A Technical Overview of Commodore Copy Protection

Glenn Holmer (“ShadowM”)
www.lyonlabs.org/commodore/c64.html
World of Commodore Expo, 12/01/2007

Why Talk About This?

- These skills were a “black art” to begin with and are in danger of being forgotten
- There's a lot of myth and legend about this stuff, but the truth is out there
- Knowing how data are written helps to understand common disk errors
- It's really cool

What is Copy Protection?

- A software loader that is able to read non-standard data on the surface of the disk
- Used to keep users from making copies of software instead of buying it
- Usually used with encryption, undocumented opcodes, etc.
- I'll only discuss physical protection

What I'll Cover

- How “normal” data are physically encoded on the surface of the disk
- Types of copy protection (how protection is encoded on the disk)
- Disk programming (technique and examples)
- Samples (disassemblies of code from protected disks)

Disk Structure

- To understand copy protection, you have to understand how data are written to the disk
- Data are stored in sectors within tracks (what we see with a sector editor)
- Number of sectors varies by zone
- Head is moved from track to track by a stepper motor (1/2 track at a time)

Data On the Disk

- Disk is covered in iron oxide (rust); write head polarizes magnetic domains to create information
- '1' detected by change in polarity, '0' by no change within a certain time
- *What about data with many '0' bits?*
- How do we tell what track we're on, or where a sector begins? (need a unique marker that's not '1' or '0')

The Sync Mark

- Ten or more '1' bits in a row are detected in hardware (sets bit 7 of register $1C00 in the drive)
- Used to mark the beginning of each sector's header and data blocks
- Gaps between blocks give the hardware time to “switch gears” before the next sync mark is written or read
- *What about data with many '1' bits?*

GCR Encoding

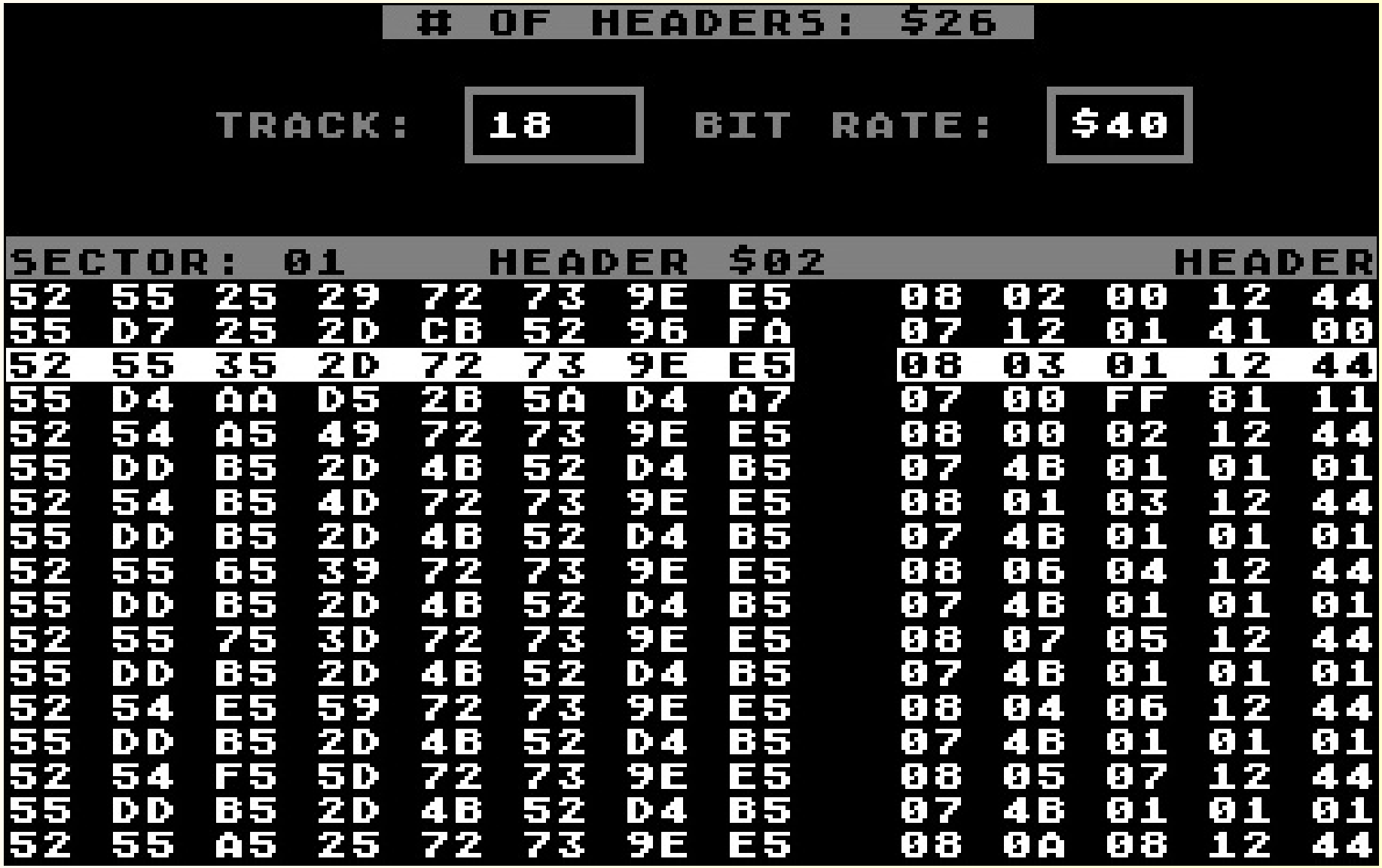
- Every nybble (4 bits) converted to 5 bits of GCR
- Conversion table set up so that no more than eight consecutive one bits or two consecutive zero bits are ever written to the disk as data
- Solves both issues:
  - ►too many zeros cause timing errors
  - ►too many ones make a sync

Block Structure

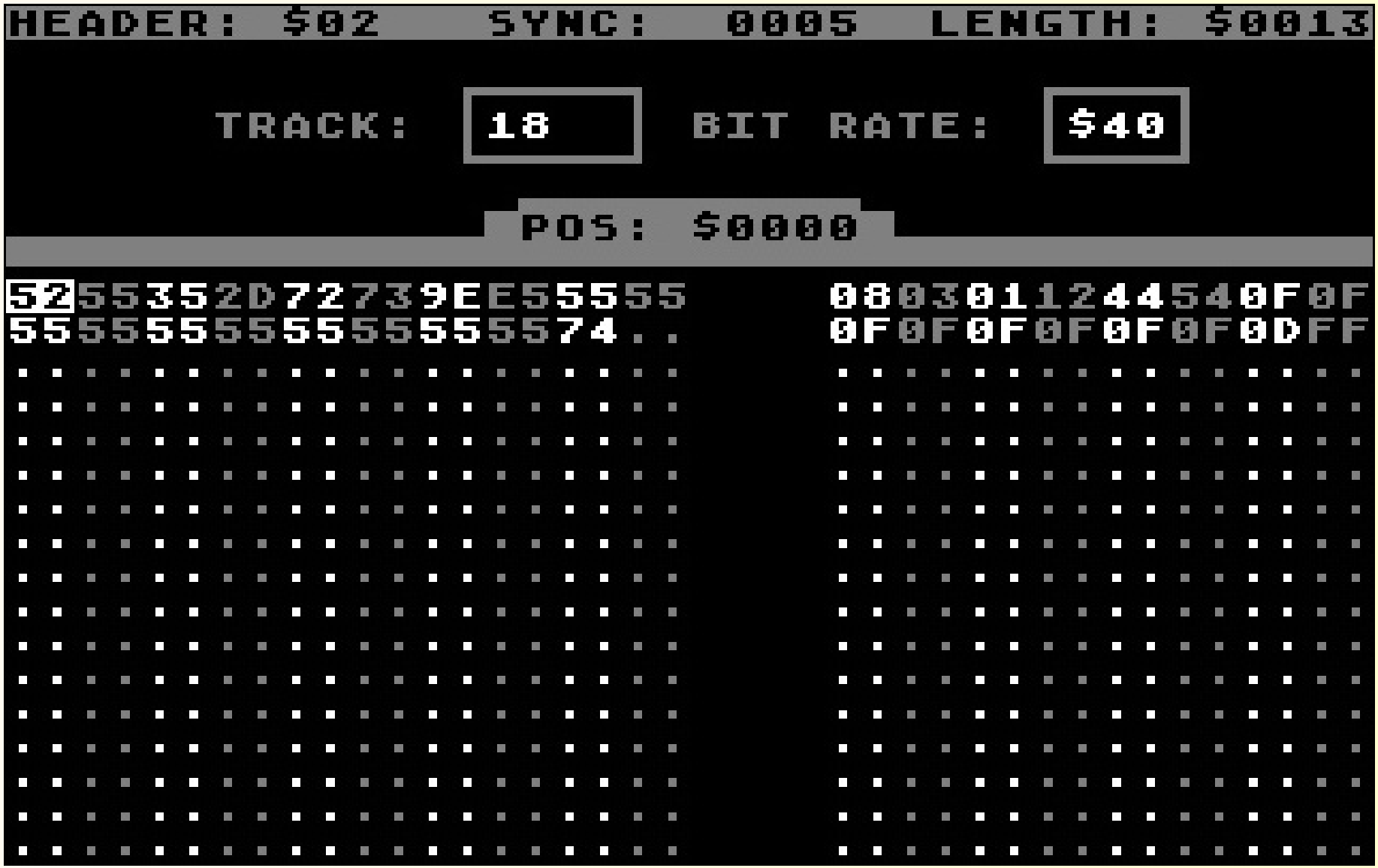
Header Block
sync mark
header ID ($08)
checksum
sector no.
track no.
disk ID 2
disk ID 1
$0F byte
$0F byte
header gap ($55)

Data Block
sync mark
data ID ($07)
data (256 bytes)
data checksum
$00 byte
$00 byte
tail gap ($55)

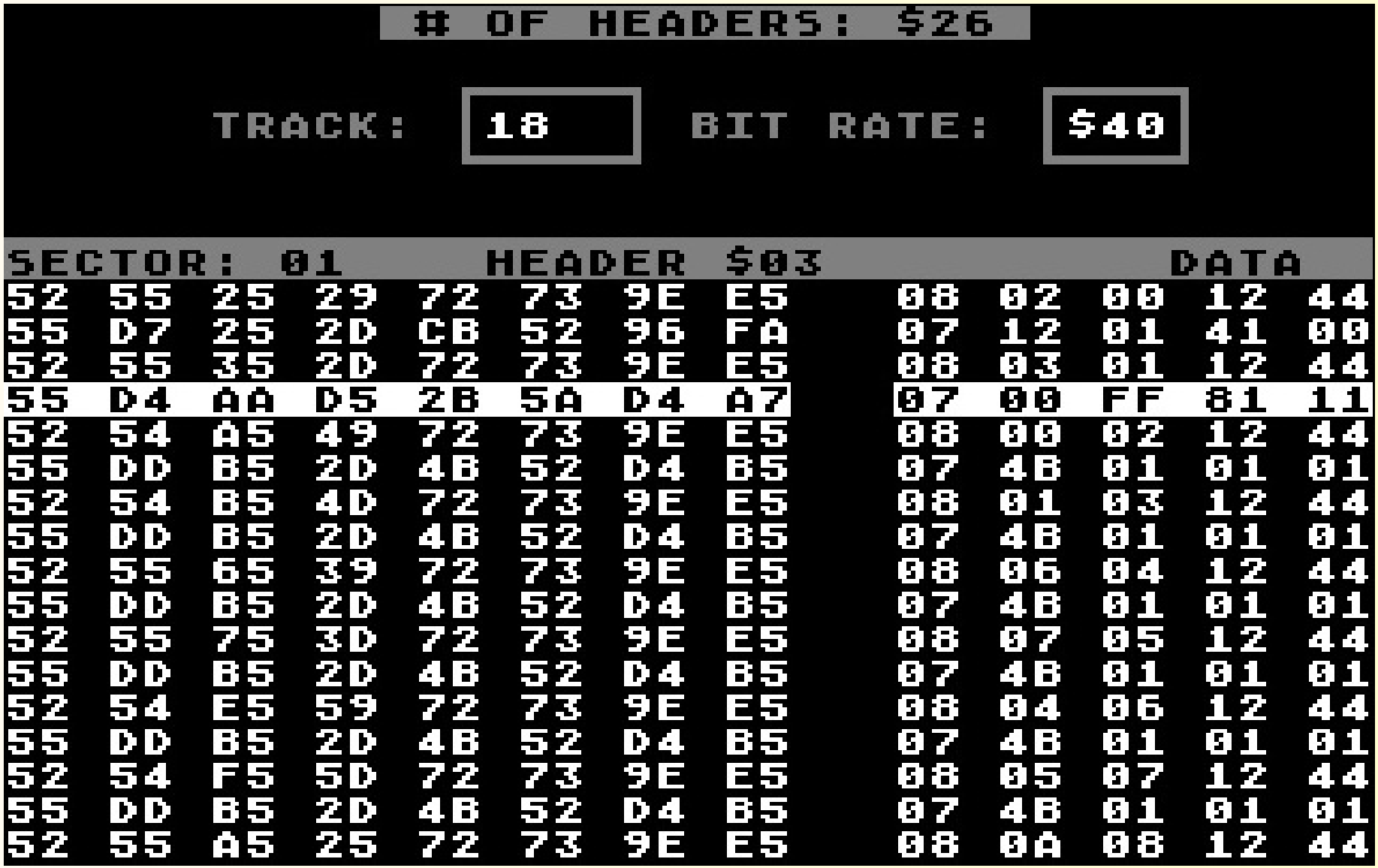
Header Block



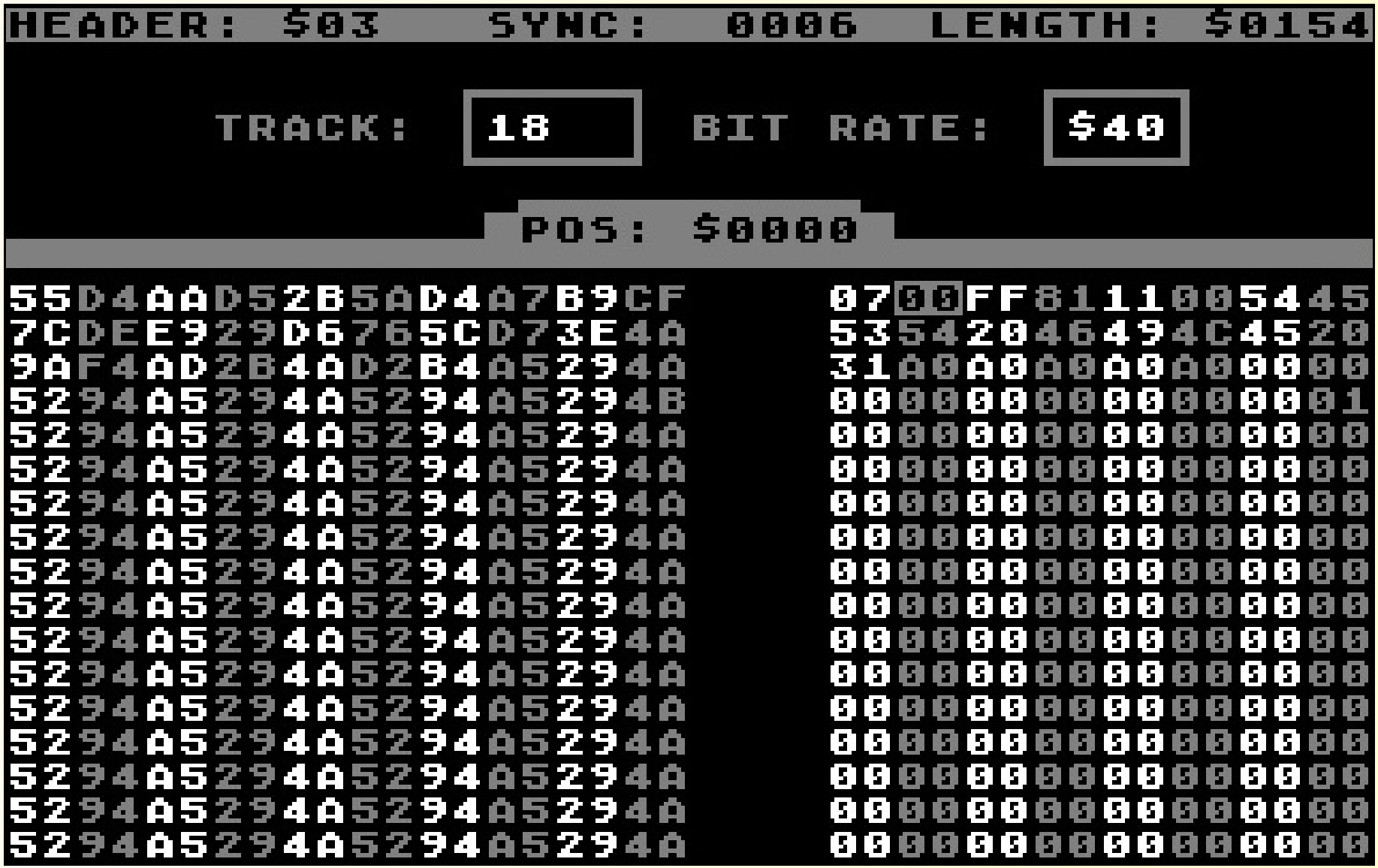
Header Block Detail



Data Block


OF HEADERS: $26
TRACK: 18
BIT RATE: $40
SECTOR: 01 HEADER $03 DATA
52 55 25 29 72 73 9E E5 08 02 00 12 44
55 D7 25 2D CB 52 96 FA 07 12 01 41 00
52 55 35 2D 72 73 9E E5 08 03 01 12 44
55 D4 AA D5 2B 5A D4 A7 07 00 FF 81 11
52 54 A5 49 72 73 9E E5 08 00 02 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 54 B5 4D 72 73 9E E5 08 01 03 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 55 65 39 72 73 9E E5 08 06 04 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 55 75 3D 72 73 9E E5 08 07 05 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 54 E5 59 72 73 9E E5 08 04 06 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 54 F5 5D 72 73 9E E5 08 05 07 12 44
55 DD B5 2D 4B 52 D4 B5 07 4B 01 01 01
52 55 A5 25 72 73 9E E5 08 0A 08 12 44

Data Block Detail



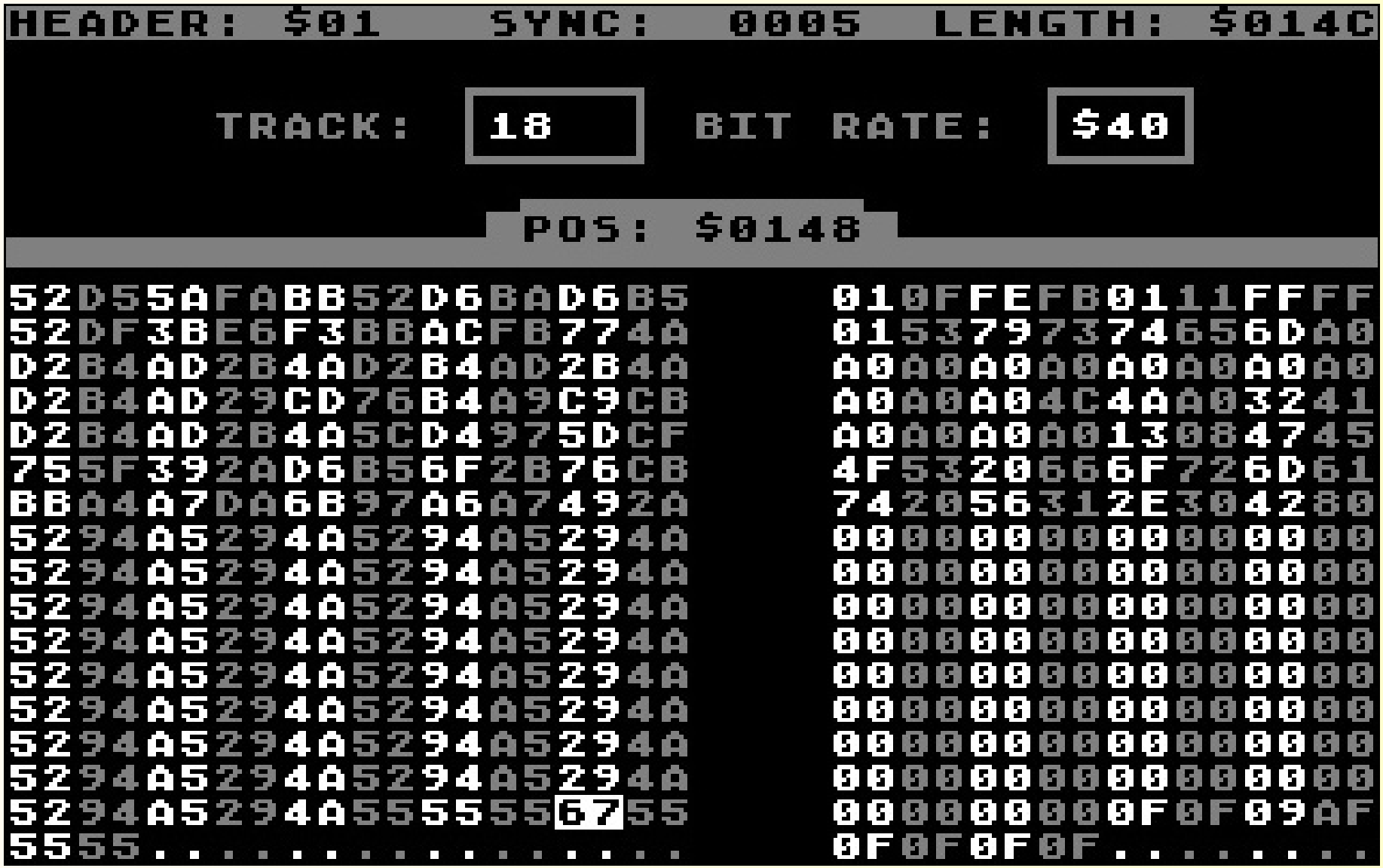
Data Block Detail #2

```
HEADER: $03      SYNC:    0006   LENGTH: $0154

         TRACK:  18       BIT RATE:  $40

                   POS: $014F

5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
5294A5294A5294A5294A    0000000000000000
52BD55294D5555555555    00EF000C0F0F0F0F
55555555555555555555    0F0F0F0F0F0F0F0F
```

Types of Copy Protection

- simple errors
- unusual header/gap data
- extra tracks (36-40)
- no-sync track
- wrong density
- fat tracks
- spiral tracking
- custom formats

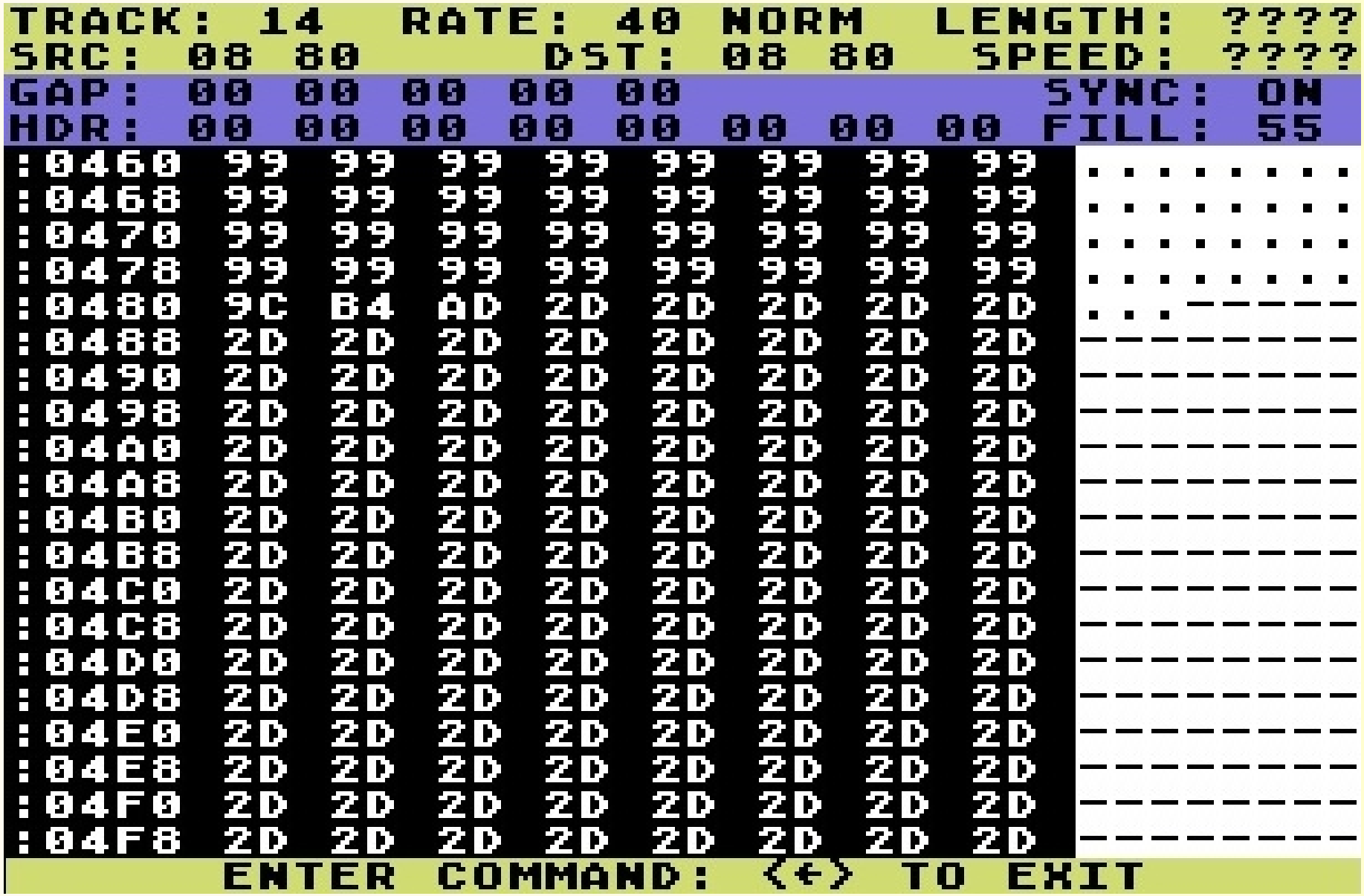
GEOS Tail Gap



Defender of the Crown #1

Defender of the Crown #2

Defender of the Crown #3



Defender of the Crown #4

The Hardware

- Both the '64 and the 1541 have CPU, RAM, ROM, and I/O chips
- Commodore drives are “intelligent peripherals”; half the operating system is in the drives (no disk buffers in main memory)
- Code can be sent to the drive and run there: *this is the heart and soul of copy protection*

1541 Memory Map

- $0000-$07FF: RAM
  - $0000-$0015: job queue
  - $0100-$01FF: CPU stack
  - $0200-$0229: command buffer
  - $0300-$07FF: data buffers
- $1800-$180E: VIA #1 (serial controller)
- $1C00-$1C0E: VIA #2 (disk controller)
- $C100-$FFFF: DOS ROM

Disk Programming

- Direct-access (“channel commands”): M-R, M-W, B-E, etc. -- some are used in conjunction with “#” file
- Placing commands in the drive's job queue and letting the controller execute them
- Custom code executed in the drive: requires knowledge of hardware registers and DOS internals

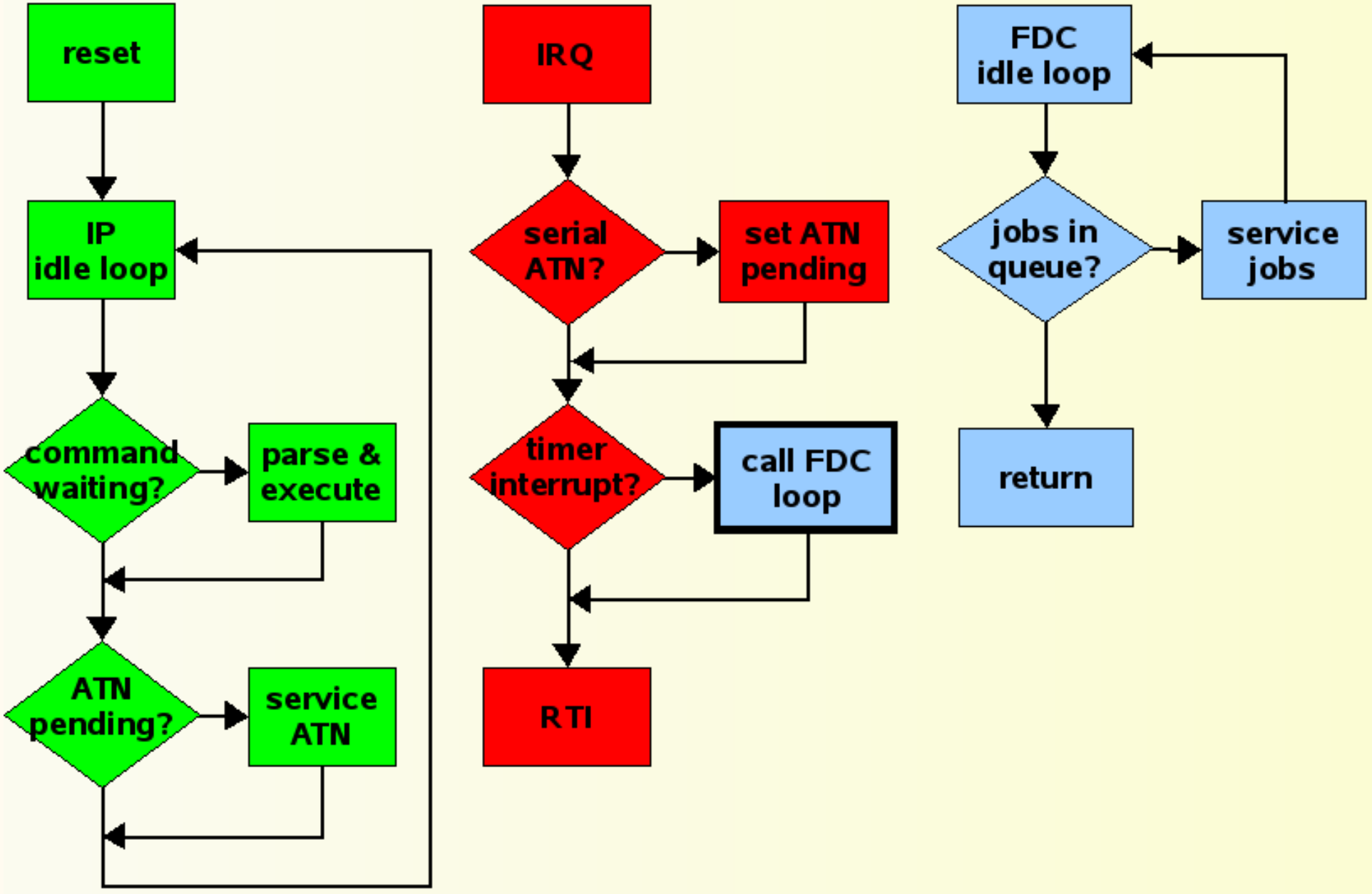
Direct Access

- Channel commands: require opening "#" file (U1, U2, B-E, B-P, etc.)
  - B-E <channel> <unit> <track> <sector>
  - B-P <channel> <position>
- Direct commands
  - M-R <lo> <hi> <no. bytes>
  - M-W <lo> <hi> <no. bytes> <data>
  - M-E <lo> <hi>

IP/FDC Processing

- Older Commodore drives had multiple CPUs; 1541 emulates with interrupts
- IP (interface processor) mode: communication with the '64, file handling (sets up FDC jobs)
- FDC (floppy disk controller) mode: triggered every 10 ms by an interrupt

DOS Flowchart



Working the Job Queue

	$0300	$0400	$0500	$0600	$0700
job	$00	$01	$02	$03	$04
track	$06	$08	$0A	$0C	$0E
sector	$07	$09	$0B	$0D	$0F

$80 READ
$90 WRITE
$A0 VERIFY
$B0 SEEK
$C0 BUMP
$D0 JUMP
$E0 EXECUTE

Job Queue Example

This code reads an illegal track into the buffer at $0300.

```
     LDA #$25 ;track 37
     STA $06
     LDA #$0F ;sector 15
     STA $07
     LDA #$80 ;READ job code
     STA $00  ;put job code for FDC
loop LDA $00
     BMI loop ;wait for FDC to clear
```

Down on the Bare Vinyl

- Requires knowledge of hardware registers and DOS internals (API and zero-page variable usage)
- Must stay aware of FDC/IP interface
- There is no safety net; anything the hardware is physically capable of can be requested!

Disk Controller Registers

$1C00 (data port B)

- bit 7: sync detect
- bits 5,6: density
- bit 4: WP sense
- bit 3: LED on/off
- bit 2: motor on/off
- bits 0,1: head phase

$1C03 (data direction: $00 = input, $FF = output)

$1C0C (peripheral control register)

	7	6	5	4	3	2	1	0
read mode:	1	1	1	x	1	1	1	x
write mode:	1	1	0	x	1	1	1	x

(bits 1, 2, and 3 select overflow enable to CPU)

Reading/Writing Sync

read sync:

```
loop BIT $1C00
     BMI loop
     CLV
     LDA $1C01
```

write sync:

```
     LDA #$FF
     LDX #$05
     STA $1C01
     CLV
loop BVC loop
     CLV
     DEX
     BNE loop
```

Reading/Writing Data

read data:

```
        LDA $1C0C
        ORA #$E0
        STA $1C0C ;PCR
        LDA #$00
        STA $1C03 ;DDR
        CLV
loop    BVC loop
        CLV
        LDA $1C01
        STA $data
```

write data:

```
        LDX #$FF
        STA $1C03 ;DDR
        LDA $1C0C
        AND #$1F
        ORA #$C0
        STA $1C0C ;PCR
        LDA $data
        STA $1C01
        CLV
loop    BVC loop
        CLV
```

Setting Density

set density for tracks 18-24:

```
LDA $1C00 ;density is bits 5, 6
AND #$9F  ;mask off density bits
ORA #$40  ;set density
STA $1C00
```

density zone bit values:

```
$60 tracks  1-17 (sectors 0-20)
$40 tracks 18-24 (sectors 0-18)
$20 tracks 25-30 (sectors 0-17)
$00 tracks 31-35 (sectors 0-16)
```

Stepping the Head

```
LDX $1C00 ;head phase is bits 0, 1
INX       ;step inward
TXA
AND #$03  ;mask phase bits only
STA temp
LDA $1C00
AND #$FC  ;mask off phase bits
ORA temp  ;apply new phase bits
STA $1C00
```

DEX on second line to step outward.

Make sure to allow the head time to settle.

Abacus Assembler loader

loader pseudocode:

```
1) open 2,8,2,"#2"
   (buffer 2 is at $0500 in drive)
2) open 1,8,15,"B-E 2 0 18 5"
   (block-execute track 18, sector 5)
3) close 2
4) open 2,8,2,"#0"
   (buffer 0 is at $0300 in drive)
5) print #1,"B-P 2 0"
6) input #2 (256 bytes)
7) if 27 sectors have been read, goto 9
8) print #1,"U3" (execute $0500), goto 5
9) decrypt loaded code with final sector
```

Abacus drive code #1

```
LDA $053A
STA $80   ;track
LDA $053C
STA $81   ;sector
LDA #0    ;buffer 0
JSR $D6D3 ;set up job queue
LDX #0
LDA #$80  ;READ job code
JSR $D57D ;to job queue
JSR $D599 ;wait for completion

:053A 21 00 0F 0F 0A 02 0E 08
:0542 0C 06 0B 05 09 03 0D 07
:054A 80
```

Abacus drive code #2

```
       INC $053B ;sector counter
       LDX $053B
       LDA $053D,X
       BMI done  ;read all sectors?
       STA $053C ;set up next read
       RTS
done   LDA $053D ;reset first sector no.
       STA $053C
       LDA #0    ;reset sector counter
       STA $053B
       INC $053A ;increment track number
       INC $053A ;increment track number
       RTS
```

Zorkquest drive code #1

```
      LDX #2     ;counter
      STX $08
      LDA #$23   ;track 35
      STA $06
redo  LDA #$10   ;sector 16
      STA $07
read  LDA #$80   ;READ job code
      STA $00
      JSR $046F ;wait for completion
      CMP #$01   ;completed without error?
      BEQ next
      STA $09    ;save error code
next  DEC $07    ;another sector
      BPL read
```

Zorkquest drive code #2

```
        JSR step  ;step head in one phase
        DEC $08   ;(do three times)
        BPL redo
        LDY #2
out     JSR $0476 ;restore head position
        DEY
        BPL out
        LDA $09
        BNE done
        LDA #$FF
        STA $01FF ;success flag for loader
        JMP done  ;erase this code, return
```

Zorkquest drive code #3

```
step LDX $1C00 ;head phase is bits 0, 1
     INX       ;step inward
     TXA
     AND #$03  ;mask phase bits only
     STA $44
     LDA $1C00
     AND #$FC  ;mask off phase bits
     ORA $44   ;apply new phase bits
     STA $1C00
     LDA #$D0
     STA $1805 ;set timer
wait BIT $1805 ;allow head to settle
     BMI wait
     RTS
```

Tools for Exploration

- Simple tools: disk monitors like Disk/Extramon and SuperSnapshot (to read/write drive memory)
- More powerful tools: Hacker's Utility Kit, Maverick GCR Editor, Datel utilities (capable of directly editing the disk at the GCR level)
- Hardware assistance: RAMBOard and friends

Resources

- Inside Commodore DOS, Immers & Neufeld
  (excellent commentary, no DOS listings)
  http://project64.ath.cx/misc/index.html (item 16)
- Anatomy of the 1541, Abacus Software
  (less commentary, complete DOS listings)
- CSM Program Protection Manual, vol. II
  (fills in a lot of blanks, has good sample code)
- Kracker Jax Revealed (three booklets)
  detailed explanation of RAPIDLOK and V-MAX
  http://members.aol.com/c64dir/kjtr/index.htm