the FDC during a ***write-track*** command.
- **Detection**: Can easily be done with a ***read-address*** command.
- **Duplication**: Can easily be done by software
- **Preservation**: The exact content of the invalid ID field need to be saved in the preservation file.
- **Example**: Colorado Track 1 (Track=14, Head=164, Sector=150, Size=132) ??? To be verified

5.1.6 Invalid Data in Gap

- **Description**: During the format command any character loaded into the data register of the WD1772 is written to the disk with a normal clock pattern. However the characters $F5 and $F6 are used to write the Synch Marks and the character $F7 is used to generate of two CRC bytes. This implies that it is not possible to have a character ranging from 245 through 247 ($F5-$F7) inside any of the GAPs[7]. Reading these characters into GAPs requires using a ***read-track*** command. In order to read these invalid characters correctly with the ***read-track*** command it is recommended to precede them with one or several ***synch*** character.
- **Creation**: It is not possible with the WD1772 to write a character within the range 245-247 in any GAP. Therefore writing any of these characters into GAPs requires special hardware.
- **Detection**: Can easily be done with a ***read-track*** command.
- **Duplication**: Require special hardware.
- **Preservation**: It is necessary to save the content of the track in the preservation file.
- **Example**: Operation Neptune Track 50, Dragon Flight (???)

[7] Note that it is not possible to modify the GAP2 or GAP3b ($00) as these gaps are required by the FDC to synchronize properly. Therefore writing invalid bytes must be done in GAP1 and/or GAP3a and/or GAP4

5.1.7 Non Standard IDAM

- **Description**: The normal IDAM (ID Address Mark) used by the WD1772 is the character $FE which is sent after a synch sequence of 3 $A1 synch marks. An undocumented feature of the WD1772 is to accept the character $FF as an IDAM[8].
- **Creation**: During a write-track command it is possible to use $FF instead of the normal $FE IDAM character.
- **Detection**: As the ***read-address*** command and the ***read-sector*** command execute normally it is easy to hide the fact that a non-standard IDAM has been used. Detection can either be done through a ***read-track*** command or with the ***read-address*** command. In both cases you have to look for an $FF character instead of $FE in the *ID field*. Note that the ID Field reads with no CRC error.
- **Duplication**: Once detected this protection is easy to duplicate.
- **Preservation**: Requires storing the exact ID field or the track information in the preservation file.
- **Example**: Colorado track 1 has an extra *ID Field* with $FF IDAM. However the *ID Field* has also a CRC error and I am not sure if this is used as a protection?

5.1.8 Non Standard DAM

- **Description**: The normal DAM (DATA Address Mark) used by the WD1772 is either the character $FB for normal data and $F8 for deleted data which is sent after a synch sequence of 3 $A1 synch marks. An undocumented feature of the WD1772 is to accept the character $FC/F9 as a DAM[9].
- **Creation**: During a write-track command it is possible to use $FC or $F9 instead of the normal $FB or $F8 DAM character.
- **Detection**: As the ***read sector*** command execute normally it is easy to hide the fact that a non-standard DAM has been used. Detection can be done through a ***read track*** command where you have to look for a $FC/F9 character instead of $FB/F8 in the header of the *DATA field*. Note that the DATA Field reads with no CRC error.
- **Duplication**: Once detected this protection is easy to duplicate.
- **Preservation**: Requires storing the track information in the preservation file.
- **Example**: ???

5.1.9 Sector with No Data

- **Description**: A sector with an *ID Field* not followed by a *Data Field*.
- **Creation**: It is quite easy to format a sector of a track with an *ID field* not followed by a *Data Field*. This is done by sending appropriate data to the FDC during a ***write-track*** command.
- **Detection**: This kind of sector is found using a ***read-address*** command, but is not found using a ***read-sector*** command. This is because during the ***read-sector*** command the FDC expects to find a DAM/DDAM within 43 bytes from last *ID Field* CRC byte, if not the sector is searched again for 5 revolutions and the command is terminated with the Record Not Found (**RNF**) Status bit set.
- **Duplication**: Can easily be done by software.
- **Preservation**: Requires storing the track information in the preservation file.
- **Example**: Night Shift (US Gold) uses duplicate sectors 66 both of them having No Data fields

[8] Note that, in MFM, for the marks characters between $F8 and $FF the least significant bit is always ignored by the FDC and therefore : $F8 = $F9, …, $FE = $FF

[9] Note that, in MFM, for the marks characters between $F8 and $FF the least significant bit is always ignored by the FDC and therefore : $F8=$F9, …, $FE = $FF

5.1.10 Sector with bad ID

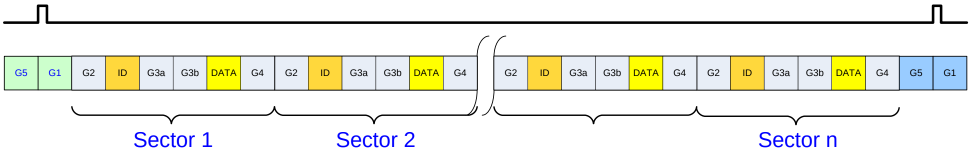
- **Description**: A sector that has a CRC error in the *ID Field*. This results in a sector that cannot be read by the ***read-sector*** command.
- **Creation**: Easy with the ***write-track*** command. For example by sending 2 normal bytes (e.g. $00, $00) at the end of the field instead of one "Write CRC" character ($F7).
- **Detection**: It is possible to read this kind of sector with a ***read-address*** command and to verify that it has a wrong CRC. But it is not possible to read the sector with a ***read-sector*** command. A ***read-track*** command can be used to read the data, but keep in mind that the ***read-track*** command cannot read reliably a data sector and that the CRC is not verified (see Synch character in *Data Field*).
- **Duplication**: Can easily be done by software
- **Preservation**: Requires storing the ID field and/or the track information in the preservation file.
- **Example**: ???

5.1.11 Sector with bad Data

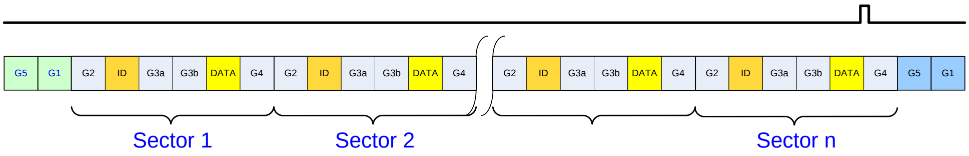
- **Description**: A sector that has a CRC error in its *Data Field*.
- **Creation**: Easy during ***write-track*** command by using the same mechanism as described above.
- **Detection**: Can easily be done using a ***read-sector*** command. The data sector is *read normally* but the CRC error status bit is set at the end of the command.
- **Duplication**: Can easily be done by software
- **Preservation**: The content of the sector should be stored as normal but a CRC error indicator must be added to the preservation file.
- **Example**: Populous

5.1.12 Data Field Over Index-pulse

- **Description**: A sector where the *Data Field* span “over the index hole”. Normally all sectors of a track should end up before the index pulse. Yet it is possible to create a track with a total length that is slightly more than what a normal track can hold. This results in the last sector “wrapping around” the beginning of the track. As there is a small area at the beginning of track (the post-index GAP), which is not used for storing data, it is possible to overwrite partially this section of the track. But if we want the track to look like a standard track the overlap should not be too large otherwise the IDAM of first sector will be erased. However it is also possible to create a totally non standard layout for the track where we actually literally shift the track in respect to the index pulse. In this case it is possible to have a Data Field almost completely placed at the beginning of the track (like in Kick Off 2)



Sector positions relative to the index pulse for a normal track

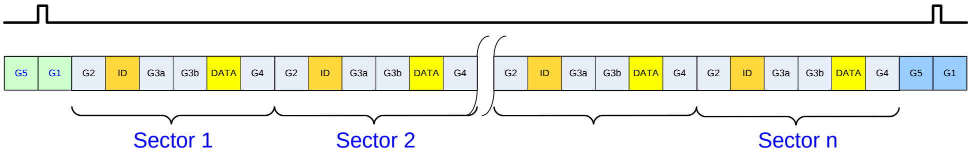


Sector positions relative to the index pulse for a track with Data Over Index

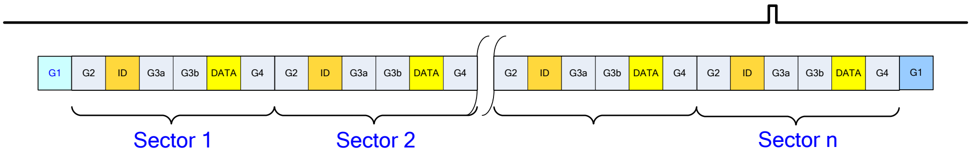
- **Creation**: As mentioned above it is possible to create a “long track” with a total length that is slightly more than what a normal track can hold (usually about 10 to 20 bytes). This result in the header of the last track sector to be placed close to the end of the track. The ***write-track*** command of the WD1772 FDC starts with the leading edge of the index pulse and continues until the next index pulse. Therefore the last sector of a “long track” will be **truncated** during the format operation. However the ***write-sector*** command on this truncated sector will execute normally and this will result in data being written beyond the index pulse.
- **Detection**: The last sector passes over the index pulse but it is read normally by the ***read-sector*** command. It is therefore necessary to use a ***read-track*** command to find out that the last sector actually spread over the beginning of the track.
- **Duplication**: *Data Field* passing over IAM can cause significant problems for copier unaware of their existence. Dumb copy will not result in correct sector position and therefore this protection has been used extensively used on Atari. However once detected the duplication of such sector is easy by formatting correctly the track.
- **Preservation**: Requires storing the track information in the preservation file.
- **Example**: Kick Off 2 places almost all the data of one sector at the beginning of a track.

5.1.13 Data Field Beyond Index-pulse

- **Description**: A sector where the *ID Field* is placed at the very end of a track and the corresponding *Data Field* is at the very beginning of the same track. This is an extreme variation of the Data Over Index protection. Normally all sectors of a track should end up before the index pulse. Yet it is possible to create a track where the *ID Field* for the last sector is placed at the very end of the track with the corresponding *Data Field* placed at the very beginning of this same track. You have to remember that the Data Address Mark of the *Data Field* is to be found within 43 bytes from the last *ID Field* CRC byte and therefore placement of the *ID Field* and corresponding *Data Field* in the track is **critical**. This results in the last sector "wrapping around" the beginning of the track. See Computer Hits Volume 2 for an example.



Sector positions relative to the index pulse for a normal track



Sector positions relative to the index pulse for a track with Sector Over Index

- **Creation**: This is done by creating a special layout for the track: the track needs to start with a *Data Field* (very close to beginning of track) then followed by a set of nine or ten *ID Field* and *Data Field* and terminated by an *ID Field* very close to the end of the track.
- **Detection**: The last sector has the *ID Field* before the index pulse and the *Data Field* after the index pulse but it is read normally by the ***read-sector*** command. It is therefore necessary to use the ***read-track*** command to find out that the last sector actually spread over the beginning of the track.
  Important note: The DMA can only transmit multiple of 16 bytes from the FDC. Therefore during a ***read-track*** command, one or several of the last bytes (always less than 16) may **not** be transferred by the DMA. Consequently it is possible that a ***read-track*** does **not** transmit the *ID Field* (or transmits it partially) when it is placed at the very end of a track. However the FDC ***read-address*** and ***read-sector*** commands will find this ID field and interpret this sector correctly.
- **Duplication**: Sector passing over IAM can cause significant problems for copier unaware of their existence. Dumb copy will not result in correct sector position. I believe that it is almost impossible to ***reliably*** place an ID field at the very end of the track by software due to floppy drives rotation speed variation. Therefore this protection requires most probably some specific hardware.
- **Preservation**: Requires to store the track information, but as the last address field might not be read correctly it also requires to store all the sector IDs
- **Example**: Computer Hits Volume 2 (Beau-Jolly)

5.1.14 Extra Tracks

- **Description**: A “normal Atari diskette” has 80 tracks numbered 0 through 79 on each side. It is possible to go beyond this value up to 82 tracks with good reliability and even more with a lower reliability. It is also possible to “hide” one or several tracks on the second side of an “officially” (as specified in the boot sector) single sided diskette.
- **Creation**: It is quite easy to create extra track by sending appropriate information to the FDC during the ***write-track*** command. Be aware that some early Atari drives cannot position the head past track 79 and that they will write the data for tracks 80 and over on track 79. Also beware that using tracks over 82 has been reported to *damage* some floppy drives.
- **Detection**: You have to probe the diskette to check if some extra tracks exist (probing for 82 tracks is usually sufficient). For Single Sided diskette, try to probe for hidden track on second side.
- **Duplication**: Easy by software.
- **Preservation**: Store information for the extra tracks.
- **Example**: Passengers on the Wind (Infogrames) uses tracks 80 & 81.

5.1.15 Missing Tracks

- **Description**: A “normal Atari diskette” has 80 tracks numbered 0 through 79 on each side. It is possible that not all of these tracks are formatted. However creating non formatted track is not as simple as it seems as most diskettes are sold preformatted.
- **Creation**: On a non-formatted diskette you only format the tracks needs to be formatted! On a preformatted diskette you need to mimic unformatted tracks by writing, for example, random data to those tracks?
- **Detection**: A ***seek*** command with the verify option should fail on unformatted track. Alternatively you can perform a ***read-track*** and look for inconsistent data. Note that it is also possible to hide data at the end of an “officially” unformatted track.
- **Duplication**: If only the presence of an invalid track is tested then it is easy to reproduce by software. Placing specific data at end of an otherwise unformatted track is more difficult to detect.
- **Preservation**: The preservation file should have some indicators for missing tracks.
- **Examples**: Barbarian Psygnosis (Track 74 – 79 missing), Run the Gauntlet (Ocean Software), Kick Off 2

5.1.16 Data into GAP

- **Description**: It is possible to write data in the post ID Gap (Gap of 22 bytes) or in the post DATA Gap (Gap of 40 bytes) as well as in the pre and post index GAP (respectively 664 and 60 bytes on standard diskettes). See “copy me I want to travel” from Claus Brod for a complete explanation and some interesting examples.
- **Creation**: Extra data can be written into Gap only during the ***write-track*** command. It is recommended to use **Synch Marks** in front of the data to be able to read them correctly (although reading pseudo random value may be part of the protection).
- **Detection**: You need to use a ***read-track*** command to be able to read the inter-sector information. But it is not easy to find this information as you do not know what and where to look for. Therefore some heuristic need to be used (e.g. presence of synch marks into GAP).
- **Duplication**: Although it is difficult to detect, it is easy to reproduce with the ***write-track*** command.
- **Preservation**: Requires storing the track information in the preservation file.
- Example: Barbarian Psygnosis (end of Track 0) ?

5.1.17 Invalid Synch-mark Sequence

- **Description**: Normally Synch mark should always be in a sequence of 3 Synch Marks (3 $A1or 3 $C2) and should always been followed by an Address Mark (IAM = $FC, IDAM = $FE, DAM = $FB, or DDAM = $F8). Therefore having a sequence of 3 Synch Marks **not followed** by an AM is considered as an abnormal condition. Note that such sequence can usually be used to synch up the data separator to read data into gap. But it is also abnormal to have **one** isolated Synch Mark. However reading only two Synch Marks with a ***read-track*** command is usually normal as usually the first Synch Mark is not read correctly.
- **Creation**: It is quite easy to create an invalid synch mark sequence during format by sending appropriate information to the FDC using the ***write-track*** command.
- **Detection**: Only possible with the ***read-track*** command as the ***read-sector*** command just ignore invalid synch mark sequences.
- **Preservation**: Requires storing the track information in the preservation file.
- **Duplication**: Easy by software.
- **Example**: Barbarian Psygnosis (one Synch alone on Track 0, series of Synch on Track 48)

5.1.18 Synch Mark in Data

- **Description**: This is not a protection per se but it can be used as an indicator: During a ***read-sector*** command the *Synch Mark Detector* of the WD1772 is disabled but during a ***read-track*** command the *Synch Mark Detector* is active at all time. For specific sequence of data bits during a ***read-track*** the detector detects a $C2 synch mark resulting in a shift of the following bits/bytes. This “feature” can be used to hide some information inside a *Data Field* (see “copy me I want to travel” from Claus Brod for examples).
- **Creation**: You have to write a specific sequence of bits, known to create a **false $C2** synch mark, within a *Data Field* during a ***write-track*** command. Note that these sequences rely on a poorly defined $C2 Synch Mark and are well known and described in many places.
- **Detection**: Read with a ***read-sector*** command, then read with a ***read-track*** command and compare the returned data.
- **Preservation**: Requires storing the track information in the preservation file.
- **Duplication**: Easy by software.
- **Example**: Turrican (shift to clock bits)

5.1.19 Track Layout Pattern

- **Description**: With the WD1772 FDC it is possible to fully control the layout of a track by playing with the width of the gaps used during formatting. With this technique it is possible to create equivalent gaps of different lengths in different position of the track (e.g. vary the length of the GAP4 placed between the different sectors). It is therefore possible to create a track with a specific layout pattern different from the standard pattern. This is a sort of FD ***watermarking*** technique. If a program is not looking for this specific protection it will read correctly the track, but will miss the pattern information.
- **Creation**: It is quite easy to format a track with specific different values for each GAPs by sending the appropriate information to the FDC during the ***write-track*** command.
- **Detection**: Measure the layout of the different fields of the track using the ***read-track*** command and look for a specific pattern. Note that some tolerance needs to be taken in account as the number of bytes reported for a specific gap may vary slightly from read to read.
- **Duplication**: Once detected it is easy to duplicate by software.
- **Preservation**: Requires storing the track information in the preservation file.
- **Example**: ???

5.1.20 Invalid Track Number

- **Description**: A track that has one or several sectors with *ID Field*s that contains a track number different from the actual track number. In order for the *type I commands* (e.g. ***seek***) to succeed, on such a track, the verify bit has to be reset. Otherwise the FDC check that at least one sector has the correct track number. The ***read-sector*** command using “standard” parameters will also fail.
- **Creation**: Using a ***write-track*** command with incorrect track number in one or several *ID Field*.
- **Detection**: The ***read-sector*** command compares the track number of the *ID Field* with the track register if this matches it then compares the sector number of the *ID Field* with the sector register. If any compare operation fails the FDC retry 5 times then terminate the command with a record not found (RNF) error. Reading this kind of sector is possible but requires playing with the FDC registers (i.e. loading the track register with the invalid track value).
- **Duplication**: Easy by software
- **Preservation**: The preservation file should store the exact ID block.
- **Example**: Virus

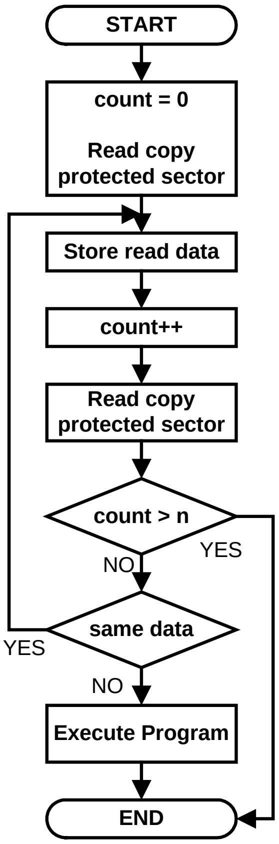
5.1.21 Sector Within Sector

- **Description**: The principle is to put a sector (or usually only a fraction of a sector) inside another sector. The normal layout of a sector has the following fields in sequence:
  GAP2, *ID Field*, GAP3, *Data Field*, and GAP4.
  In this protection, the data placed inside the *Data Field* of the including sector contains at least a GAP2, an *ID Field*, a GAP3, and a *Data Field*. If both sectors use a data block of the same size then the included *Data Field* is obviously truncated and terminates prematurely. If the including sector has a data block of size 1024 and the included sector a data block of size 512, the included sector can, in that case, fit completely. This works well because during a ***read-sector*** command the synch mark detector of the WD1772 is shutdown. A detailed explanation of this protection can be found in the Theme Park Mystery example. An even more complex variant of SWS is to have a sector within another sector which is itself located within another sector. Even with such a complex layout it is possible to read correctly the “included sector”! For an example of SWS-WS-WS look at Computer Hits Volume 2. When you read a data block the FDC disables further re-syncs. Therefore it is possible to have a data block included that is shifted by a bitcell and synced properly, in that case you'd be able to read data bits as well as clock bits as in Turrican.
- **Creation**: It is possible to create such a track by sending the appropriate information to the FDC using the ***write-track*** command.
- **Detection**: The ***read-address*** command works fine on both the containing and the contained sectors and the ***read-sector*** command may or may not fails on the contained sector and may or may not fail on the containing sector. Usually look for this protection when a track has a number of sector equal or exceeding 12. To confirm this protection you need to use a ***read-track*** command and decipher the information. Another alternative is to check the data inside the containing sector’s *Data Field* and look for GAP2 followed by an *ID Field* etc. However beware that this will not always work due to the way the FDC works. For example it is not possible to find the ID and DATA field of sector 16 inside sector 0 of track 2 of Computer Hits Volume 2 (Beau-Jolly).
- **Duplication**: Easy by software? (to be verified)
- **Preservation**: Once the protection is detected the preservation program should store the track layout and store the information about the different including and included sectors and if they read correctly or not (CRC).
- **Example**: Theme Park Mystery , Computer Hits Volume 2 (Beau-Jolly), Turrican, Nitro Boost Challenge (Codemasters)

5.2 Protections based on Fuzzy Bits

Fuzzy bits are known under many names: *weak bits*, *wandering bits, flaky bits, flakey bits, phantom bits*, etc. **Weak bits** is the most commonly used, however I find it misleading (as there is usually no weakness in weak bits) and therefore I prefer to use the term **Fuzzy bits** that does not infer any underlying cause but clearly indicate the “fuzziness” of the returned data. Although fuzzy bits can be created by using different techniques the result is always the same: a byte containing fuzzy bits (also referred as a *fuzzy byte*) will be read with different values for different read commands. Fuzzy bytes can be located at any place of a track. However fuzzy bytes are usually used in a data field of a sector and in that case the data returned will differ at each read sector command (see Fuzzy bits in Data). But fuzzy bits can also be used in the ID field (see Fuzzy Bits in ID). As we will describe below the fuzzy bytes can be created by using Flux reversals in Ambiguous Area, Bit Cell Timing Violation, or Weak Bit but for emulation purpose it is usually not necessary to know the underlying cause.

5.2.1 Fuzzy bits in Data



- **Description**: The flowchart on the right describes a copy recognition routine that tests for fuzzy bytes in the data field (patent 4,849,836). The protected sector that contains fuzzy bytes is read several times and randomness of the returned data is checked. If the same data is read several times on the protected sector the program is not executed. Very often, as in *Dungeon Master*, the protection is verified several times during execution of the game/program. The detection mechanism should also test that the random values returned are not due to usage of simple tricks like duplicated sectors.
- **Creation**: Please refer to Bits in Ambiguous Area, MFM Timing Violation, and Weak Bit for the creation on Fuzzy data fields.
- **Detection**: By reading the same fuzzy data several times and checking that returned data are random. See the generic description.
- **Duplication**: Difficult and requires special hardware (i.e. the Atari WD1772 cannot be used to copy this kind of sector). Analog or digital copiers can be used but, as usual, digital copier should be preferred.
- **Preservation**: The preservation file should have an indicator to record the fact that a track has a Fuzzy data sector. It is probably a good idea to store as well the position of the first and last different byte in the sector. Usually the 32 bytes at the beginning and at the end of the sector are always read correctly.
- **Example**: refer to Flux reversals in Ambiguous Area, MFM Timing Violation, Weak Bit

5.2.2 Fuzzy Bits in ID

- **Description**: What has been described for *Data Field* can also apply to *ID Fields*. A *fuzzy ID field* contains some fuzzy bits that will result in random values for different reads and in most cases a CRC error.
- **Creation**: Please refer to Flux reversals in Ambiguous Area, MFM Timing Violation, and Weak Bit for the creation on Fuzzy ID Fields.
- **Detection**: By reading the same fuzzy ID (i.e. ID that contains fuzzy bits) several times and checking that returned data are random. See the generic description. This protection causes some interesting programming problem in order to read correctly the addresses and the sectors.

- **Duplication**: Difficult and requires special hardware (i.e. the Atari WD1772 cannot be used to copy this kind of sector). Analog or digital copiers can be used but, as usual, digital copier should be preferred.
- **Preservation**: The preservation file should have an indicator to record the fact that a track has a Fuzzy ID sector.
- **Example**: refer to Flux reversals in Ambiguous Area, MFM Timing Violation, Weak Bit

5.2.3 Flux Reversals in Ambiguous Area

- **Description**: These fuzzy bits are obtained by "placing" certain flux reversals in so called "Ambiguous areas" i.e. *at the border of the inspection window*. As described above these kinds of *fuzzy bits* can be used in Fuzzy bits in Data or Fuzzy bits in ID.
- **Creation**: These fuzzy bits are obtained by placing the bit flux reversals in "Ambiguous areas". More precisely the bit reversals are placed in locations that will confuse the DPLL (Digital Phase Lock Loop) of the data separator resulting in random values read (i.e. sometimes 0, sometimes 1). This is obtained by positioning the bit reversals at the **border of the inspection window** (more detail here). In that case the data separator will return random values due to small variation of the drive rotation speed. In the US patent "Copy Protection for computer Disc 4,849,836" one of the techniques to create fuzzy bits consists in having bit reversals gradually sliding in and out of the inspection window border. Of course creating this kind of reversals requires special hardware that has capability to vary the FDC clock on the fly, or the capability to directly control the bit cell width/position (e.g. the Discovery Cartridge, KryoFlux board).
- **Detection**: By reading the same fuzzy sector (i.e. sector that contains fuzzy bits) several times and checking that returned data are random (see Fuzzy bits in Data and Fuzzy Bits in ID). Without specific hardware (e.g. KryoFlux board) it is not possible to find the real underlying cause of the fuzzy bits.
- **Duplication**: Difficult and requires special hardware (i.e. the Atari WD1772 cannot be used to copy this kind of bytes). Analog or digital copiers can be used but, as usual, digital copier should be preferred.
- **Preservation**: The preservation file should have an indicator to record the fact that the sector is a fuzzy sector.
- **Example**: Dungeon master Track 0, sector 7

5.2.4 MFM Timing Violation

- **Description**: These fuzzy bits are obtained by using flux reversals that violate the timing of the MFM rules.
- **Creation**: These fuzzy bits are obtained by placing flux reversals that contains MFM timing **violations** (data separated by less than 4 µs or more than 8 µs). For example a long series of zero data with missing clock bits. These bit-cell width are beyond the normal DPLL capture range and the next received reversal will be interpreted differently based on small random variation of the DPLL clock and/or the drive rotation speed. Of course this technique requires special hardware that has capability to vary the FDC clock on the fly, or the capability to directly control the bit cell width/position (e.g. the Discovery Cartridge).
- **Detection**: By reading the same fuzzy sector (i.e. sector that contains fuzzy bits) several times and checking that returned data are random (see Fuzzy bits in Data and Fuzzy Bits in ID). Without specific hardware (e.g. KryoFlux board) it is not possible to find the real underlying cause of the fuzzy bits.
- **Duplication**: Difficult and requires special hardware (i.e. the Atari WD1772 cannot be used to copy this kind of bytes). Analog or digital copiers can be used but, as usual, digital copier should be preferred.
- **Preservation**: The preservation file should have an indicator to record the fact that the sector is a fuzzy sector.
- **Example**: D50 Editor - Track 0 - Sector 10 (over 700 timing violation in the *Data Field*!)

5.2.5 No Flux reversals Area

- **Description**: These fuzzy bits are obtained by having ***a long area without flux reversals*** (this is an extreme version of the above timing violation). Note that the lack of flux reversal increases the gain on the head (AGC), eventually leading to an amplified level that generates a fake flux reversals and the PLL data separator can't lock onto the clock/data bits. The result is that the sector is read with fuzzy bits.
- **Creation**: Requires specific hardware. A normal drive can't create such a long spacing between two flux reversals. This is a limitation of the drive, and not a limitation of the controller.
- **Detection**: By reading the same fuzzy sector (i.e. sector that contains fuzzy bits) several times and checking that returned data are random (see Fuzzy bits in Data and Fuzzy Bits in ID). Without specific hardware (e.g. KryoFlux board) it is not possible to find the real underlying cause of the fuzzy bits.
- **Duplication**: Difficult and requires special hardware (i.e. the Atari WD1772 cannot be used to copy this kind of bytes). Analog or digital copiers can be used but, as usual, digital copier should be preferred.
- **Preservation**: The preservation file should have an indicator to record the fact that the sector is a fuzzy sector.
- **Example**: Turrican.

5.2.6 Weak Bit

- **Description**: We use the term ***weak bits*** for data bits that produce **weak flux reversals** below a certain threshold that will therefore result in ambiguous reading returning different values on different reads (see fuzzy bits for a generic description). The SpinRight documentation (from **SpinRite's** Defect Detection Magnetodynamics site) gives a good explanation on weak recorded reversals.
Weak bits can be created by many different means but the most popular have being described in the US Patent 4,849,836.
One method consists to move the head slightly out of alignment during write operation (see figure 3). As the Atari FD drives do not have a sophisticated track follower mechanism, this result in weak reversals during read (see figure 4).
Another method consists in writing a “protection track” in between normal tracks (see figure 5). It is obvious that this extra track will induce perturbations in the data bit flux of the adjacent tracks resulting in weak bits when there is opposition in the fluxes.
Yet another method consists in placing bits on top of *physical defects* on floppy surface. To be useful these defects have to be created precisely on specific spots of the surface layer using for example evaporation with an infrared laser.

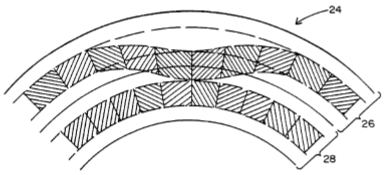


FIG. 3

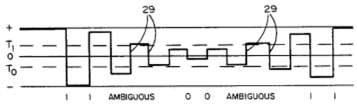


FIG. 4

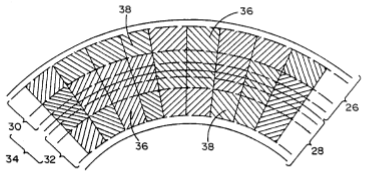


FIG. 5

- **Creation**: Creation of this type of weak bits requires very specialized hardware.
- **Detection**: As describe in the Fuzzy bits section, the weak bits will result in random values returned for subsequent read operations and are therefore easy to detect.
- **Duplication**: It is obviously at least extremely difficult if not impossible to exactly reproduce the weak bits described in this section. However it is possible to mimic their behavior by placing Flux Reversals in Ambiguous area as this result in the same behavior and therefore should be transparent to the detection mechanism of the protected program.
- **Preservation**: The preservation file should have an indicator to record the fact that the sector is a fuzzy sector.
- **Examples**: I am not aware that this technique has been used on Atari.

5.3 Protections based on Bit-rate Variation

This section describes the protections based on variations of the bit-rate from the standard 4 µs cell. Although different techniques are used the end result of using bit-rate variation is always the same: the overall time-length of a byte, transferred to/from the drive, is different from a "normal 32 µs byte". Therefore detection of this protection requires to be able to measure timing information when reading a block of bytes and/or a sector.

5.3.1 Long / Short Sector

- **Description**: This kind of sector can be created by writing a sector of a track with an apparent rotation speed of the drive slightly above or below the normal speed. This results in a reading time for this sector above or below the reading time of a "normal sector". In practice this is obviously not done by varying the rotation speed of the drive (not practical, inaccurate, and with slow variation due to mechanical inertia), but by changing the FDC's bit-cell clock. The IBM standard specifies that the FDC circuitry should handle a variation of the drive's rotation speed within ± 2% range. Therefore the DPLL of a FDC is supposed to accept at least a 4% variation. But in practice the WD1772 DPLL (See WD1772 DPLL Input Circuitry) can handle a 10% variation for MFM encoding (as described in the DPLL Patent). It is therefore possible to write sectors with bit cells at frequencies between 225 and 275 KHz (corresponding respectively to 3.6 to 4.4 µs bit width) and to still read the data correctly. However the resulting sector will be longer or shorter than a normal sector. The most famous usage of this protection was done by **R**ob **N**orthen in the **Copylock** (RNC) protection mechanism[10] (see an interview with Rob Northen): in this case the bit width is changed to approximately 4.2µs (about 4 to 5% variation) to result in a shorter sector. The beginning of the sector (for about 32 bytes) is written at normal speed so that we are sure that the data in this section are always read correctly. Note that due to the sharp transition done of the clock bit-rate, the sector may also contain **fuzzy bits** and in turn this results in a CRC error.
- **Creation**: It requires special hardware: e.g. the capability to vary the drive rotation speed, or the capability to vary the FDC bit cell clock on the fly, or the capability to directly control the bit cells width like with the **Discovery Cartridge** from *Happy Computing*.
- **Detection**: can't be done with standard TOS call as it is necessary to measure the time it takes to read the bytes in the short/long sector and compare it with the reading time of other sectors on the same track. Therefore it requires to write specific routines.
- **Duplication**: Difficult and requires special hardware. Analog or Digital copiers can be used but, as usual, digital copier should be preferred whenever possible.
- **Preservation**: The preservation file should store information about the timing information.
- **Example**: Populous - Track 0 Sector 6.

[10] According to vauvillf: there has been 2 RNC. The old one used for example on Arkanoid2, and Thundercats… It was possible to copy RNC-1 with the ***acopy*** program (only 2 to 3 times). Then there was a big evolution of the RNC protection sometime in 1988: with this one it was no more possible to copy the protection by software, and it was also using the famous trace decoding loop. Apparently the description provided here refers to the RNC-2 protection.

5.3.2 Long/Short Track

- **Description**: This kind of track can be created by writing all sectors of a track with an apparent rotation speed of the drive slightly above or below the normal speed (i.e. having Long / Short Sector for all sectors). This results in a track that contains more or less bytes than a normal 6240 bytes track. In practice this is obviously not done by varying the rotation speed of the drive (not practical, inaccurate, and with slow variation due to mechanical inertia), but by changing the FDC's bit-cell clock. The IBM standard specifies that the FDC circuitry should handle a variation of the drive's rotation speed within ± 2% range. Therefore the DPLL of a FDC is supposed to accept at least a 4% variation. But in practice the WD1772 DPLL (See WD1772 DPLL Input Circuitry) can handle a 10% variation for MFM encoding (as described in the DPLL Patent). It is therefore possible to write sectors with bit cells at frequencies between 225 and 275 KHz (corresponding respectively to 3.6 to 4.4 µs bit width) and to still read the data correctly.
- **Creation**: It requires special hardware: e.g. the capability to vary the drive rotation speed, or the capability to vary the FDC bit cell clock on the fly, or the capability to directly control the bit cells width like with the **Discovery Cartridge** from *Happy Computing*.
- **Detection**: You have to use a ***read track*** command. The normal length is around 6240 bytes and usually the program using this protection checks that the track has more or less than a specific number (e.g. less 6027 in Arkanoid).
- **Duplication**: Difficult and requires special hardware. Analog or Digital copiers can be used but, as usual, digital copier should be preferred whenever possible.
- **Preservation**: The preservation file should store information about the timing information.
- **Example**: Arkanoid , Indiana jones last crusade, Guntlet II, Garfield, speedball

5.3.3 Intra-Sector Bit-rate Variation

- **Description**: This is a more difficult to detect bit-rate variation. One sector of a track is divided into several parts and each of them is written with a "drive rotation speed" slightly above or below the normal speed. In practice this is actually not done by varying the drive rotation speed (not practical, inaccurate, and slow variation due to mechanical inertia), but by changing the FDC's bit-cell clock. By using faster and slower parts in the same sector it is possible to have the timing of these parts to compensate resulting in a sector with an overall normal length. The **Macrodos** protection from *Speedlock Associates* uses such sector: i.e. Track 1 Sector 1 of the Colorado disk is divided into 4 parts: normal-fast-slow-normal rotation speed. Another variant (apparently only used on IBM platform) is to continuously modulate the bit-cell width (for example with a sinusoidal signal) also resulting in a standard overall timing of the sector.
- **Creation**: Requires special hardware that has capability to vary the FDC clock on the fly, or the capability to directly control the bit cell width/position (e.g. the Discovery Cartridge).
- **Detection**: It is quite difficult to detect this protection because the overall sector length is usually kept to a "normal" length. It is therefore necessary to measure the timing of block of characters (usually multiple of 16) inside a sector and to compare it to standard block length to check for specific above or below patterns.
- **Duplication**: Of course it is impossible for the WD1772 FDC to copy this kind of sector and therefore special HW is required. Analog or digital copiers can be used but, as usual, digital copier should be preferred whenever possible.
- **Preservation**: The preservation file should store information about the timing information. It is only possible to store timing information about reading a 16 bytes block.
- **Example**: Damocles, Colorado, Starblade, Treasure Trap

5.4 Protections based on Track Alteration

These protections are based on alteration of a track resulting in “incorrect” results during reading. Sectors that contain these alterations are usually read with CRC error and possibly fuzzy bits.

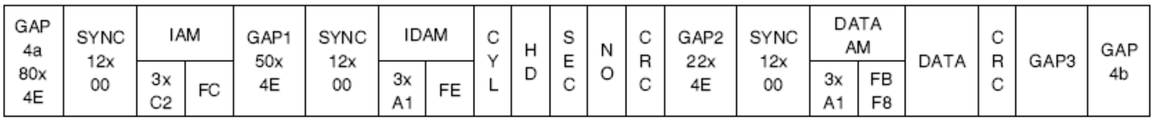
Actually these techniques should probably always result in Fuzzy Bits otherwise only having bad CRC would be too easy to reproduce?

5.4.1 Physical Alteration of Track

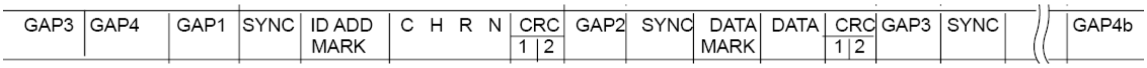
- **Description**: Obtained by physically altering a track: lots of techniques have been used ranging from disk scratching to careful evaporation of surface layer with an infrared laser. These techniques (like making a small hole in the diskette surface with a laser) have been largely used with IBM and APPLE2 5 ¼ diskettes but as far as I know they have not been used on Atari.
- **Creation**: Directly related to the defect and usually requires specific hardware.
- **Detection**: The physical defects produce default during reading (at least CRC error and possibly fuzzy bits). Note that the original defects cannot always be positioned exactly and detection should take this into account.
- **Duplication**: Normally not possible (although some people had developed expertise like in reproducing holes with a needle at the same exact disk location!), but approximation of equivalent defect can sometimes be created using CRC error and/or fuzzy bits.
- **Preservation**: Same as for Fuzzy sector.
- **Example**: None on Atari?

6 Atari Low-Level Formats

The Atari ST uses the Western Digital WD1772 Floppy Disc Controller (FDC) to access the 3 1/2 inch (or to be more precise 90mm) floppy diskettes. Western Digital recommends to use the **IBM 3740 Format** for Single Density diskette and to use the **IBM System 34** Format for Double Density diskette. Actually the default format used by the Atari TOS is slightly different (closer to the ISO Double Density Format) as it does not have an **IAM** byte (and associated the associated GAP), before the first **IDAM** sector of the track (see diagram below). However the WD1772 (and therefore the Atari) is capable of reading both format without problem but the reverse is usually not true (i.e. floppies created on PC can be read on Atari but floppies *formatted* on early Atari machines can't be read on PCs).

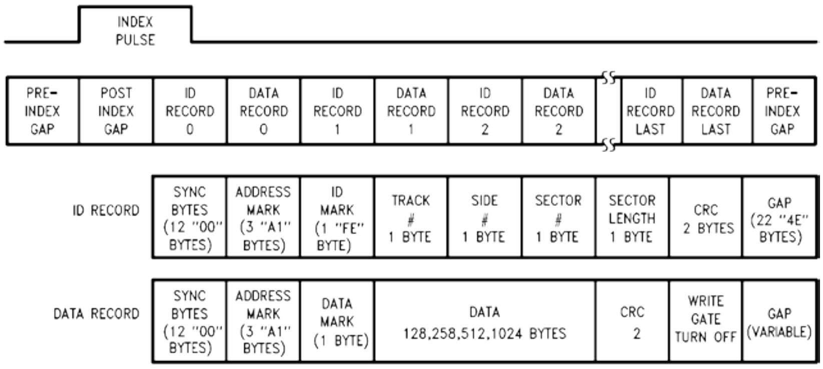


*IBM **System 34** Double Density Format (produced on a DOS machine formatting in 720K)*

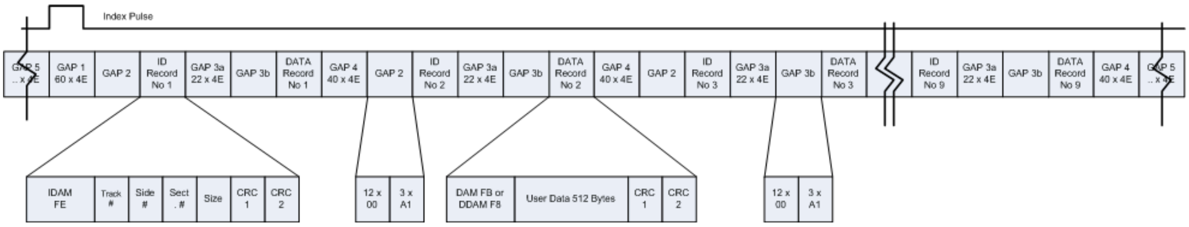


ISO Double Density Format.

Below is a detail description of the **Standard Atari Double Density Format** created by the early TOS.



Note: Many different conventions have been used to decompose and name the GAPS of a track. This document uses a GAP numbering scheme which is a combination of the IBM and ISO standards. It also decomposes the GAP between the ID record and the DATA record. Usually only one gap is described between these two records but in this document it is decomposed into a ID postamble gap (Gap 3a) and a DATA preamble gap (Gap 3b). This allows a more detail description, but of course they can be recombined into one more standard gap (Gap3). Although not shown in the diagram below a floppy formatted on an IBM has an extra IAM (index address mark) before the first sector. In that case the Gap1 is decomposed into two gaps: A post index gap (Gap1a) and a post IAM gap (Gap1b).



The table below indicates the standard values of the different gaps in the standard Atari diskette with 9 sectors of 512 user data bytes. It also indicates the minimum acceptable values (as specified in the WD1772 datasheet) of these gaps when formatting nonstandard diskettes.

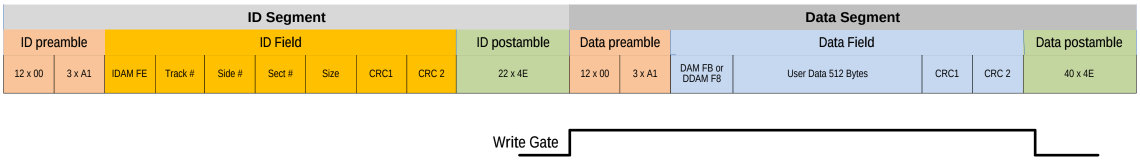
NAME	STANDARD VALUES (9 SECTORS)	MINIMUM VALUES (DATASHEET)
Gap 1 Index postamble	60 x $4E	32 x $4E
Gap 2 ID preamble	12 x $00 + 3 x $A1	8 x 00 + 3 x $A1
Gap 3a ID postamble	22 x $4E	22 x $4E
Gap 3b Data preamble	12 x $00 + 3 x $A1	12 x $00 + 3 x $A1
Gap 4 Data postamble	40 x $4E	24 x $4E
Gap 5 Index preamble	~ 664 x $4E	16 x $4E

Standard Sector Gaps Value (Gap 2 + Gap 3a + Gap 3b + Gap 4) = 92 Bytes / Sector
Minimum Sector Gaps Value (Gap 2 + Gap 3a + Gap 3b + Gap 4) = 72 Bytes / Sector
Standard Sector Length (Sector Gaps + ID + DATA) = 92 + 7 + 515 = 614 bytes

Note that the minimum values as specified in the WD1772 datasheet are not respected in the case of a track formatted with 11 sectors:
Minimum Sector Length (Sector Gaps + ID + DATA) = 72 + 7 + 515 = 594

The ID and DATA preamble are used to lock the PLL and should normally be kept as 12 $00 bytes. The FD format do not reserve a write splice byte (where the head write current is switched on or off) and therefore it should be considered as part of the data preamble field for format and write operations, and as part of the ID postamble for read operations.

One complete ID/DATA segment looks like this



As this format does not define any *write splice* field, it should be included as part of the DATA preamble field for ***format*** and ***write*** operations and as part of the ID postamble for read operations.

6.1 "Standard" 9-10-11 Sectors of 512 Bytes Format

Note that the 3 1/2 FD are spinning at 300 RPM which implies a 200 ms total track time. As the MFM cells have a length of 4 µsec this gives a total of 50000 cells and therefore about 6250 bytes per track. The table below indicates possible values of the gaps for tracks with 9, 10, and 11 sectors.

Name	9 Sectors: # bytes	10 Sectors: # bytes	11 Sectors: # bytes
Gap 1 Index postamble	60	60	10
Gap 2 ID preamble	12+3	12+3	3+3
Gap 3a ID postamble	22	22	22
Gap 3b Data preamble	12+3	12+3	12+3
Gap 4 Data postamble	40	40	1
Total Gap 2-4	92	92	44
Record Length	614	614	566
Gap 5 Index preamble	664	50	20
Total Track	6250	6250	6250

Respecting all the minimum value on an 11 sectors / track gives a length of:
L = Min Gap 1 + (11 x Min Record Length) + Min Gap 5 = 32 + 6534 + 16 = 6582
(which is about 332 bytes above max track length). Therefore we need to decrease each sector by about 32 bytes in order to be able to write such a track. For example the last column of the table above shows values as used by Superformat v2.2 program for 11 sectors/track (values analyzed with a Discovery Cartridge).

As you can see the track is formatted with a Gap 2 reduced to 6 and Gap 4 reduced to 1! These values do not respect the minimum specified by the WD1772 datasheet but they make sense as it is mandatory to let enough time to the FDC between the ID block and the corresponding DATA block which implies that Gap 3a & 3b should not be shortened. The reduction of Gap 4 & 2 to only 7 bytes between a Data Field and the next ID Field does not let enough time to the FDC to read the next sector on the fly but this is acceptable as this sector can be read on the next rotation of the FD.

This has an obviously impact on performance that can be minimized by using sectors interleaving. But it is somewhat dangerous to have such a short gap between the data and the next ID because the writing of a Data Field need to be perfectly calibrated or it will collide with the next ID block. This is why such a track is usually reported as “read only” (as in DC documentation) and is sometimes used as a protection mechanism.
Of course you have more chance to successfully write 11 sectors on the first track (the outer one) than on the last track (the inner one) as the bit density gets higher in the latter case. It is also important to have a floppy drive that have a stable and minimum rotation speed deviation (i.e. RPM should not be more than 1% above).

6.2 “Standard” 128-256-512-1024 Bytes / Sector Format

The table below indicates standard (i.e. classical) gaps values for tracks with sectors of size of 128, 256, 512, and 1024.

Name	29 sectors of 128 bytes	18 sectors of 256 bytes	9 Sectors of 512 bytes	5 Sectors of 1024 bytes
Gap 1 Index postamble	40	42	60	60
Gap 2 ID preamble	10+3	11+3	12+3	40+3
Gap 3a ID postamble	22	22	22	22
Gap 3b Data preamble	12+3	12+3	12+3	12+3
Gap 4 Data postamble	25	26	40	40
Total Gap 2-4	75	77	92	120
Record Length	213	343	614	1154
Gap 5 preamble	73	76	664	480
Total Track	6250	6250	6250	6250

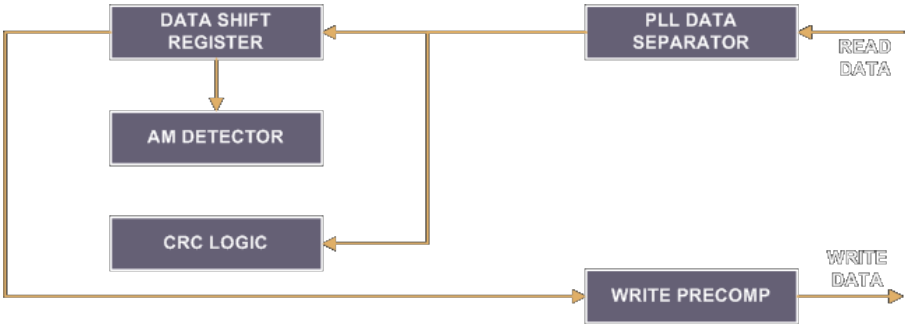
7 WD1772 Floppy Disk Controller

For a complete description please refer to the WD1772 Datasheet. Here we only present some information of interest in understanding the behavior of the FDC in the context of certain fuzzy-bits and long/short bytes.

7.1 WD1772 DPLL Input Circuitry

This section provides basic information on the DPLL of the WD1772 and how the decoded bits are entered into the FDC shift register. It does not describe the *data separator* which is based on usage of an AM (Address Marks) detector to find a specific pattern in the shift register (usually during gaps) as it is pretty simple to understand and not useful in the context of this document.

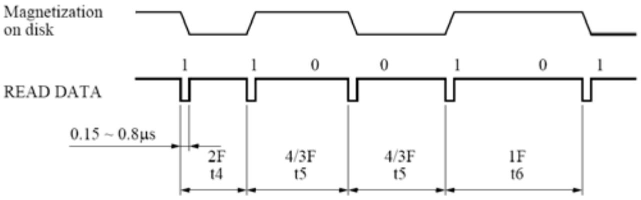
This is a simplified block diagram of the input circuitry of the FDC:



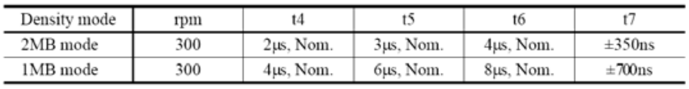
The WD1772 uses a digital phase lock loop (DPLL) circuit for reading the input data transmitted from FD media. Inspection windows are established that have duration proportional to the frequency of arrival of the data, and **start/stop times** that can be adjusted so that subsequent data bits will be received in the **middle** of the inspection windows. To achieve this, the DPLL circuitry applies ***frequency*** and ***phase*** corrections that compensate the input data frequency drift. This drifts are usually due to unsteadiness of the motor drive speed (the frequency drift), and the migrations of the magnetic reversals area (the phase drift). The DPLL used inside the WD1772, as well as many other FDC build in the 80s, implements an algorithm described in the public US patent 4,870,844. The patent is rather complex and in this section I will only highlight some of the most important aspects of the DPLL algorithm that are useful to understand the behavior in the context of fuzzy bits, long/short track, etc.

If you want to fully understand the behavior of the DPLL please refer to the patent. Note that in order to provide precise results my ***Analyze***, ***KFAnalyze***, and ***KFPanzer*** programs ***fully implement the DPLL algorithm as described in the patent***.

Let's first look at typical MFM data encoding:



Note : READ DATA pulse will be detected within t7 from is nominal position. (When PLL separator is used with recommended write pre-compensation.)



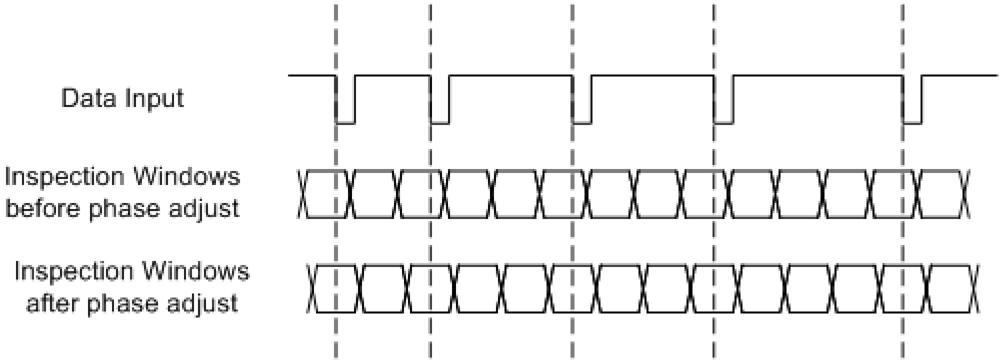
Density mode	rpm	t4	t5	t6	t7
2MB mode	300	2µs, Nom.	3µs, Nom.	4µs, Nom.	±350ns
1MB mode	300	4µs, Nom.	6µs, Nom.	8µs, Nom.	±700ns

As we can see the **nominal values** for the possible reversals spacing in **DD MFM** (1MB mode) are: 4µs, 6µs, or 8µs.

The data input circuit of the FDC ensures that the data pulses received are converted into data bits and stored in the **data shift register (DSR)**. For that matter the digital phase lock loop defines *inspection windows* that repeat every 2µs (a half cell size). A one is input to the shift register if a data pulse is received at any time during one inspection windows; otherwise a zero is stored in the shift register as the value for the current bit.

The period of the inspection windows is gradually adjusted (expanded or shortened) to compensate an eventual frequency shift affecting the input data transfer. This frequency correction is computed based on the **history** of the location (relative to the inspection window) of the **last three** flux reversals.

Ideally, individual pulses should be located in the middle of the inspection windows. To achieve this, the start and stop times of the inspection windows are adjusted to compensate for deviation (from ideal) in time of arrival of the most recently detected data pulse. This phase correction is done proportionally to the distance of the reversals with the middle of the inspection window.


Data Input
Inspection Windows before phase adjust
Inspection Windows after phase adjust

The proper ratio of phase and frequency correction provided in the loop is carefully balanced so that the DPLL is **fast settling** but **stable**. A large amount of phase correction cause the loop to settle faster but also make it more sensible to noise. On the other hand if too much frequency correction is used, the loop can become unstable.

It is interesting to note that the DPLL as defined in the patent allow an input frequency variation of up to **9%**. This corroborates the actual measurement made with a WD1772 that correctly interprets bits with a variation of at least 9 to 10 % for DD MFM (and about 100% for SD FM!). Note that these values are well above the variation used by the **Copylock** and **Macrodos** protection mechanisms (usually less than 5%) and therefore the data within this kind of sector should be read correctly.

7.2 WD1772 Detection of Fuzzy Bits

With the above information it is now easy to understand that if a bit reversals happens close to the border of an inspection window (also called Ambiguous area) it will be detected into the first or the next inspection window based on small variation of the drive rotation speed between two ***read-sector*** commands and this will therefore result in pseudo random values returned (fuzzy bits).

For example having a reversal 5µs apart from the previous one can be interpreted as a reversal after 4µs or a reversal after 6µs based on small frequency fluctuation of the rotation speed between two reads. One might argue that it is not possible to make sure that these “marginal reversals” will be positioned correctly due to the fact that the rotation’s speeds of different drives are somewhat different and therefore precise reversals timing on a floppy diskette cannot be guaranteed. But in practice this is where the frequency and phase correction of the WD1772 DPLL comes into play. As explained above the inspection window will have it size (i.e. frequency) and position **corrected** based on the input reversals stream after reception of only a few reversals. Therefore the DPLL of the FDC automatically adjust the frequency of inspection windows for any acceptable (about 10%) variation of drive speed and adjust the phase so that a “normal reversal” will be perfectly in the middle of the inspection window and a “marginal reversal” will be perfectly at the border of the inspection window.

This also explains why, in most cases, “fuzzy bits” are used in “compensating pair”: for every two subsequent fuzzy bits the first reversal is placed at one extreme (e.g. at the beginning) of the inspection window and the “compensating reversals” of the next fuzzy bit at the other extreme (e.g. at the end) of the inspection window. By using this kind of “compensating bits” we guarantee that the frequency and the phase of the inspection windows are (almost) not affected.

8 Analysis of Games/Programs

This section provides detailed analyses of some programs/games using key disk protection. The analyses have been done with the goal to illustrate the usage of the protections described in this document.

However it must be noted that:
- The presence of a described protection mechanism does not imply that it is actually used.
- It is possible that for one game analyzed more protections than the one described exist.
- Beware that several releases of one game may exist with different protections.
- Only Original diskettes have been used (unless specifically noted). However it is difficult to know for sure that a diskette has not been tampered.

In most cases the detection of protections has been performed using the "automatic mode" of the ***Panzer*** / ***KFPanzer*** programs. However whenever a protection or a strange behavior has been detected further analysis has been performed specially with the ***Analyze*** / ***KFAnalyze*** programs working at flux reversals level.

8.1 Dungeon Master (FTL Inc.)

For detail analysis of the Dungeon Master & Lost Scroll protection please refer to the DM Protection document, the detailed analysis of the Dungeon Master and Chaos Strikes Back for Atari ST Floppy Disks and the US patent "Copy Protection for computer Disc 4,849,836")

The game "Dungeon Master" uses the following protection mechanisms:

- ✶ Invalid Sector Number: Track 0 the sector 8 is numbered 247.
- ✶ Fuzzy bits & Sector with bad *Data*: Track 0 sector 7 the *Data Field* has bits in Ambiguous areas resulting in a fuzzy sector with CRC error.

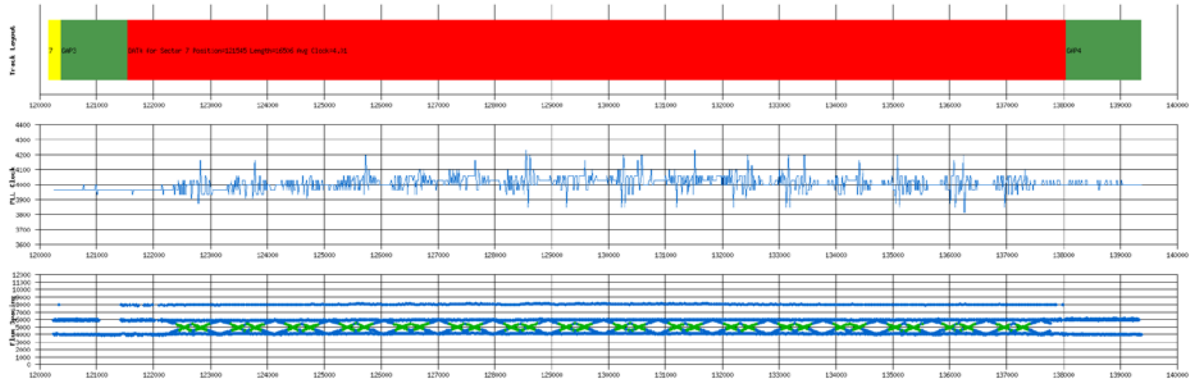
Here is the Layout of track 0 as analyzed by the ***KFAnalyze*** program

```
****************************************************************************
Track Layout Information: 6258 Bytes - length=199.981 ms
ID Good/Bad=10/0 - Data Good/Bad=9/1 - Synch Good/Bad =20/0
****************************************************************************

GAP1 56 bytes length=1818.28 us
-----------+------------------+-----------+---------------------------+------------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt   Lgt   |Sct Pos    Lgt CRC|Bt  Lgt  BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt   BS
-----------+------------------+-----------+---------------------------+------------
15   458   |1   2276   223 OK |37  1179  0|515  16433 OK  0   0   3.99|41  1307   0
15   478   |2   21899  223 OK |37  1179  0|515  16493 OK  0   0   4.00|41  1308   0
15   477   |3   41581  222 OK |37  1177  0|515  16452 OK  0   0   3.99|41  1305   0
15   477   |4   61217  222 OK |37  1174  0|515  16392 OK  0   0   3.98|41  1302   0
15   475   |5   80785  222 OK |37  1171  0|515  16451 OK  0   0   3.99|41  1313   0
15   480   |6   100425 224 OK |37  1186  0|515  16525 OK  0   0   4.01|41  1308   0
15   477   |7   120148 222 OK |37  1174  0|515  16506 BAD 0   495 4.01|41  1313   0
15   479   |247 139845 223 OK |37  1179  0|515  16410 OK  0   0   3.98|41  1304   0
15   476   |9   159441 222 OK |37  1173  0|515  16418 OK  0   0   3.98|41  1311   0
15   480   |10  179047 223 OK |37  1181  0|515  16536 OK  0   0   4.01|93  2991   0
-----------+------------------+-----------+---------------------------+------------
```

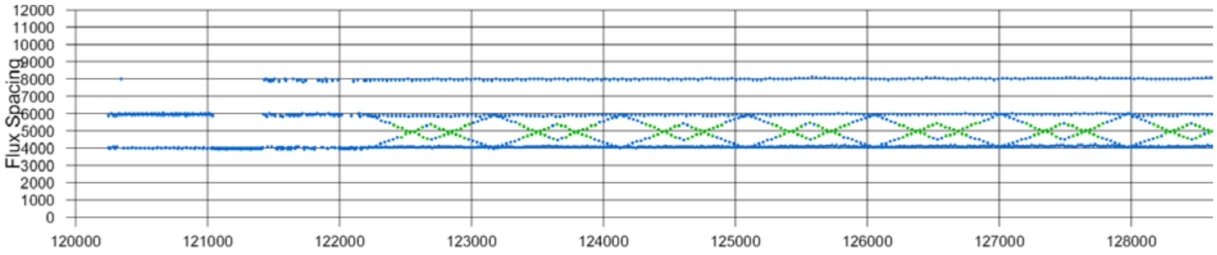
As you can see in sector 7 we have a lot of **border bits** (BRD) aka bits in Ambiguous area. Looking at the content of this sector we can see that the clock period range from 3938 ns to 4031 ns with an overall clock period of 4.01 µs

```
Detail buffer content for sector 7 with 515 bytes
= DATA ID=7 515 bytes @121545 us length=16506.79 CRC BAD CLK=4.01 TMV=0 BRD=495 DOI=0
  *** Fuzzy Sector *** starting at byte position 34
  0000 121545 3968  fb 07 50 41 43 45 2f 46 42 09 53 65 72 69 ca 08  ..PACE/FB.Seri..
  0010 122055 3968  00 00 ef e9 01 68 68 68 68 68 68 68 68 68 68 68  .....hhhhhhhhhhh
  0020 122565 3938  68 68 68 e8 e8 e8 e8 e8 e8 68 68 68 68 68 68 68  hhh......hhhhhhh
  0030 123073 3968  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  0040 123583 4031  68 e8 e8 e8 e8 e8 68 68 68 68 68 68 68 68 68 68  h.....hhhhhhhhhh
  0050 124092 3968  68 68 68 68 68 68 68 68 68 68 68 68 68 68 e8 e8  hhhhhhhhhhhhhh..
  0060 124604 4000  e8 e8 e8 e8 68 68 68 68 68 68 68 68 68 68 68 68  ....hhhhhhhhhhhh
  0070 125114 4000  68 68 68 68 68 68 68 68 68 68 68 68 e8 e8 e8 e8  hhhhhhhhhhhh....
  0080 125628 3968  e8 e8 e8 68 68 68 68 68 68 68 68 68 68 68 68 68  ...hhhhhhhhhhhhh
  0090 126141 4000  68 68 68 68 68 68 68 68 68 68 e8 68 e8 e8 e8 68  hhhhhhhhhh.h...h
  00a0 126654 4031  e8 e8 68 68 68 68 68 68 68 68 68 68 68 68 68 68  ..hhhhhhhhhhhhhh
  00b0 127168 4031  68 68 68 68 68 68 68 68 e8 e8 e8 e8 e8 68 68 68  hhhhhhhh.....hhh
  00c0 127683 3968  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  00d0 128197 3938  68 68 68 68 68 68 68 e8 e8 e8 e8 e8 28 68 68 68  hhhhhhh.....(hhh
  00e0 128710 4000  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  00f0 129226 4063  68 68 68 68 68 68 e8 e8 e8 e8 68 68 68 68 68 68  hhhhhh....hhhhhh
  0100 129741 4031  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  0110 130257 4162  68 68 e8 e8 e8 e8 e8 68 68 68 68 68 68 68 68 68  hh.....hhhhhhhhh
  0120 130771 4000  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 e8  hhhhhhhhhhhhhhh.
  0130 131288 3938  68 e8 e8 e8 e8 e8 e8 68 68 68 68 68 68 68 68 68  h......hhhhhhhhh
  0140 131802 4000  68 68 68 68 68 68 68 68 68 68 68 68 68 e8 e8 68  hhhhhhhhhhhhh..h
  0150 132319 4063  e8 e8 e8 68 e8 68 68 68 68 68 68 68 68 68 68 68  ...h.hhhhhhhhhhh
  0160 132831 4000  68 68 68 68 68 68 68 68 68 68 68 68 e8 e8 e8 e8  hhhhhhhhhhhh....
  0170 133346 3938  e8 e8 e8 68 68 68 68 68 68 68 68 68 68 68 68 68  ...hhhhhhhhhhhhh
  0180 133858 4031  68 68 68 68 68 68 68 68 e8 68 e8 e8 e8 e8 e8 68  hhhhhhhh.h.....h
  0190 134371 4063  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  01a0 134882 4000  68 68 68 68 68 68 e8 68 68 e8 e8 e8 e8 e8 68 68  hhhhhh.hh.....hh
  01b0 135395 4063  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  01c0 135906 4063  68 68 68 68 68 68 68 e8 e8 e8 e8 68 e8 e8 68 68  hhhhhhh....h..hh
  01d0 136418 3968  68 68 68 68 68 68 68 68 68 68 68 68 68 68 68 68  hhhhhhhhhhhhhhhh
  01e0 136931 4000  68 68 68 68 e8 68 e8 e8 e8 e8 68 68 68 68 68 68  hhhh.h....hhhhhh
  01f0 137443 4000  68 68 68 68 68 68 68 68 68 68 68 68 68 68 ac 46  hhhhhhhhhhhhhh.F
  0200 137956 4000  42 3a f8                                         B:.
```

To get a more detailed vision of the sector with the fuzzy bits we use the plot capability of KFAnalyze:



We can see that the flux reversals spacing follow a strange pattern and includes a lot of "border bits" shown as green dots. Let's zoom to the flux spacing line at the beginning of the sector:



Here we can see that the beginning of the sector has normal timing. But after the position 122000 we have the bit reversals gradually sliding to the border of the inspection window (close to 5000 ns). We can see that we have a pattern that looks like a sine wave and this implies that many bits are at the border of the inspection window (shown as **green** dots).

As explained in the WD1772 DPLL Input Circuitry, having reversals at the border of the inspection windows will result in random value latched by the DPLL data separator and therefore these bits can be considered as **Fuzzy Bits**. Reading this sector several times will results in different values returned due to the floppy disk rotation speed fluctuations.

8.2 D50 Editor (DrT)

The D50 Sound Module Editor program from DrT uses the following protection mechanisms:

- Fuzzy bits: Track 0 sector 10 has fuzzy bits in the *Data Field*.
- Timing violations: Track 0 sector 10 has many timing violations in the *Data Field* as well as many border bits (bits in Ambiguous area).

Here is the Layout of track 0 as analyzed by the ***KFAnalyze*** program:

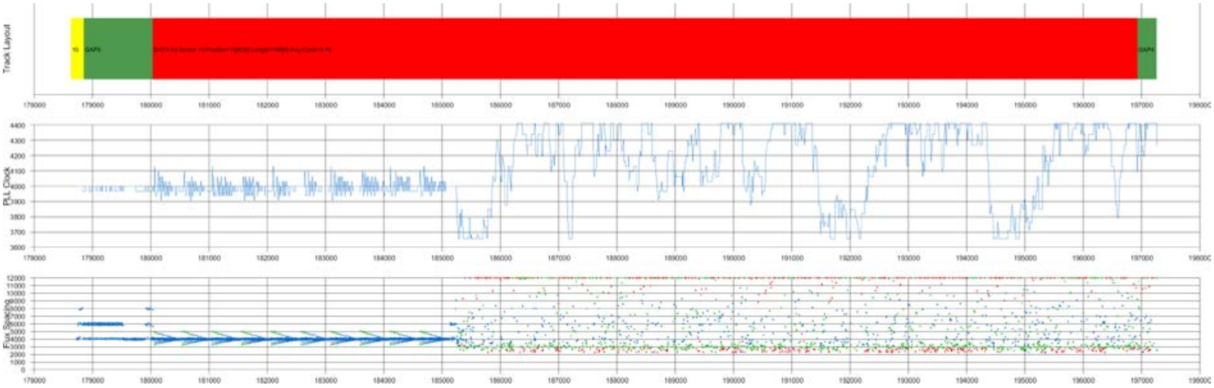
```
****************************************************************************
Track Layout Information: 6249 Bytes - length=199.976 ms
ID Good/Bad=10/0 - Data Good/Bad=9/1 - Synch Good/Bad =20/0
****************************************************************************

GAP1 5 bytes length=199.85 us
-----------+------------------+-----------+---------------------------+------------
GAP2       |ID                 |GAP3       |DATA                       |GAP4
Bt   Lgt   |Sct Pos    Lgt CRC|Bt  Lgt   BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt    BS
-----------+------------------+-----------+---------------------------+------------
117  3724  |1   3924    223 OK |37  1179   0|515  16387 OK  0   0   3.98|35  1111   0
15   477   |2   23304   223 OK |38  1210   0|515  16442 OK  0   1   3.99|33  1048   0
15   465   |3   42694   222 OK |37  1177   0|515  16413 OK  0   0   3.98|35  1112   0
15   476   |4   62096   222 OK |37  1176   0|515  16410 OK  0   0   3.98|35  1112   0
15   476   |5   81496   222 OK |37  1175   0|515  16425 OK  0   0   3.99|35  1114   0
15   477   |6   100911 222 OK |37  1175   0|515  16414 OK  0   0   3.98|35  1115   0
15   477   |7   120316 222 OK |38  1202   0|515  16453 OK  0   0   3.99|34  1086   0
15   470   |8   139751 223 OK |37  1177   0|515  16447 OK  0   0   3.99|35  1119   0
15   478   |9   159197 223 OK |37  1177   0|515  16431 OK  0   0   3.99|35  1118   0
15   479   |10  178628 223 OK |37  1178   0|515  16895 BAD 849 815 4.10|88  3050   0
-----------+------------------+-----------+---------------------------+------------
```

We can see that sector 10 has a lot of border bits and a lot of timing violations. To better understand let's look at a dump of the data track 10.

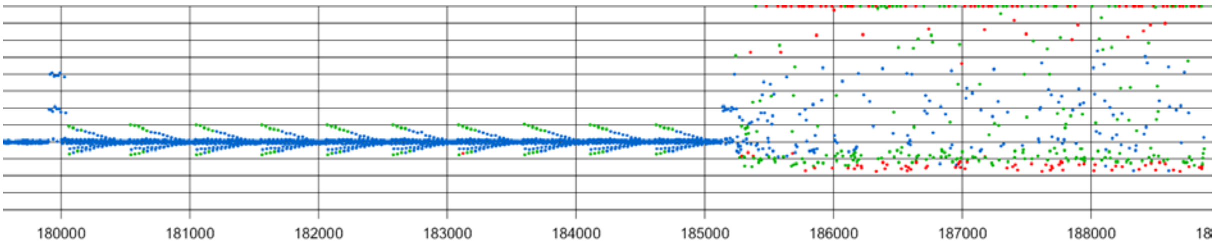
```
Detail buffer content for sector 10 with 515 bytes
= DATA ID=10 515 bytes @180030 us length=16895.59 CRC BAD CLK=4.10 TMV=849 BRD=815 DOI=0
  *** Fuzzy Sector *** starting at byte position 80
  0000 180030 4000  fb 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0010 180542 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0020 181052 4129  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0030 181561 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0040 182071 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0050 182580 4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0060 183091 4129  00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0070 183598 3968  01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0080 184112 4129  00 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0090 184624 4096  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00a0 185138 4000  00 90 40 85 5f a2 f3 d2 13 83 31 82 30 00 18 18  ..@._.....1.0...
  00b0 185612 3683  41 41 00 ad c0 40 14 00 37 1e 05 05 00 82 80 40  AA...@..7......@
  00c0 186112 3878  41 0c 90 90 47 11 00 26 1a 24 20 d0 10 c0 a4 53  A...G..&.$ ....S
  00d0 186659 4338  39 40 0d 12 40 01 40 83 dc 35 32 12 00 84 08 60  9@..@.@..52....`
  00e0 187203 3657  60 61 44 20 c0 14 02 22 03 10 01 20 02 20 4a d4  `aD ..."... . J.
  00f0 187742 4338  8f 4b 6e 46 21 94 85 d8 05 40 20 10 04 91 80 68  .KnF!....@ ....h
  0100 188288 4129  09 18 00 08 60 d2 22 33 40 92 12 22 02 c5 1a c4  ....`."3@.."....
  0110 188839 3968  21 00 00 00 00 c0 c4 24 44 08 93 11 d5 0e 5c 10  !......$D.....\.
  0120 189349 4376  01 54 4a 21 54 04 cd 60 60 c0 14 6c 01 0b a5 4a  .TJ!T..``..l...J
  0130 189888 4413  28 84 8c 29 05 d0 70 19 58 c2 18 f0 ee 1b 97 04  (..)..p.X.......
  0140 190428 4063  70 00 11 0e 93 84 00 98 b1 b1 8c 4f 50 c1 08 82  p..........OP...
  0150 190977 4413  87 01 25 59 08 6c 4c 11 0e c2 43 20 a7 00 50 87  ..%Y.lL...C ..P.
  0160 191523 3820  65 62 00 00 cf 80 26 40 41 41 82 00 87 02 08 40  eb....&@AA.....@
  0170 192008 3849  04 04 00 00 16 06 02 00 01 35 fc 26 41 38 4b 10  .........5.&A8K.
  0180 192521 4266  10 40 00 00 b2 2d d8 ce 50 94 52 0f 00 c3 75 b0  .@...-..P.R...u.
  0190 193119 4413  b0 00 21 01 a8 0b 83 03 03 25 15 0b 44 a1 00 90  ..!......%..D...
  01a0 193631 4413  42 10 42 a5 c4 74 3b a0 a7 36 1c 00 e8 15 01 10  B.B..t;..6......
  01b0 194241 4266  10 00 13 00 64 c5 90 26 05 c0 8c a0 10 04 1f 06  ....d..&........
  01c0 194697 3657  40 40 00 8a 01 30 20 23 06 b0 8b 7d 80 0a ac 26  @@...0 #...}...&
  01d0 195177 3878  02 0a 1e 00 ca 8a f0 29 80 83 20 02 eb d8 86 84  .......).. .....
  01e0 195729 4413  90 10 80 0a 04 09 09 04 42 00 18 30 d0 43 44 76  ........B..0.CDv
  01f0 196275 4413  08 34 49 8c 28 02 00 90 32 04 48 80 00 c4 0a 03  .4I.(...2.H.....
  0200 196819 4413  2a 21 1c                                         *!.
```

As you can see the track looks normal. However we can already notice that the clock ranges from 3.6 µs to 4.4 µs. This is a **wide** variation (about 8%) which goes far beyond normal fluctuation. We should also note that the sector has fuzzy bytes starting at position 80.

To get a more detailed vision of the sector 10 with fuzzy bits we use the plot capability of the program:



As we can see that the sector has a lot of timing violation in the flux reversals (bits less than 4µs or more than 8µs apart) as well as a lot of border bits (in the 3000 and 5000 regions). It is also interesting to note that the overall length of the track (16585 µs) is about the same as a normal track (16437 µs) and this indicates that the different timing violations “compensate”. Let’s zoom in the flux spacing line:



Here we can see that after the position 180000 we have a strange pattern with a lot of border bits (shown in green). After the position 185000 we can see that we have random flux reversals. This pattern is typical of an unformatted track. Therefore we can conclude that the formatting of the track is stopped after about one third of the last sector. This is obviously not feasible with the WD1772 FDC and on top of that it is also not possible to write random flux reversals with the FDC. Therefore to copy this track it is necessary to have special hardware device like Discovery Cartridge or KryoFlux board.

Note that random flux reversals result into unpredictable clock frequency (and also unpredictable inspection windows position) of the DPLL. This and the presence of border bits results in fuzzy bytes in the sector.

8.3 Populous (Electronic Arts)

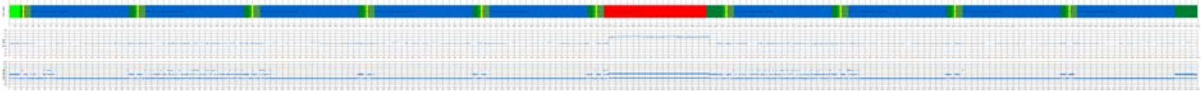
Populous from Electronic Arts uses the following protection mechanisms:

- Timing violations: Track 0 sector 6 has timing violation in the *Data Field*.
- Long Sector: Track 0 sector 6 is has a “long data sector” of 17206µs which is about 4.2% above a normal sector of 16502µs.

Here is the Layout of track 0 as analyzed by the ***KFAnalyse*** program:

```
****************************************************************************
Track Layout Information: 6240 Bytes - length=199.98 ms
ID Good/Bad=10/0 - Data Good/Bad=9/1 - Synch Good/Bad =20/0
****************************************************************************

GAP1 56 bytes length=1815.49 us
-----------+------------------+-----------+--------------------------+------------
GAP2       |ID                |GAP3       |DATA                      |GAP4
Bt   Lgt   |Sct Pos    Lgt CRC|Bt  Lgt  BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt   BS
-----------+------------------+-----------+--------------------------+------------
15   458   |1   2273   223 OK |37  1178  0|515  16443 OK  0   0   3.99|30  955    0
15   477   |2   21552  222 OK |37  1176  0|515  16447 OK  0   0   3.99|30  957    0
15   478   |3   40835  223 OK |37  1178  0|515  16456 OK  0   0   3.99|30  956    0
15   477   |4   60128  223 OK |37  1175  0|515  16454 OK  0   0   3.99|30  960    0
15   479   |5   79421  223 OK |37  1177  0|515  16446 OK  0   0   3.99|30  958    0
15   479   |6   98707  223 OK |37  1178  0|515  17209 BAD 1   0   4.18|87  2799   0
15   481   |7   120600 222 OK |37  1174  0|515  16418 OK  0   0   3.98|30  955    0
15   477   |8   139849 222 OK |37  1174  0|515  16418 OK  0   0   3.98|30  958    0
15   478   |9   159102 223 OK |37  1176  0|515  16426 OK  0   0   3.99|30  957    0
15   479   |10  178365 223 OK |37  1178  0|515  16446 OK  0   0   3.99|117 3766   0
-----------+------------------+-----------+--------------------------+------------
```

Here we can see that sector 6 length is equal to 17209 µs which is about 4.4% above a normal 16480 µs *Data Field.* The average clock period for the sector is 4.18 µs instead of 4 µs. This is confirmed by the following plot (difficult to read without zoom) that shows that the clock is raised in sector 6 and that this sector reads with a CRC error.

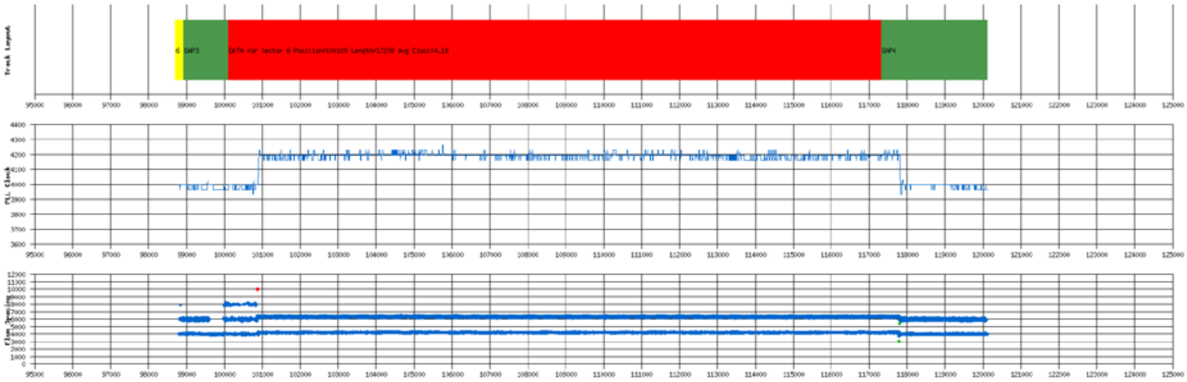


To better understand the timing violations detected by the program let’s first look at a dump of the data track 6

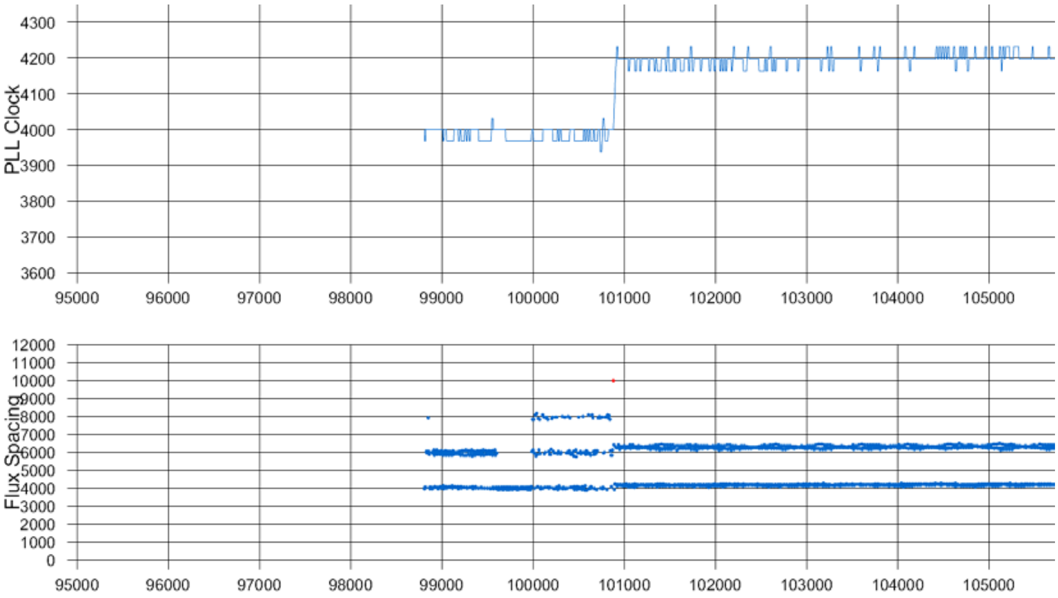
```
Detail buffer content for sector 6 with 515 bytes
= DATA ID=6 515 bytes @100109 us length=17209.96 CRC BAD CLK=4.18 TMV=1 BRD=0 DOI=0
  0000 100109 4000  fb 45 6c 65 63 74 72 6f 6e 69 63 20 41 72 74 73  .Electronic Arts
  0010 100621 4000  2e 3a 9c 8a ad b8 ab 55 32 3c 82 79 04 f2 09 e4  .:.....U2<.y....
  0020 101141 4196  13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13  ..'.O .A<.y.....
  0030 101678 4196  c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8  .'.O .A<.y......
  0040 102211 4196  27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27  '.O .A<.y......'
  0050 102749 4196  90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90  .O .A<.y......'.
  0060 103283 4162  4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f  O .A<.y......'.O
  0070 103824 4196  20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20   .A<.y......'.O
  0080 104359 4196  9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e  .A<.y......'.O .
  0090 104894 4196  41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41  A<.y......'.O .A
  00a0 105437 4196  3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c  <.y......'.O .A<
  00b0 105972 4196  82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82  .y......'.O .A<.
  00c0 106506 4196  79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79  y......'.O .A<.y
  00d0 107047 4196  04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04  ......'.O .A<.y.
  00e0 107580 4196  f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2  .....'.O .A<.y..
  00f0 108113 4231  09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09  ....'.O .A<.y...
  0100 108651 4196  e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4  ...'.O .A<.y....
  0110 109184 4196  13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13  ..'.O .A<.y.....
  0120 109722 4196  c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8  .'.O .A<.y......
  0130 110255 4231  27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27  '.O .A<.y......'
  0140 110793 4162  90 4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90  .O .A<.y......'.
  0150 111328 4196  4f 20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f  O .A<.y......'.O
  0160 111869 4231  20 9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20   .A<.y......'.O
  0170 112403 4196  9e 41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e  .A<.y......'.O .
  0180 112937 4196  41 3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41  A<.y......'.O .A
  0190 113476 4196  3c 82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c  <.y......'.O .A<
  01a0 114008 4196  82 79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82  .y......'.O .A<.
  01b0 114541 4231  79 04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79  y......'.O .A<.y
  01c0 115079 4196  04 f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04  ......'.O .A<.y.
  01d0 115612 4162  f2 09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2  .....'.O .A<.y..
  01e0 116145 4196  09 e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09  ....'.O .A<.y...
  01f0 116683 4196  e4 13 c8 27 90 4f 20 9e 41 3c 82 79 04 f2 09 e4  ...'.O .A<.y....
  0200 117216 4196  13 c8 27                                         ..'
```

As we can see the data looks normal with a repeating pattern. However we can observe that if the bit cell width starts at the normal 4.0µs, and stay to this value for the first few bytes, it then quickly changes to 4.2µs (+5%) and stay at this value for the rest of the sector. This is a clear indication of a long track which is confirmed by an overall *Data Field* length of 17209 µs.

We can now look at a plot of sector 6:



We can see that at the beginning of the sector the clock is normal then it rises to 4.2 µs until the end of the sector



Confirmation of the Rob Northen Computing protection is found in sector 1:

```
Detail buffer content for sector 1 with 515 bytes
= DATA ID=1 515 bytes @3675 us length=16443.88 CRC OK CLK=3.99 TMV=0 BRD=0 DOI=0
  0000 3675   4000  fb 00 00 00 00 00 00 00 00 6d 19 9f 00 02 02 01  .........m......
  0010 4189   3968  00 02 70 00 20 03 00 05 00 0a 00 01 00 00 00 00  ..p. ...........
  0020 4700   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0030 5213   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0040 5725   4000  00 50 72 6f 74 65 63 74 69 6f 6e 20 28 43 29 31  .Protection (C)1
  0050 6235   4000  39 38 38 20 52 6f 62 20 4e 6f 72 74 68 65 6e 20  988 Rob Northen
  0060 6746   4000  43 6f 6d 70 75 74 69 6e 67 2e 20 41 6c 6c 20 52  Computing. All R
  0070 7258   4000  69 67 68 74 73 20 52 65 73 65 72 76 65 64 2e 00  ights Reserved..
  0080 7771   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0090 8282   3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00a0 8793   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00b0 9304   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00c0 9816   4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00d0 10327  3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  00e0 10839  4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
```

8.4 Theme Park Mystery (Image Works)

Theme Park Mystery from Image Works uses the following protection mechanisms:

- Number Of Sectors: **12** sectors per track on all tracks!
- Fuzzy Sectors on all tracks
- Sectors with bad *Data Field*s on all tracks
- Sector Within Sector on all tracks
- Data Over Index on all tracks
- No flux reversals area

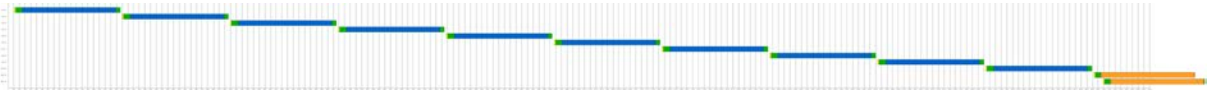
We are going to describe mainly the Sector Within Sector protection used on every track.

Here is a dump of the end of track 1 (sector 11):

```
+ GAP2 11 bytes @189917 us length=347.72 us - TMV=0 BRD=0
  1754 189917 3908  ff ff ff ff ff ff ff fc a1 a1 a1                 ...........
= ID=11 7 bytes @190265 length=224.00 T=0 H=0 S=11 Z=512 CRC=25a4 OK TMV=0 BRD=0 BS=0
  175f 190265 3908  fe 00 00 0b 02 25 a4                             .....%.
+ GAP3 31 bytes @190489 us length=990.74 us - TMV=0 BRD=0 BS=0 IDG=0
  1766 190489 4000  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  1776 191001 3968  4e 4e 4e 4e 4e 4e 00 00 00 00 00 00 a1 a1 a1     NNNNNN.........
= DATA ID=11 266 bytes @191480 us length=8491.81 us - CRC=0000 *** BAD *** - TMV=2 BRD=1 BS=0
  1785 191480 4000  fb 00 00 00 00 00 00 00 00 a1 a1 a1 fe 00 00 0c  ................
  1795 191996 4000  02 bc 33 4e 4e 4e 4e 4e 4e 4e 4e d9 23 76 c5 e6  ..3NNNNNNNN.#v..
  17a5 192504 4000  d3 31 b2 4e 4e 4e 4e 4e 4e 4e 4e ff ff ff ff ff  .1.NNNNNNNN.....
  17b5 193017 4000  fe a1 a1 a1 fb 00 00 00 00 00 00 00 00 00 00 00  ................
  17c5 193526 4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  17d5 194036 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

Inside the data block of the sector 11 we have a synch sequence of 3 $A1 followed by an IDAM followed by the *ID Field* for sector 12. Then we have a GAP3 followed by a synch sequence followed by a DAM and the *Data Field*.

This can be seen graphically by using the all sector plot capability of ***KFAnalyzer***.



Here we clearly see that:

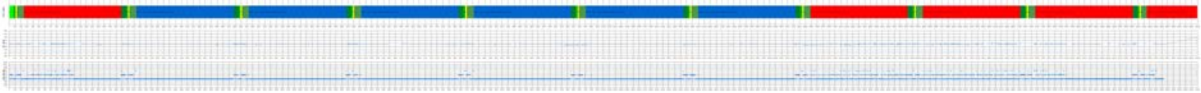
- Sector 10 is normal.
- Sector 11 has a DATA Field wrapping at the beginning of the track (DOI) is read with a CRC error (SBD) and fuzzy bits, ant it contains sector 12 (SWS).
- Sector 12 has DATA field starting inside sector 11 and wraps at the beginning of the track (DOI) it is also read with a CRC error (SBD) and fuzzy bits.

We can also look at all sectors layout information:

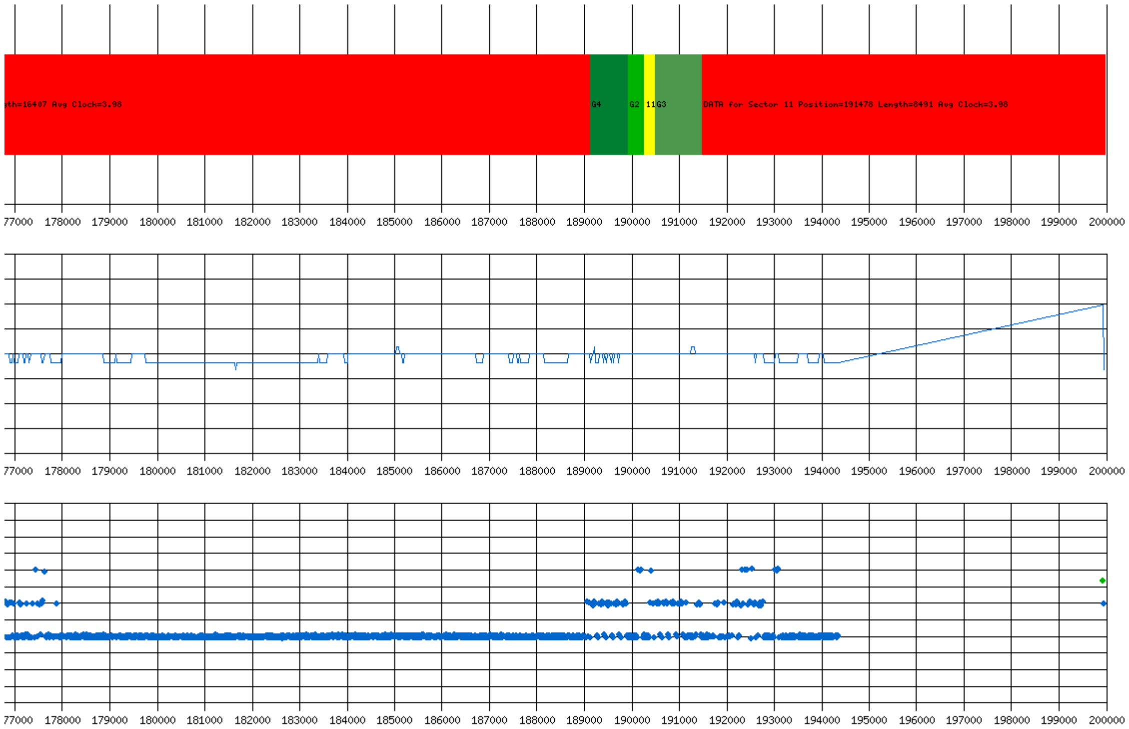
```
All Sectors Layout Information:
------------------+-------+-------------------------------------------+-------
ID                |GAP3   |DATA                                       |GAP4
Sct Pos    Lgt CRC|Bt Lgt |Bt   Pos    Lgt   CRC TMV BRD Clk  DOI  FZP |Bt Lgt
------------------+-------+-------------------------------------------+-------
1   1090    223 OK |37 1177|515  2490    16424 OK  0   0   3.99 0    0    |24 764
2   20030   222 OK |37 1175|515  21428   16399 OK  0   0   3.98 0    0    |24 764
3   38943   223 OK |37 1174|515  40340   16398 OK  0   0   3.98 0    0    |24 764
4   57855   223 OK |37 1179|515  59257   16422 OK  0   0   3.99 0    0    |24 762
5   76792   222 OK |37 1177|515  78193   16394 OK  0   0   3.98 0    0    |24 759
6   95695   221 OK |37 1171|515  97088   16392 OK  0   0   3.98 0    0    |24 762
7   114592 222 OK |37 1173|515  115987 16387 OK  0   0   3.98 0    0    |24 763
8   133487 222 OK |37 1170|515  134880 16379 OK  0   0   3.98 0    0    |24 765
9   152376 222 OK |37 1174|515  153773 16413 OK  0   0   3.98 0    0    |24 767
10  171307 224 OK |37 1181|515  172713 16433 OK  0   0   3.99 0    0    |24 766
11  190265 224 OK |31 990 |515  191480 16413 BAD 2   1   3.98 250  266 |1  31
12  191866 224 OK |33 1050|515  193141 16410 BAD 2   1   3.98 305  214 |4  127
------------------+-------+-------------------------------------------+-------
```

Here we see the overlapping sectors as well as the fact that sector 11 has 250 bytes passed the index (DOI) and sector 12 has 305 bytes passed the index.

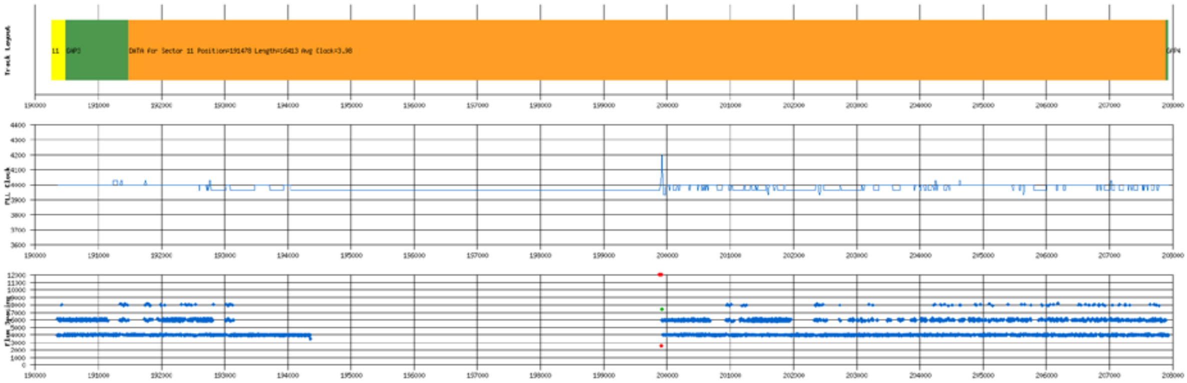
We have also a no flux reversal area at the end of the track:



After zooming at the end of the track we see the no flux reversal area (NTA):



This NTA is located within the overlapping sectors 11 and 12. For example if we look at sector 11 layout:



We can see that between 194500 & 199900 (close to end of track) we have a no flux reversal area. The consequence is that sector 11 and 12 (remember both wrap to beginning of track - DOI) read with fuzzy bits/bytes.

8.5 Computer Hits Volume 2 (Beau-Jolly)

This release is a set of two diskettes that contains the following games (compilation):

- Disk 1: Tau Ceti, Tetris,
- Disk 2: Joe Blade, and Tracker.

Computer Hits Volume 2 uses the following protection mechanisms:

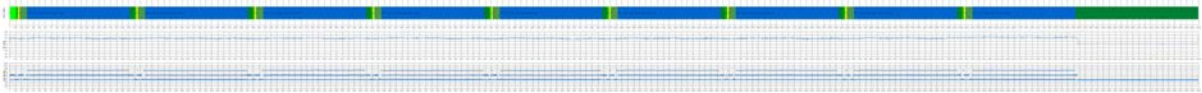
- Short track 79 of diskettes 1 and 2 (Long Sectors)
- Non standard Sector's Number: 11 Sectors/Track
- Data Beyond Index pulse on tracks 0-78 of diskette 2

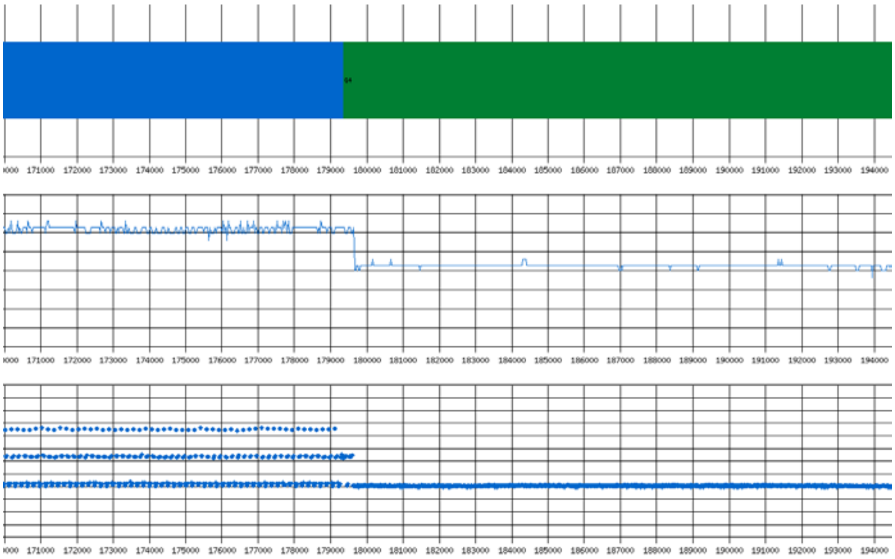
Short Track

All the sectors of track 79 of diskettes 1 and 2 are all long sectors above 17250 µs instead of the normal 16480 µs (about 5%) sector. Of course on these tracks the sector count is reduced to only 9 sectors to fit on the track. This results in a short track with less than 6000 bytes instead of a normal 6240 bytes track.

```
****************************************************************************
Track Layout Information: 5994 Bytes - length=199.979 ms
ID Good/Bad=9/0 - Data Good/Bad=9/0 - Synch Good/Bad =18/1
****************************************************************************

GAP1 31 bytes length=1070.66 us
-----------+------------------+-----------+---------------------------+-----------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt    Lgt  |Sct Pos     Lgt CRC|Bt   Lgt   BS|Bt    Lgt   CRC TMV BRD Clk |Bt  Lgt   BS
-----------+------------------+-----------+---------------------------+-----------
11   347   |1   1418    234 OK |37  1237   0|515  17264 OK  0   0   4.19|24  802    0
11   367   |2   21323   233 OK |37  1235   0|515  17242 OK  0   0   4.18|24  802    0
11   367   |3   41205   233 OK |37  1234   0|515  17263 OK  0   0   4.19|24  803    0
11   367   |4   61108   234 OK |37  1235   0|515  17257 OK  0   0   4.19|24  801    0
11   367   |5   81004   233 OK |37  1232   0|515  17209 OK  0   0   4.18|24  800    0
11   366   |6   100847  233 OK |38  1232   1|515  17240 OK  0   0   4.18|24  801    0
11   367   |7   120722  233 OK |37  1232   0|515  17242 OK  0   0   4.18|24  802    0
11   367   |8   140600  233 OK |37  1234   0|515  17280 OK  0   0   4.19|24  808    0
11   370   |9   160527  235 OK |37  1243   0|515  17360 OK  0   0   4.21|640 20611  0
-----------+------------------+-----------+---------------------------+-----------
```

Here is a plot of the complete track.





We can see that the clock period is immediately around 4.2 µs and stay at this value until after the last sector.

If we zoom we can see that the clock period goes back to 4.0 after position 180000 inside GAP4 of the last sector.

Non Standard Sector

As we already mentioned using 11 sectors per track is not really a protection, however it pushes the WD1772 at its limit. For example let's look at the layout of track 0 of the first diskette.

```
****************************************************************************
Track Layout Information: 6274 Bytes - length=199.978 ms
ID Good/Bad=9/2 - Data Good/Bad=9/2 - Synch Good/Bad =22/7
****************************************************************************

GAP1 0 bytes length=0.00 us
-----------+------------------+-----------+---------------------------+------------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt   Lgt   |Sct Pos    Lgt CRC|Bt  Lgt  BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt   BS
-----------+------------------+-----------+---------------------------+------------
37   1187  |NO ID             |0   0     0|515  16442 OK  0   0   3.99|4   127    0
11   351   |5    18109  223 OK |31  987    0|515  16447 OK  0   0   3.99|4   127    0
11   350   |9    36246  223 OK |31  987    0|515  16440 OK  0   0   3.99|4   127    0
11   349   |2    54373  202 BAD|32  1002   0|515  16384 BAD 0   0   3.98|5   153    0
11   350   |6    72467  223 OK |31  983    0|515  16406 OK  0   0   3.98|4   127    0
11   351   |10   90559  223 OK |31  989    0|515  16405 OK  0   0   3.98|4   127    0
11   349   |3    108655 222 OK |31  984    0|515  16402 OK  0   0   3.98|4   127    0
11   351   |7    126743 223 OK |31  986    0|515  16428 BAD 0   0   3.99|5   153    0
11   352   |11   144887 224 OK |31  989    0|515  16395 OK  0   0   3.98|4   127    0
11   349   |4    162974 222 OK |31  985    0|515  16437 OK  0   0   3.99|4   127    0
11   350   |8    181097 222 OK |31  984    0|515  16447 OK  0   0   3.99|18  572    0
20   632   |0    199958 19  BAD|0   0      0|NO DATA                    |0   0      0
-----------+------------------+-----------+---------------------------+------------
```

First we can see that there is no GAP1 as we start immediately in GAP2. Further analysis will show that we are in fact in an ID field.

What we see is that the layout of this track uses strange values for the number of bytes in GAPS. The GAP3 is set to 31 bytes and GAP4 is only 4 byte. This is a weird layout for 11 sectors/track (please refer to Standard 9-10-11 Sectors of 512 Bytes Format for a more reasonable one). Normally Gap3 must be 37 bytes (22x$4E+12x$00+3x$A1) and is not compressible. This corresponds to the time it takes for the WD1772 to switch from reading an *ID Field* to a *Data Field.* Here we have the following GAP3

```
+ GAP3 31 bytes @18333 us length=987.49 us - TMV=0 BRD=0 BS=0 IDG=0
  023e 18333  4000  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  024e 18844  4000  4e 4e 4e 4e 4e 4e 00 00 00 00 00 00 a1 a1 a1     NNNNNN.........
```

This format results in a **"read only" track** because we have the normal 22x$4E bytes (GAP3a) but we only have 6x$00 bytes. If a write is done on such sector the write gate is raised at the end of the ID postamble (GAP3a) then the WD1772 write 12x$00 3 synch bytes and a normal data field. This results in the sector to be shifted by 6 bytes but the data postamble (GAP4) is only 4 bytes and therefore we are already in the next sector!

Sector Over Index

Now we are going to describe the Data Beyond Index pulse protection. The KFAnalyze program finds this information during the ***read track*** phase:

```
Detail buffer content 6274 (0x1882) bytes
+ GAP1 0 bytes @0.000 ms length=0.00 us - TMV=1 BRD=0 BS=0

+ GAP2 37 bytes @0 us length=1187.36 us - TMV=0 BRD=0
  0000 33     4031  00 00 40 b2 9b d3 93 93 93 93 93 93 93 93 93 93  ..@.............
  0010 541    4000  93 93 93 93 93 93 93 93 93 93 93 80 00 00 00 00  ................
  0020 1053   3968  00 c2 a1 a1 a1                                   .....
= ID=0 0 bytes @0 length=0.00 T=0 H=0 S=0 Z=512 CRC=0000 OK TMV=0 BRD=0 BS=0
+ GAP3 0 bytes @0 us length=0.00 us - TMV=0 BRD=0 BS=0 IDG=0
= DATA ID=0 515 bytes @1187 us length=16442.76 us - CRC=e31e OK - TMV=0 BRD=0 BS=0
  0025 1187   3968  fb e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 00 02 02 e5  ................
  0035 1696   3968  e5 02 40 00 70 03 e5 05 00 0b 00 01 00 e5 e5 e5  ..@.p...........
  0045 2206   4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  0055 2716   3968  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  0065 3226   4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  0075 3737   4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
```

As we can see at about 37 bytes ($25) from the beginning of the track we find a DAM (highlighted in yellow) followed by a complete *data field* of 512 bytes*.* Obviously the first few bytes of the track are part of an ID field not decoded correctly.

Now if we look at the end of this track buffer we find something like:

```
+ GAP2 20 bytes @199325 us length=632.73 us - TMV=0 BRD=0
  186d 199325 4000  ff ff ff ff fe 01 39 39 39 38 00 00 00 00 00 00  ......9998......
  187d 199840 4000  02 a1 a1 a1                                      ....
= ID=0 1 bytes @199958 length=19.95 T=0 H=0 S=0 Z=512 CRC=0000 *** BAD *** TMV=0 BRD=0 BS=0
  1881 199958 4031  fe
```

As you can see here we only have a synch sequence followed by an IDAM but not the rest of the ID field (remember the read track command terminates at the index). This start of the ID field (the IDAM) is therefore at the **very end** (only few micro seconds) of the track and therefore the rest of ID field must be at beginning of track.

Therefore if you do a ***read track*** command on a real Atari you have all the chance not to see this ID field. For example here is the content of the end of the track buffer as read by the ***Panzer*** program on a real Atari:

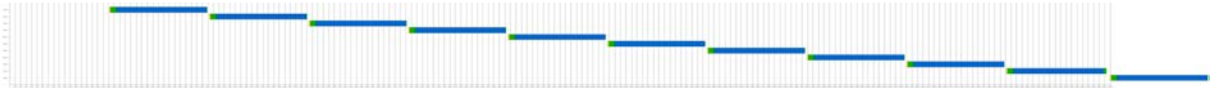
```
1830 3973  ff 80 00 00 00 3f ff ff ff 80 00 00 00 3f ff ff  .....?.......?..
1840 3973  ff 80 00 00 00 3f ff ff ff 80 00 00 00 3f ff ff  .....?.......?..
1850 4037  ff 80 00 00 00 3f ff ff ff e0 10 c8 48 48 48 48  .....?......HHHH
1860 3973  48 48 48 48 48 48 48 48 00 00 00 00 00 00 00 00  HHHHHHHH........
1870 4069  00 00 10 90 90 90 90 ff ff ff ff ff ff ff c2 a1  ................
```

Here you can see that we have the start of the synch sequence but not the IDAM. This is probably due to the Atari DMA circuit: the DMA always delivers multiples of 16 bytes due to the buffering mechanism and therefore up to 15 bytes may be “stuck” in the DMA buffer at the end of the ***read-track*** command.

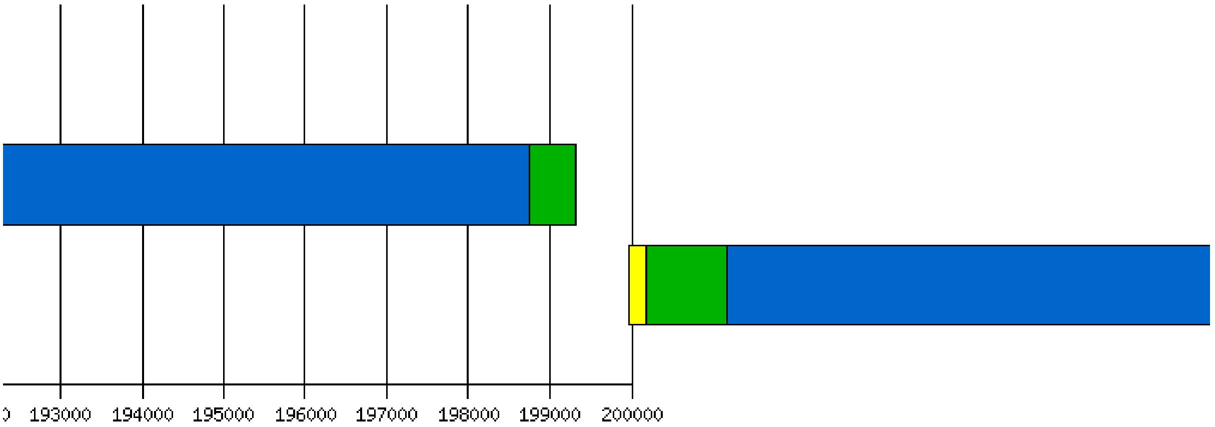
However the WD1772 will detect this ID field without problem with a ***read-address*** command and will find the corresponding DATA field with the ***read-sector*** command.

Therefore it looks almost impossible to position this *ID Field* with this precision by software and some hardware device is most likely required.

If we look at all sectors plot:



And if we zoom at the end we see clearly that the ID field has its beginning before the index (but very close to it) and the rest of the field is “passed the index”.



8.6 Kick Off 2 (Anco Software)

Kick Off 2 (by Anco Software 1990) uses various combinations of the following protection mechanisms on tracks 2 to 6:

- Non standard Sector’s Number: 12 Sectors/Track
- Data Over Index pulse
- Sector Within Sector (and even Sector Within Sector Within Sector)
- Non Standard sector Size (1024)
- No Flux reversal Area
- Fuzzy bytes

Let’s look at the end of the buffer from the ***read-track*** command:

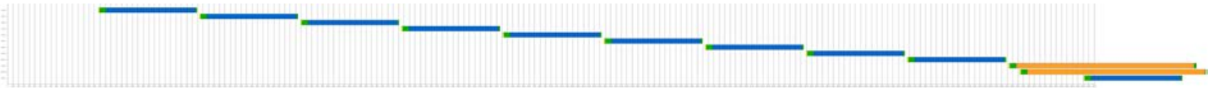
```
+ GAP2 31 bytes @183298 us length=965.75 us - TMV=0 BRD=0
  169d 183298 3968  00 43 00 e4 24 24 24 24 24 24 24 24 24 24 24 3f  .C..$$$$$$$$$$$?
  16ad 183806 4000  ff ff ff ff ff ff ff ff ff ff ff c2 a1 a1 a1     ...............
= ID=0 7 bytes @184264 length=223.29 T=2 H=0 S=0 Z=1024 CRC=0417 OK TMV=0 BRD=0 BS=0
  16bc 184264 3968  fe 02 00 00 03 04 17                             .......
+ GAP3 37 bytes @184487 us length=1178.12 us - TMV=0 BRD=0 BS=0 IDG=0
  16c3 184487 4000  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  16d3 184998 4000  4e 4e 4e 4e 4e 4e 00 00 00 00 00 00 00 00 00 00  NNNNNN..........
  16e3 185508 4000  00 00 a1 a1 a1                                   .....
= DATA ID=0 451 bytes @185665 us length=14314.28 us - CRC=0000 *** BAD *** - TMV=0 BRD=1 BS=1
  16e8 185665 4000  fb 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  16f8 186180 3968  00 a1 a1 a1 fe 02 00 10 03 07 64 4e 4e 4e 4e 4e  ..........dNNNNN
  1708 186688 4000  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  1718 187199 3968  4e ff ff ff ff ff ff ff ff ff ff ff fe a1 a1 a1  N...............
  1728 187703 3968  fb 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  1738 188215 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  1748 196265 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  1758 196265 3968  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
  1858 197363 4000  09 09 09 09 09 09 0f ff ff ff ff ff ff ff ff ff  ................
  1868 197876 4000  ff ff f0 a1 a1 a1 fe 02 00 01 02 27 07 4e 4e 4e  ...........'.NNN
  1878 198377 4000  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  1888 198890 4000  4e 4e 4e 00 00 00 00 00 00 00 00 00 00 00 00 a1  NNN.............
  1898 199400 4000  a1 a1 fb ae 28 2b a3 7d 24 b1 cc 3d 84 c0 9f 63  ....(+.}$..=...c
  18a8 199912 4000  0b 4d 6d                                         .Mm
```

As we can see we have a synch sequence followed by an *ID Field* at $16BC followed by a GAP3 followed by a synch sequence and a *Data Field* starting at byte $16E8. We are too close to the end of the track to have a complete *Data Field* so we can say that this sector (sector 00) has Data Over the Index pulse (DOI). Reading this sector with a ***read sector*** command indicates that the sector has Fuzzy bits and reads with a CRC error (SBD).

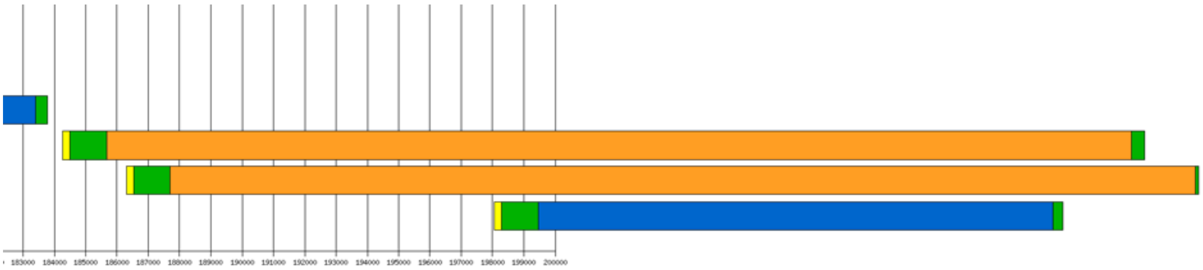
Now if we look inside this sector 0 *Data Field* we can see that we have a synch sequence followed by an *ID Field* at byte $16FC followed by a GAP3 followed by a synch sequence followed by a *Data Field* starting at byte $1728. So here we have a Sector 16 Within Sector 00 (SWS). We are too close to the end of the track to have a complete *Data Field* so we can say that this sector (sector 16) has Data Over the Index pulse (DOI). Reading this sector with a ***read-sector*** command indicates that the sector has Fuzzy bits and reads with a CRC error (SBD).

But if we continue looking inside the sector 16 *Data Field* (which is itself inside the sector 00 *Data Field!*) we can see that we have a synch sequence followed by an *ID Field* at byte $186E followed by a GAP3 followed by a synch sequence followed by a data field starting at byte $189A. So here we have a Sector 01 within Sector 16 (SWS) which is in fact it is a Sector 01 Within Sector 16 Within Sector 00! We are too close to the end of the track to have a complete *Data Field* so we can say that this sector (sector 01) has Data Over the Index pulse (DOI). Reading this sector with a ***read sector*** command returns a good sector.

The layout is the following:



If we zoom to the end of this plot:



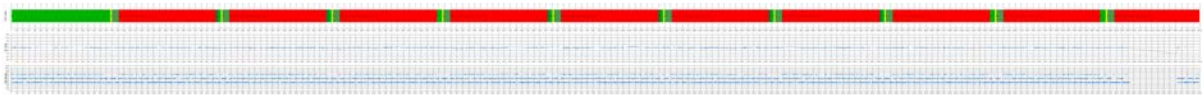
We can see that most of the data for sector 01 are in fact located at the beginning of the track. The first *ID Field* of the track for sector 02 is only found at byte 521 after a synch sequence.

So here we can summarize the protection as follow:

- ✶ We have a sector 00 that has Data Over Index (DOI) as well as Fuzzy bits (FZD) and CRC error (SBD).
- ✶ Inside the sector 00 we have a sector 16 (SWS) that has Data Over Index (DOI) as well as Fuzzy bits (FZD) and CRC error (SBD).
- ✶ Inside sector 16 (which is inside sector 00) we have a sector 01 (SWS) that has Data Over Index (DOI), with most of the data are at the beginning of the track, that reads correctly. So here we have a recursive SWS

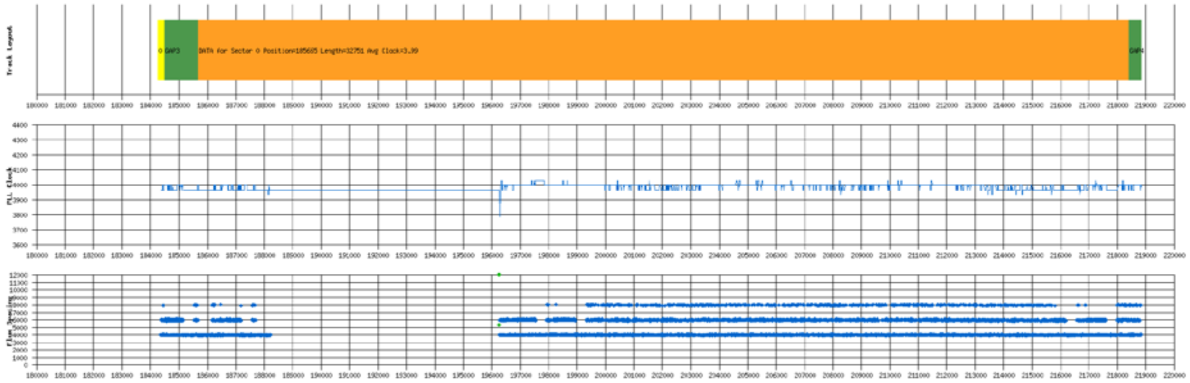
We can see for track 2 the sectors 0 & 16 are defined with a non standard data size of 1024 bytes

Now let’s look at the flux reversals for the complete track:



We can see a large area without reversals at the end of the track.

If we look at sector 0 plot we have:



Here we clearly see the no reversal area in sector 0. The sector 16 is also located on top of this NTA. Therefore both sectors read with fuzzy bits. But sector 1 is located at the very end of the track after the NTA and therefore reads correctly.

8.7 Night Shift

Night Shift (US Gold) uses various combinations of the following protection mechanisms:

- Sector with No Data: Sector 66 (2 sectors) on track 0-78
- Duplicate Sector: Sector 66 on track 0-78
- Long Sectors: Sector 0-9 on track 79
- Sector with Fuzzy Bits: Sector 6 on track 79.
- Sector with MFM timing violation sector 6 track 79
- Short Track 79

Let's first look at the Sector with No Data and Duplicate Sector protection for this game.

First we look at the layout of track 00:

```
****************************************************************************
Track Layout Information: 6280 Bytes - length=199.973 ms
ID Good/Bad=8/3 - Data Good/Bad=7/2 - Synch Good/Bad =20/5
****************************************************************************

GAP1 501 bytes length=15978.41 us
-----------+------------------+-----------+---------------------------+------------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt   Lgt   |Sct Pos    Lgt CRC|Bt  Lgt  BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt   BS
-----------+------------------+-----------+---------------------------+------------
15   472   |66  16450  202 BAD|38  1197  0|NO DATA                    |0   0      0
0    0     |1   17850  223 OK |37  1175  0|515  16385 OK  0   0   3.98|38  1206   0
15   477   |2   37319  202 BAD|38  1196  0|515  16362 BAD 0   0   3.97|38  1197   0
15   479   |3   56758  222 OK |37  1173  0|515  16355 OK  0   0   3.97|38  1203   0
15   475   |4   76188  221 OK |37  1173  0|515  16378 OK  0   0   3.98|38  1203   0
15   475   |5   95641  222 OK |37  1174  0|515  16413 OK  0   0   3.98|38  1206   0
15   476   |6   115135 222 OK |37  1175  0|515  16424 OK  0   0   3.99|38  1211   0
15   477   |7   134646 222 OK |37  1176  0|515  16469 BAD 0   0   4.00|38  1208   0
15   482   |8   154205 223 OK |37  1177  0|515  16453 OK  0   0   3.99|38  1216   0
15   479   |9   173755 223 OK |37  1180  0|515  16475 OK  0   0   4.00|38  1214   0
15   478   |66  193327 203 BAD|203 6442  0|NO DATA                    |0   0      0
-----------+------------------+-----------+---------------------------+------------
```

As we can see we have two sectors 66 (DUP) one located at the beginning of the track and one located at the end of the track. Furthermore these two sectors have no associated data field (SND).

If we look at the track buffer after the GAP1 we have:

```
+ GAP2 15 bytes @15978 us length=472.50 us - TMV=0 BRD=0
  01f5 15978  4000  ff ff ff ff ff ff ff ff ff ff ff fc a1 a1 a1     ...............
= ID=66 7 bytes @16450 length=202.43 T=0 H=0 S=66 Z=512 CRC=c240 *** BAD *** TMV=0 BRD=0 BS=1
  0204 16450  4000  fe 00 00 42 02 c2 40                             ...B..@
+ GAP3 38 bytes @16653 us length=1197.20 us - TMV=0 BRD=0 BS=0 IDG=0
  020b 16653  3968  79 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  y...............
  021b 17162  4000  09 09 09 09 09 09 0f ff ff ff ff ff ff ff ff ff  ................
  022b 17671  4000  ff ff f0 a1 a1 a1                                ......
= ID=1 7 bytes @17850 length=223.20 T=0 H=0 S=1 Z=512 CRC=ca6f OK TMV=0 BRD=0 BS=0
  0231 17850  4000  fe 00 00 01 02 ca 6f                             ......o
+ GAP3 37 bytes @18073 us length=1175.83 us - TMV=0 BRD=0 BS=0 IDG=0
  0238 18073  3968  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  0248 18583  4000  4e 4e 4e 4e 4e 4e 00 00 00 00 00 00 00 00 00 00  NNNNNN..........
  0258 19092  4000  00 00 a1 a1 a1                                   .....
= DATA ID=1 515 bytes @19249 us length=16385.97 us - CRC=dfc4 OK - TMV=0 BRD=0 BS=0
  025d 19249  3968  fb 00 00 4e 4e 4e 4e 4e 4e 57 cb a5 00 02 02 01  ...NNNNNNW......
  026d 19760  3968  00 02 70 00 d0 02 f8 05 00 09 00 01 00 00 00 4e  ..p............N
  027d 20269  3968  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
  028d 20777  3968  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 00 00 00  NNNNNNNNNNNNN...
  029d 21286  3968  00 00 00 00 00 00 00 00 00 f5 f5 f5 fe 4f 00 06  .............O..
  02ad 21796  3968  02 f7 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  ..NNNNNNNNNNNNNN
  02bd 22303  4000  4e 4e 4e 4e 4e 4e 4e 4e 00 00 00 00 00 00 00 00  NNNNNNNN........
  02cd 22811  3968  00 00 00 00 f5 f5 f5 fb e5 e5 e5 e5 e5 e5 e5 e5  ................
  02dd 23319  4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  02ed 23829  4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  02fd 24339  4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  030d 24849  4000  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
  031d 25360  3968  e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5 e5  ................
```

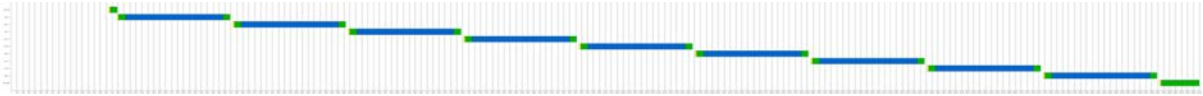
After a long GAP1 (501 bytes) we have an ID field at location $204 for a sector 66 ($42) and after a GAP we find another ID field at location $231 for a sector 1. The second ID field follows immediately the first one and therefore the FDC can't find the DAM for sector 66 within 48 bytes and reports an RNF.

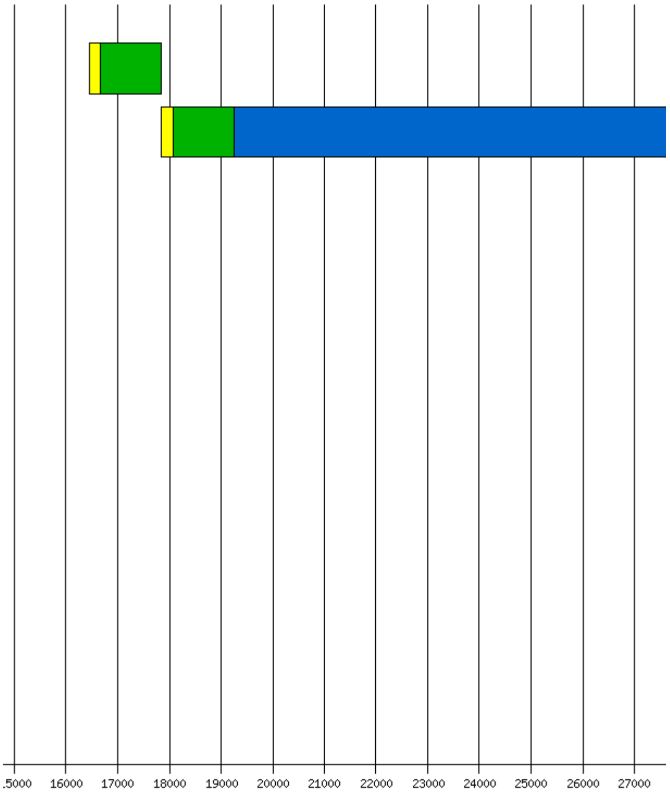
Personal note: inside sector 1 ➔ investigate kind of synch seq followed by strange short IDAM, followed by GAP and kind of synch and DAM? (Not detected but very strange)

If we now look at the end of the buffer

```
+ GAP2 15 bytes @192848 us length=478.46 us - TMV=0 BRD=0
  17a7 192848 4000  00 00 00 00 00 00 00 00 00 00 00 00 a1 a1 a1     ...............
= ID=66 7 bytes @193327 length=203.47 T=0 H=0 S=66 Z=512 CRC=c240 *** BAD *** TMV=0 BRD=0 BS=1
  17b6 193327 4000  fe 00 00 42 02 c2 40                             ...B..@
+ GAP3 203 bytes @193530 us length=6442.18 us - TMV=0 BRD=0 BS=0 IDG=0
  17bd 193530 3968  79 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  y...............
  17cd 194040 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  17dd 194550 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  17ed 195059 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  17fd 195568 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  180d 196077 3968  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  181d 196587 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  182d 197097 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  183d 197607 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  184d 198118 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  185d 198629 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  186d 199139 4000  09 09 09 09 09 09 09 09 09 09 09 09 09 09 09 09  ................
  187d 199648 3968  09 09 09 09 09 09 09 09 09 09 09                 ...........
```

We see an ID field starting at byte 6067 followed by a long long GAP of $09 till the end. The ID field indicates a sector 66 ($42) but no DAM can be found within 48 bytes and therefore a ***read sector*** command returns a RNF (record not found) status for this sector (SND). As we already have found the same sector 66 at the beginning of the track we are in presence of Duplicate Sector (DUP).

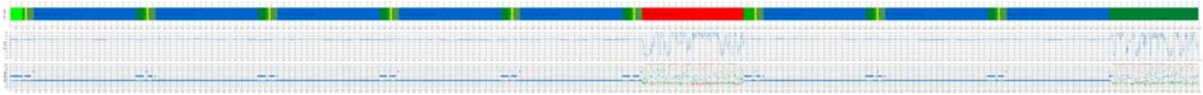




If we zoom we can see that the first ID 66 is followed by a gap and followed by another ID without the normal data field.

What looks strange is the fact that the fist ID is located at about 16500 µs. This is almost enough room for an extra sector especially if we have a sector located at the end of the track with data over index. However this does not seems to be the case and therefore this space is occupied by a GAP1

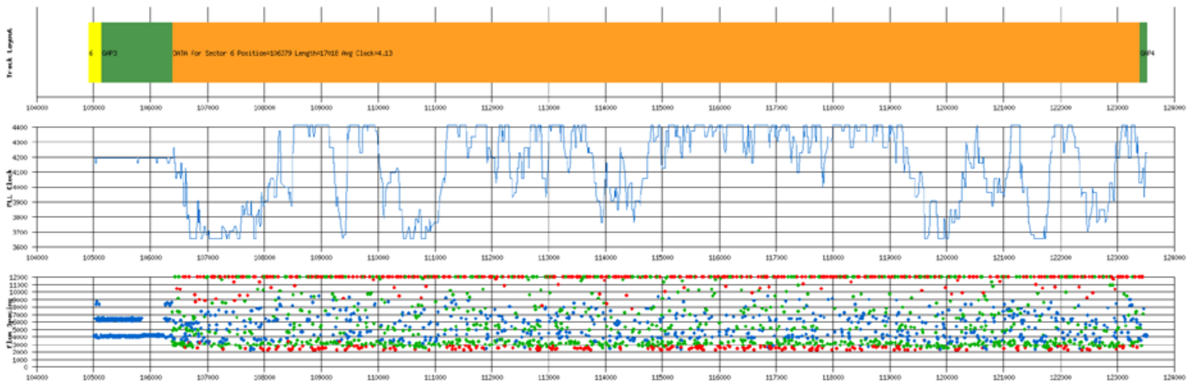
Now we are going to look at track 79



We can first see that we have short track with less than 6000 bytes

```
   Stream file 'NightShift\NightShift(1-2)79.0.raw' 5 rot - Avg RPM=300.203

*****************************************************************************
Track Layout Information: 5993 Bytes - length=199.971 ms
ID Good/Bad=9/0 - Data Good/Bad=8/1 - Synch Good/Bad =18/1
*****************************************************************************

GAP1 60 bytes length=2034.68 us
-----------+------------------+-----------+---------------------------+-----------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt    Lgt  |Sct Pos    Lgt CRC|Bt   Lgt   BS|Bt   Lgt   CRC TMV BRD Clk |Bt  Lgt    BS
-----------+------------------+-----------+---------------------------+-----------
15    500  |1   2535   234 OK |37   1235   0|515  17244 OK  0   0   4.19|38  1271   0
15    502  |2   23023  234 OK |37   1240   0|515  17248 OK  0   0   4.19|38  1268   0
15    501  |3   43517  234 OK |37   1237   0|515  17202 OK  0   0   4.18|38  1268   0
15    501  |4   63961  234 OK |37   1238   0|515  17183 OK  0   0   4.17|38  1268   0
15    502  |5   84388  234 OK |37   1238   0|515  17203 OK  0   0   4.18|40  1339   0
15    503  |6   104907 234 OK |38   1236   1|515  17018 BAD 982 946 4.13|4   125    0
54    1816 |7   125339 235 OK |37   1239   0|515  17260 OK  0   0   4.19|38  1274   0
15    503  |8   145854 234 OK |37   1235   0|515  17201 OK  0   0   4.18|38  1273   0
15    502  |9   166302 234 OK |37   1234   0|515  17226 OK  0   0   4.18|455 14973  0
-----------+------------------+-----------+---------------------------+-----------
```

This is due to the fact that each of the sectors in this track is a long sectors (all are about 17200 ms long) we can also see that the sector 6 contains a lot of border bits (in ambiguous area) and a lot of timing violations. Therefore let's look more carefully at this sector:



We can see that in the data block of the sector we have random flux reversals that are equivalent to an "unformatted" area. Of course as indicated by the orange color this sector returns random values (fuzzy bits). Therefore this track cumulates 5 protections which cannot be reproduced without a dedicated hardware.

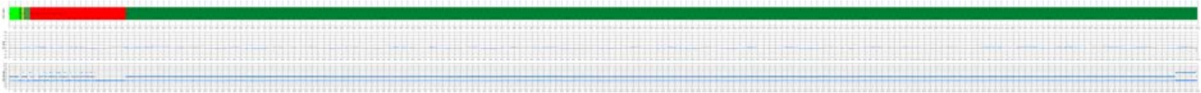
8.8 Barbarian

The game Barbarian (Psygnosis) has the following protections:

- Non Standard Number of sector: Track 0 only one sector!
- Track Not Found: Track 74-79
- Invalid Synch Sequence: Track 0, 45, 48 …
- Data Into Gap: Possibly in track 0
- Invalid Data into GAP track 14 disk A
- Sector 18 with bad data track 72 disk B

As already mentioned the **Panzer**/**KFPanzer** programs cannot directly detect Data Into Gap however when an Invalid Synch Sequence is found it is usually interesting to see if there is a DIG following the ISS. Due to the well-known behavior of the FDC, the ***read-track*** command read incorrectly most of the data of the track. The only way to read the data correctly is to add a Synch mark just before the data to read.

If we look at track 0 of Barbarian we first see that the layout is rather unusual as the track has only one sector of 512 bytes!



After this sector the track is filled with character $12. But close to the end (this value may vary) we find an $A1 Synch Mark followed immediately by a sequence of 8 * $09 followed by a sequence $00 bytes until the end of the track.

```
1834 193807 3908  12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12  ................
1844 194308 3908  12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12  ................
1854 194808 3908  12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12  ................
1864 195308 3908  12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12  ................
1874 195808 3908  12 12 12 12 12 12 16 a1 09 09 09 09 09 09 09 09  ................
1884 196305 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
1894 196805 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18a4 197307 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18b4 197809 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18c4 198311 3938  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18d4 198813 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18e4 199314 3908  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
18f4 199814 3908  00 07 0c 00 48 48                                ....HH
```

This can definitively be used as a protection even though it is easy to reproduce such a track.

On track 48 we have a different sort of invalid Synch sequence:

```
186b 195393 3908  42 42 42 42 42 42 42 42 42 42 42 42 42 42 42 42  BBBBBBBBBBBBBBBB
187b 195893 3878  42 42 42 42 42 41 e4 24 24 24 24 24 21 a1 a1 a1  BBBBBA.$$$$$!...
188b 196391 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
189b 196891 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
18ab 197392 3938  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
18bb 197893 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
18cb 198394 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
18db 198895 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1  ................
18eb 199395 3908  a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 a1 c0 96 21  ...............!
18fb 199896 3878  2b 09 09                                         +..
```

Here we have a very very long sequence of $A1 Synch. Again this is an invalid sequence that can be detected using the ***read-track*** command.

TODO byte 30 trk 79 has to be 00 or FF

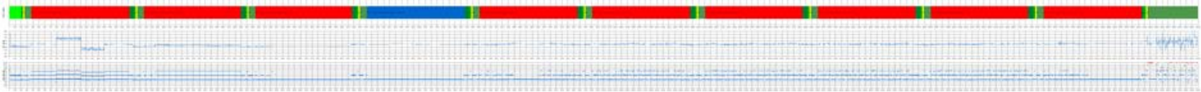
8.9 Colorado

Important Note: I do not have the original diskette for Colorado. I have received a track's content from Ijor generated with a DC cartridge and I have "recreated" this track on a blank diskette. The analysis has been done on this diskette and therefore results might not be as accurate as on an original.

On this track I find the following protections:

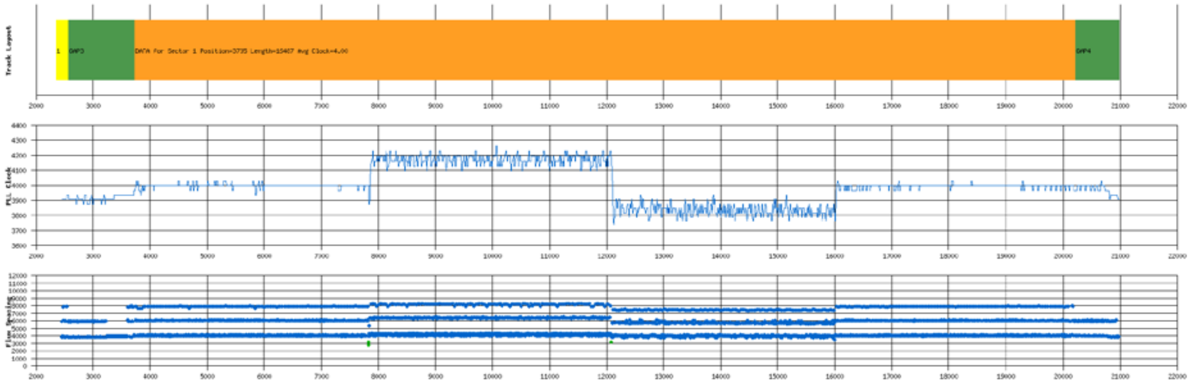
- Intra-sector Bit-rate Variation (IBV)
- Sector with Fuzzy Bits (FZD) and Bad Data (SBD)
- Invalid Track Number (ITN), Sector Bad ID (SBI), Invalid ID Field (IIF)

Here is a plot of the complete track:



If we zoom in the first sector 1 we can see some large **intra-sector** clock rate variation.

If we look at the Intra-sector Bit-rate Variations we can recognize a **macrodos** protection from **speedlock**.



Here we can see that the data field is roughly dived into four segments. In the first segment we have normal timing, in the second segment we have above normal clock values, in the third segment we have below normal clock values, followed by the last segment with normal values. This corresponds well to the definition of IBV where we have the sector divided into 4 regions with timing: normal, above, below, and normal. Note that each segment is about 128 bytes and that the above and below clock rate compensate. This means that the overall length of this sector is 16487.46 µs which is very close to a normal 16480 µs sector.

Probably due to the quick shifting of the clock we have some border bits and therefore the sector also reads with fuzzy bytes and CRC error.

Now if we read the complete track and look at the end of the buffer we have some strange values:

```
+ GAP2 14 bytes @190845 us length=438.03 us - TMV=0 BRD=0
  1776 190845 4031  ff ff ff ff ff ff e1 a1 a1 a1 a1 a1 a1 a1       ..............
= ID=150 7 bytes @191283 length=230.14 T=142 H=164 S=150 Z=2048 CRC=1214 * BAD * TMV=9 BRD=4 BS=0
  1784 191283 4031  ff 8e a4 96 84 12 14                            .......
+ GAP3 264 bytes @191513 us length=8466.75 us - TMV=303 BRD=108 BS=2 IDG=0
  178b 191513 4063  b2 8c 20 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  .. NNNNNNNNNNNNN
  179b 192032 4031  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
```

Here we can see an abnormally long synch sequence followed by an IDAM with the following errors: ITN, SBI, and IIF. However as I do not have the original I am not sure if the end of the track has been "regenerated" correctly?

8.10 Turrican

Turrican contains a lot of interesting protection mechanisms. You should refer to information provided by Markus Fritze on Turrican protection and the Atari Forum

We are going to look at the following protections:

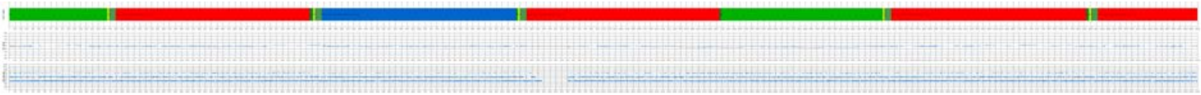
- Non-standard sector size 1 * 512 + 5 * 1024 (total of 5632 bytes)
- No Flux reversal Area
- Sector within Sector - with cell bit shifting allowing to read clock bits as data!
- Fuzzy sector with CRC error
- Data Over Index

The read track provides the following layout:

```
****************************************************************************
Track Layout Information: 6290 Bytes - length=199.98 ms
ID Good/Bad=4/1 - Data Good/Bad=1/4 - Synch Good/Bad =10/42
****************************************************************************

GAP1 1 bytes length=63.00 us
-----------+------------------+-----------+---------------------------+------------
GAP2       |ID                |GAP3       |DATA                       |GAP4
Bt   Lgt   |Sct Pos      Lgt CRC|Bt   Lgt   BS|Bt   Lgt    CRC TMV BRD Clk |Bt  Lgt    BS
-----------+------------------+-----------+---------------------------+------------
517  16488 |3   16551  222 OK |38   1177   1|1027 32677 BAD 0    0   3.98|13  415    0
6    172   |6   51217  224 OK |37   1185   0|1027 32703 OK  0    0   3.98|4   127    0
7    223   |0   85682  217 BAD|38   1183   0|1027 32503 BAD 0    1   3.96|8   252    0
863  27242 |2   147081 222 OK |37   1175   0|1027 32835 BAD 0    0   4.00|10  318    0
6    191   |5   181825 223 OK |37   1178   0|525  16753 BAD 0    0   3.99|0   0      0
-----------+------------------+-----------+---------------------------+------------
```

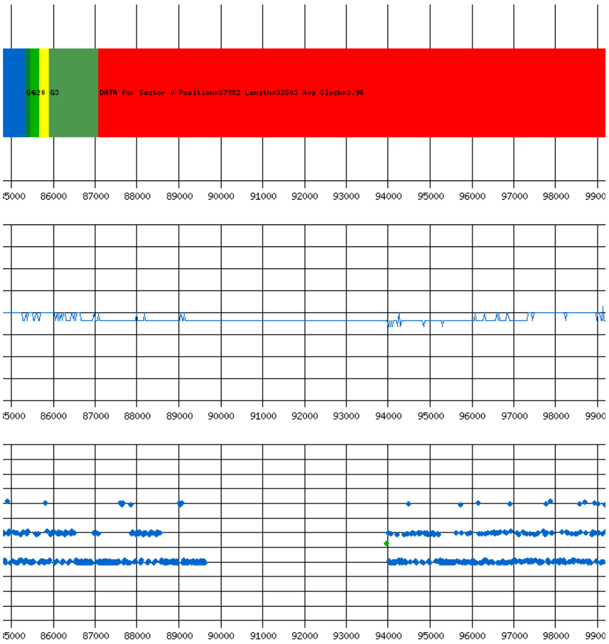
We can see that the FD uses several 1024 bytes sector and that the last sector is truncated indicating Data over Index.

The track also contains a long area without flux reversals. A normal FD controller / FD drive can't create such a long spacing between two flux reversals. The lack of flux reversal reversals increase the gain on the head (AGC), eventually leading to an amplified level that generates a fake flux reversal (fuzzy bits) and the PLL data separator can't lock onto the clock/data bits. This area is extremely difficult to reproduce even with specialized HW. As explained above this result in Fuzzy bytes read in sectors containing this area (which also imply reading the sector with CRC error). It is hard to see on the following plot this area:

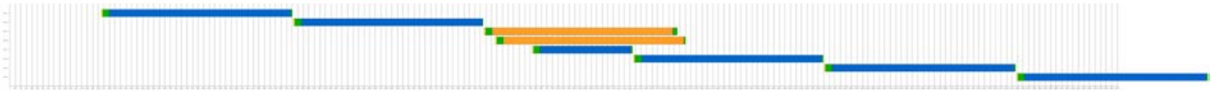


But if we zoom to the concerned area we can see that there is no flux reversal (neither data nor clock flux reversals) in the range 89500-94000 (that's more than 4 ms).

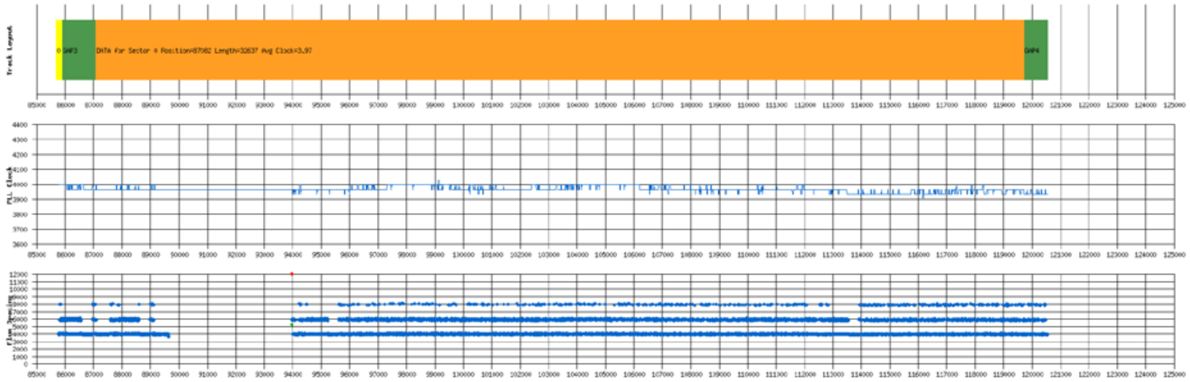
This area is located inside the sector 0 but we will see that this sector 0 in fact contains sector 16 and sector 1. This will be detailed below.



To get a more accurate view of all sectors we use the all sectors plot:



Here we can see clearly that sector 0 contains sector 16 and sector 1 (Sector within sector) and that sector 16 fully contains sector 1 of 512 bytes (sector within sector within sector). We can also see that sector 0 and sector 16 reads with fuzzy bits (orange bar on the plot). The reason is that sector 0 and sector 16 contains the no flux reversal area.



However it is interesting to note that the sector 1 included in sector 0 and 16 reads **correctly** as it is located beyond the no flux reversal area.

We can also see that the sector 5 has a large portion of its data over the index.

All this is summarized in the all sectors layout:

```
All Sectors Layout Information:
------------------+-------+-------------------------------------------+-------
ID                |GAP3   |DATA                                       |GAP4
Sct Pos     Lgt CRC|Bt Lgt |Bt     Pos     Lgt    CRC  TMV BRD Clk  DOI  FZP |Bt Lgt
------------------+-------+-------------------------------------------+-------
3   16551   222 OK |37 1177|1027 17952  32751 OK   0   0   3.99 0    0   |10 321
6   51217   224 OK |37 1185|1027 52627  32703 OK   0   0   3.98 0    0   |4  127
0   85682   223 OK |37 1177|1027 87082  32637 BAD 0   1   3.97 0    217 |26 821
16  87721   222 OK |37 1173|1027 89118  32621 BAD 0   1   3.97 0    153 |10 297
1   94350   222 OK |37 1172|515  95745  16402 OK  0   0   3.98 0    0   |10 317
4   112655  221 OK |37 1168|1027 114045 32527 OK  0   0   3.96 0    0   |10 318
2   147081  222 OK |37 1175|1027 148479 32835 OK  0   0   4.00 0    0   |10 318
5   181825  223 OK |37 1178|1027 183226 32794 OK  0   0   3.99 513  0   |10 317
------------------+-------+-------------------------------------------+-------
```

Another interesting mechanism is used: Sector 0 start with the following bytes:

```
Detail buffer content for sector 0 with 1027 bytes
= DATA ID=0 1027 bytes @87082 us length=32637.85 CRC BAD CLK=3.97 TMV=0 BRD=1 DOI=0
  *** Fuzzy Sector *** starting at byte position 217
  0000 87082  4000  fb 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
                    00 7f ff ff ff ff ff ff ff ff ff ff ff ff ff ff  .□..............
  0010 87596  3968  00 a1 a1 a1 fe 07 00 10 03 bb 21 4e 4e 4e 4e 4e  ..........!NNNNN
                    ff 0a 0a 0a 00 f8 7f e7 fc 00 4e 10 90 90 90 90  ......□...N.....
  0020 88103  3968  4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e 4e  NNNNNNNNNNNNNNNN
                    90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90  ................
  0030 88614  3968  4e ff ff ff ff ff ff ff ff ff ff ff fe 14 14 14  N...............
                    90 00 00 00 00 00 00 00 00 00 00 00 00 a1 a1 a1  ................
  0040 89124  4000  00 ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff  ................
                    fb 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0050 89629  3968  ff ff 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

In green we can see inside data block the presence of 3 synch character followed by the ID block of sector 16 (sector within sector) however if we look further we do not see directly the synch mark for the data block. Instead we see the presence of 3 bytes with value $14 followed by a byte $00. If we turn the "clock" flag of the ***KFAnalyze*** program it also print the clock value of the decoded byte. Here we can see that in fact the $A1 synch bytes are in fact in the "clock" bytes. The synch mark detector will take care of shifting by a half cell to correctly read the data of sector 16. This result in reading the "data" bytes for sector 0 and reading the "clock" bytes for sector 16. Not very useful but fun ☺

8.11 Operation Neptune

Operation Neptune (Smash) uses the following protection mechanisms:

- Invalid Data in Gap – Track 50
- Sector with Fuzzy Bits (FZD) and Bad Data (SBD) – Track 75-78 Side 1

We use this game to demonstrate the usage of Invalid Data in Gap. Normally the value of data written in Gap3a (post-index) and Gap4 (post-data) is $4E. However this value is not critical for the FDC and any value can be used in these gaps. In Operation Neptune this value is replaced by the invalid character $F7. Normally all the Gap information is written during the format command (write track command) and the usage of $F7 is not permitted as it is used to send to CRC character. Therefore it is not possible to generate such a track on an Atari using the standard FDC. If we look at the beginning of the track we find:

```
Detail buffer content 6285 (0x188d) bytes

+ GAP2 78 bytes @0 us length=2497.88 us - TMV=0 BRD=0
  0000 32     4000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0010 539    3938  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0020 1045   3938  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
  0030 1551   3938  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ff  ................
  0040 2055   3968  ff ff ff ff ff ff ff ff ff ff fe a1 a1 a1        ..............
= ID=1 7 bytes @2497 length=219.73 T=50 H=0 S=1 Z=512 CRC=0bee OK TMV=0 BRD=0 BS=0
  004e 2497   4000  fe 32 00 01 02 0b ee                             .2.....
+ GAP3 37 bytes @2717 us length=1173.24 us - TMV=0 BRD=0 BS=0 IDG=21
  0055 2717   3938  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  0065 3224   3968  f7 f7 f7 f7 f7 f7 00 00 00 00 00 00 00 00 00 00  ................
  0075 3733   3938  00 00 a1 a1 a1                                  .....
= DATA ID=1 515 bytes @3890 us length=16366.08 us - CRC=8823 OK - TMV=0 BRD=0 BS=0
  007a 3890   3968  fb 70 00 80 00 f0 00 80 0b 00 8d 30 00 10 00 30  .p.........0...0
```

As you can see the value of the data in Gap3a are set to $F7 (highlighted in red)

Now if we look at the end of the same data block (first data block):

```
  026a 19656  3968  00 c0 00 fe 00 c0 03 00 95 01 ff 00 57 01 ff 2a  ...........W..*
  027a 20161  4000  af 88 23                                        ..#
+ GAP4 40 bytes @20256 us length=1273.10 us - TMV=0 BRD=0 BS=0 IDG=39
  027d 20256  3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  028d 20765  4000  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  029d 21273  3938  f7 f7 f7 f7 f7 f7 f7 f7
```

Here we can see that we also have the value $F7 in Gap4. This protection repeats for all sectors of the track.

And at the end of the track we have the last Gap4 filled with $7F until the end of the track:

```
+ GAP4 731 bytes @176866 us length=23105.60 us - TMV=0 BRD=0 BS=0 IDG=730
  15b2 176866 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  15c2 177374 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  15d2 177882 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  15e2 178390 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  15f2 178898 4000  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  1602 179405 3938  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  1612 179912 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
...
  1852 198129 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  1862 198636 3938  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  1872 199144 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7  ................
  1882 199651 3968  f7 f7 f7 f7 f7 f7 f7 f7 f7 f7 f7                 ...........
```

This protection can be tested easily by using the read track command but cannot be duplicated with a WD1772 FDC.

9 References

9.1 Documents / Articles

- Article on protection "copy me I want to travel" from Claus Brod the expert who wrote the book Scheibenkleiste covering all sort of interesting details about floppy disks, hard disks, RAM disks, CD-ROMs and other mass storage devices for the Atari (Claus web site).
- Probing the FDC: *Learn the Secrets of your Floppy* - By David Small
- Atari Protected Disk Image Format & Atari Protected Disk Image Format
- Floppy disk formatHow can I copy my copy-protected Atari software
- An interview with Rob Northen
- Dungeon Master Copy Protection
- Disk Backup Programs: Do they really work
- Teac & Citizen Micro Floppy Disk Drive Specification
- Floppy from HP
- How to HD install Pacland (MFM format) using WHDLoad
- Commodore C1581-handler
- S100-Manuals - Disks and Disk Drives
- Wipe Swap File
- SpinRight Technical note

9.2 Forums Threads

- Looking for Rob Northen originals
- Rob Northern Code Found
- Weak Bits, Bit-rate var., data under index: Copy Protection
- Questions Regarding STT Images
- Protected disk images project & CAPS
- Ideas about ST floppy image make program for PC
- PASTI Project
- Copy II ST
- Looking for AntiBitos 1.4 by Illegal
- Most memorable Hack/crack
- Protected Disk Image Project Seeking Beta Tester
- Ideas about ST floppy image make program for PC
- Looking for DMA file under interrupt
- Mega STE Specifics
- Copy Protected Disks
- Gcopy DIM file
- ST Protection routines
- Putting a second internal floppy drive in the STF
- RamDisk and ATARI-ST Disk IO
- X-out original protected

9.3 Related Patents

You may want to look at the following patents that describe some protection mechanisms:

- Copy Protection for computer Disc 4,849,836
- Computer Program protection method 4,462,078
- Hardware key-on-disc for copy protecting magnetic storage data 4,577,289
- Copy protecting system for software protection 4,584,641
- Techniques for preventing unauthorized copying of information recorded on a recording medium and a protected recording medium 4,734,796
- Copy protection disc format controller 5,432,647
- Data Input Circuit with Digital Phase Lock Loop

9.4 Web Sites

- Atari ST FD (Hardware view)
- Atari ST FD (Software view)
- Atari FD Protection/Preservation
- Atari ST Copy Protections (Markus Fritze)
- Protections sur Atari ST/Amiga
- PASTI Project
- Software Preservation Society
- KryoFlux Products & Services Limited
- C64 Preservation Project (Commodore)
- Atari Disk Image FAQ
- Tim Mann's TRS-80 Pages
- The .ADF (Amiga Disk File) format FAQ
- Introduction to Magnetic Recording
- Funny presentation about perpendicular magnetic recording !!!
- Individual Computer Support
- The Central Point Option Board
- SpinRite's Defect Detection Magnetodynamics
- The Gentle art of Protection
- The XCOMP/2 home page
- LIBDSK library for accessing discs and disc image files
- WinUAE Amiga Emulator

9.5 FDC & Related Information

- Western Digital Corporation 5.25" WD1770/1772 Floppy Disk Controller/Formatter
- 8272 SINGLE/DOUBLE DENSITY FLOPPY DISK CONTROLLER
- Intel 82077AA FDC Datasheet
- Commodore C1581 - WD1770 FLOPPY DISK CONTROLLER
- PC87310 (SuperI/OTM) Dual UART with Floppy Disk Controller and Parallel Port
- Hard Disk Data Encoding / Decoding.
- Cyclic Redundancy Check, CRC16-CCITT, The Great CRC Mystery Terry Ritter
- Atari ST – Floppy Disk Programming – Jean Louis-Guérin
- WD1772 Floppy Disk Formatter/Controller - Western Digital Corporation

10 Document history

- V1.0 Major Revision - Added information on low level format, particularly about the write splice. Added description about ***KFPanzer*** and ***KFAnalyze***. Now the analysis of games uses the output from ***KFAnalyze*** and especially the nice plots. Added the Short/Long Track and No Flux reversal Area protections. Remove documentation of ***Analyze*** program. Added more analysis of games (Turrican and others). New information about games protection based on new ***KFPanzer*** capabilities. Added more links to new sites. Added reference to the new **KryoFlux** board and related - After 5 years of development I consider the document mature enough to go to version 1.0! - November 2011
- V0.9 Major Revision - Clean-up text based on feedback. Modified documentation to reflect the usage of the new **Panzer** (Protection ANalyZER) program. Added ID Fuzzy Bits, Invalid Data in Gap, and Non Standard DAM Protection. Added a *section on Preservation* for each of the protections. Added description for Barbarian, Operation Neptune Game. Work with Gothmog (Christophe Fontanel) on getting more accurate information on Dungeon Master fuzzy bits protection – September 2010
- V0.8 Major Revision: Added taxonomy for the different protection categories. Rewrote of large portion of the explanations about fuzzy bits. Added 5 new protections: Invalid ID Field, Non Standard IDAM, Sector over Index pulse, Missing Track and Sector within Sector. Added description for several games (Theme Park Mystery, Computer Hits Volume 2, Kick Off 2, Colorado). Better documented Intra-sector Bit Variation with reference to Colorado. For the first time lots of diskettes (over 50) have been tested and references for them have been entered in the document. And again lots of clean-up – October 2007
- V0.7 several modifications based on feedback from Ijor and Obo. Added a new section on weak bits based on US patent and a section on Invalid character during format. Plus lots of miscellaneous cleanup. – January 2007
- V0.6 Modifications based on feedback from Ijor, I have added one section about Double Density diskette format, the Invalid sector number protection, and the intra-sector variable bit rate protection – December 2006
- V0.5 Incorporated feedback from Gothmog about the DM protection patent, added a section with several US patent about protection, modified the section on fuzzy bits, modified the fuzzy bit detection in WD1772 DPLL – December 2006
- V0.4 Complete documentation cleanup and links verification - November 2006.
- V0.3 Major Revision: Merged several related sector protections, modified extensively the description of several protections, added section on example of protections, added analyze program short presentation, added DPLL presentation, and added new protections: PAT and NAT. - October 2006.
- V0.2 Minor correction based on feedback - June 2006.
- V0.1 Initial writing - May 2006.