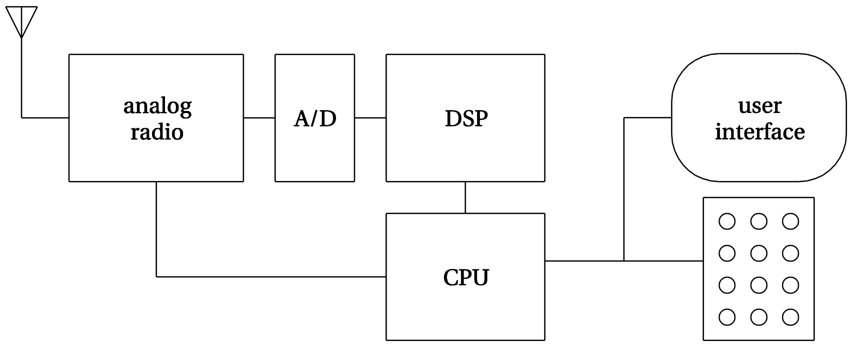
Cell phone platforms

- Today's cell phones use analog front end, digital baseband processing.
  - Future cell phones will perform IF processing with DSP.
- Baseband processing in DSP:
  - Voice compression.
  - Network protocol.
- Other processing:
  - Multimedia functions.
  - User interface.
  - File system.
  - Applications (contacts, etc.)



Mobile Phone Trends

TABLE I
MOBILE PHONE TRENDS IN 5-YEAR INTERVALS.

year	1995	2000	2005	2010	2015
cellular generation	2G	2.5-3G	3.5G	pre-4G	4G
cellular standards	GSM	GPRS UMTS	HSPA	HSPA LTE	LTE LTE-A
downlink bitrate [Mb/s]	0.01	0.1	1	10	100
display pixels [$\times$1000]	4	16	64	256	1024
battery energy [Wh]	1	2	3	4	5
CMOS [ITRS, nm]	350	180	90	50	25
PC CPU clock[MHz]	100	1000	3000	6000	8500
PC CPU power [W]	5	20	100	200	200
PC CPU MHz/W	20	50	30	30	42
phone CPU clock[MHz]	20	100	200	500	1000
phone CPU power [W]	0.05	0.05	0.1	0.2	0.3
phone CPU MHz/W	400	2000	2000	2500	3000
workload [GOPS]	0.1	1	10	100	1000
software [MB]	0.1	1	10	100	1000
#programmable cores	1	2	4	8	16

Power and Battery Capacity

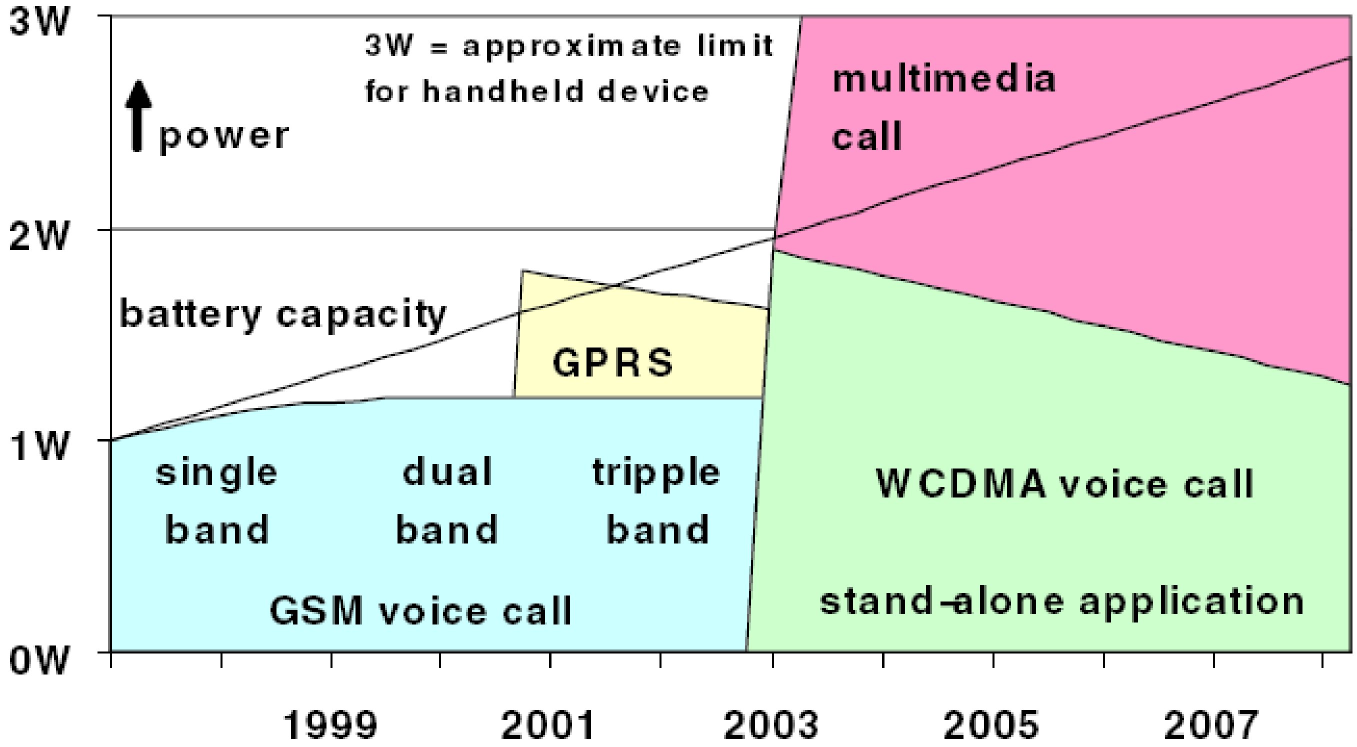
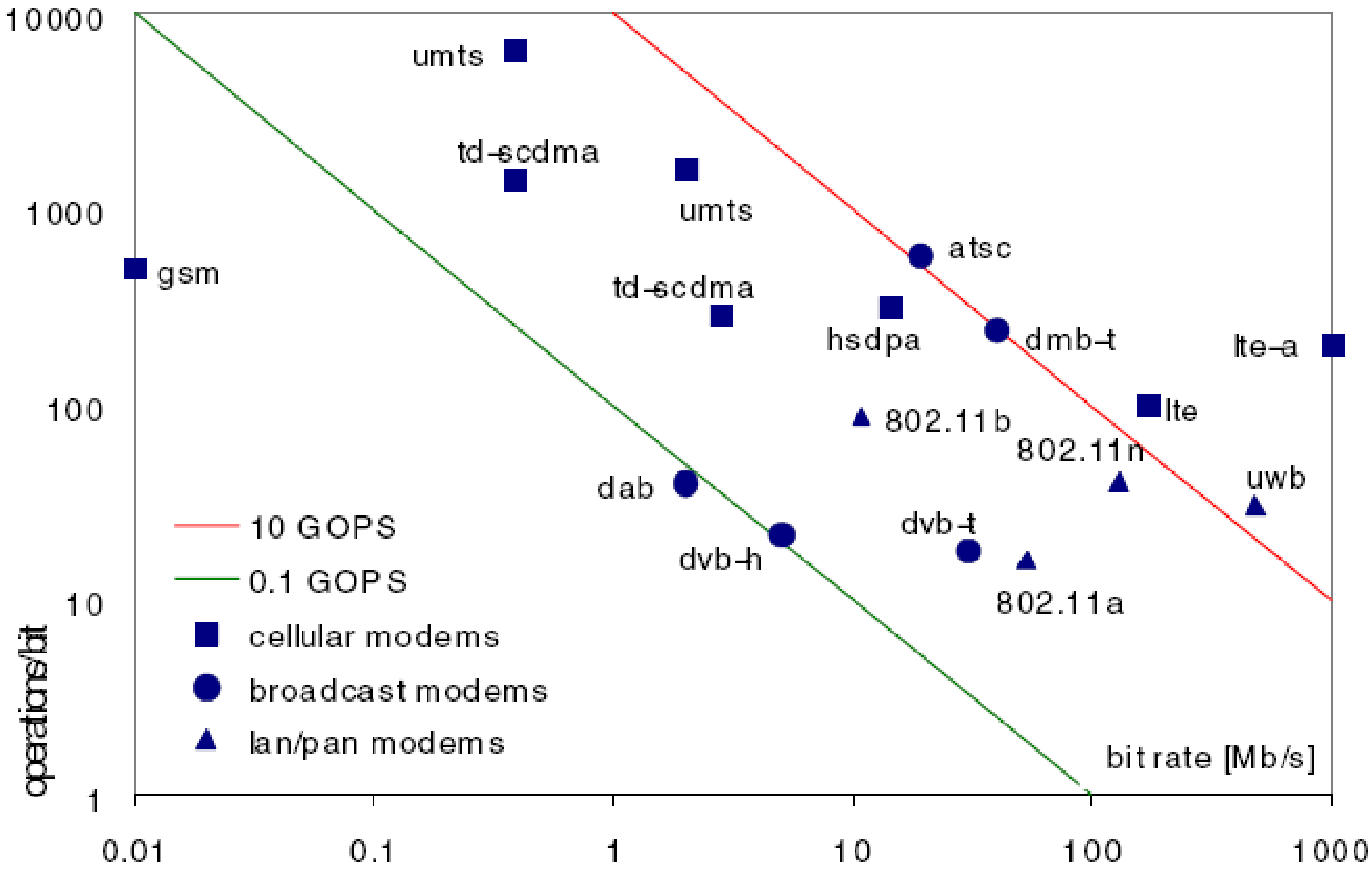
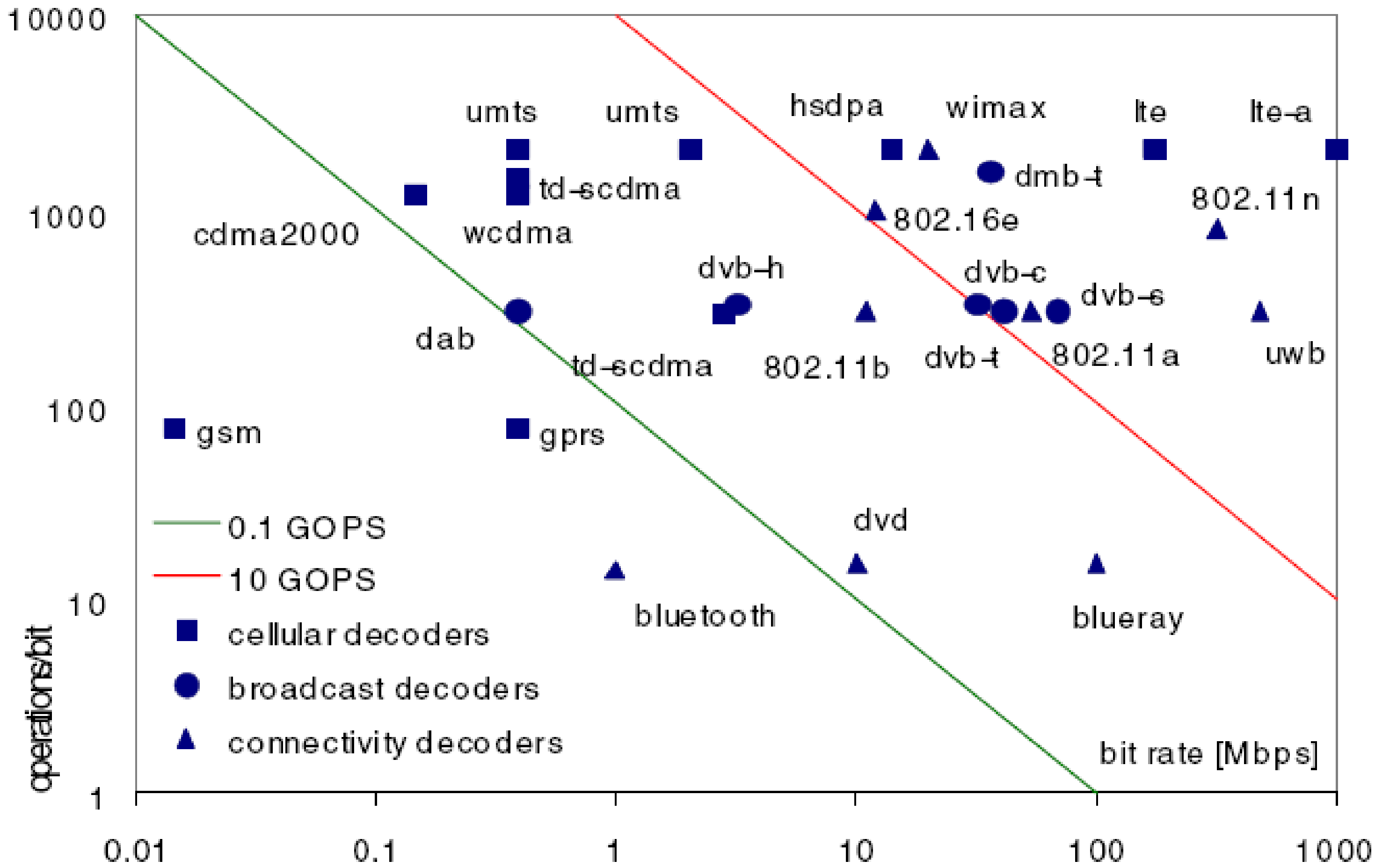


Fig. 1. Battery capacity and power consumption at maximum output power level in cellular transmitters, adapted from [3].

Radio Demodulation Workload



Radio Decoding Workload



3.5G Workload

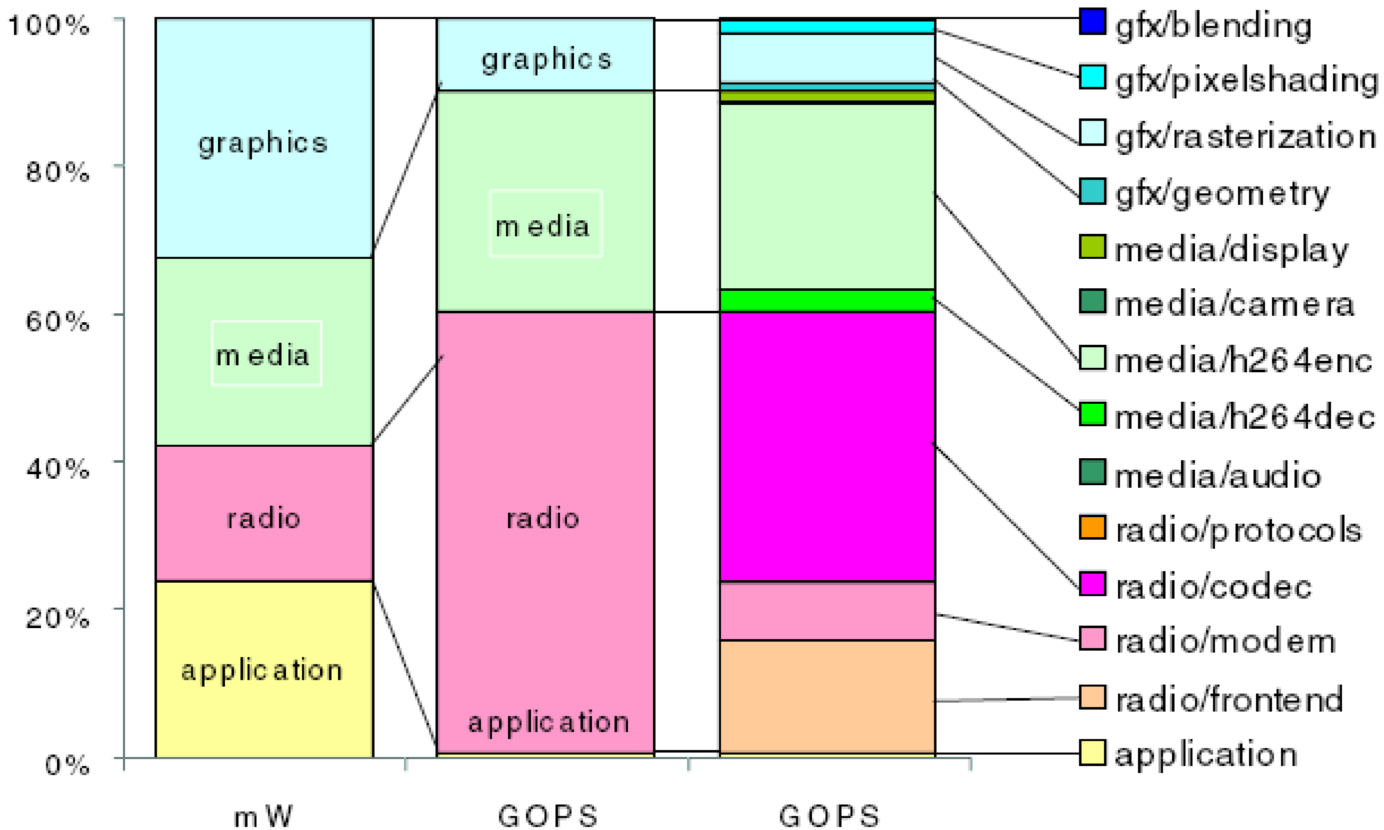


Fig. 3. 3.5G workload (power consumption) as fractions of 100GOPS (1W).

Workload vs Energy/operation

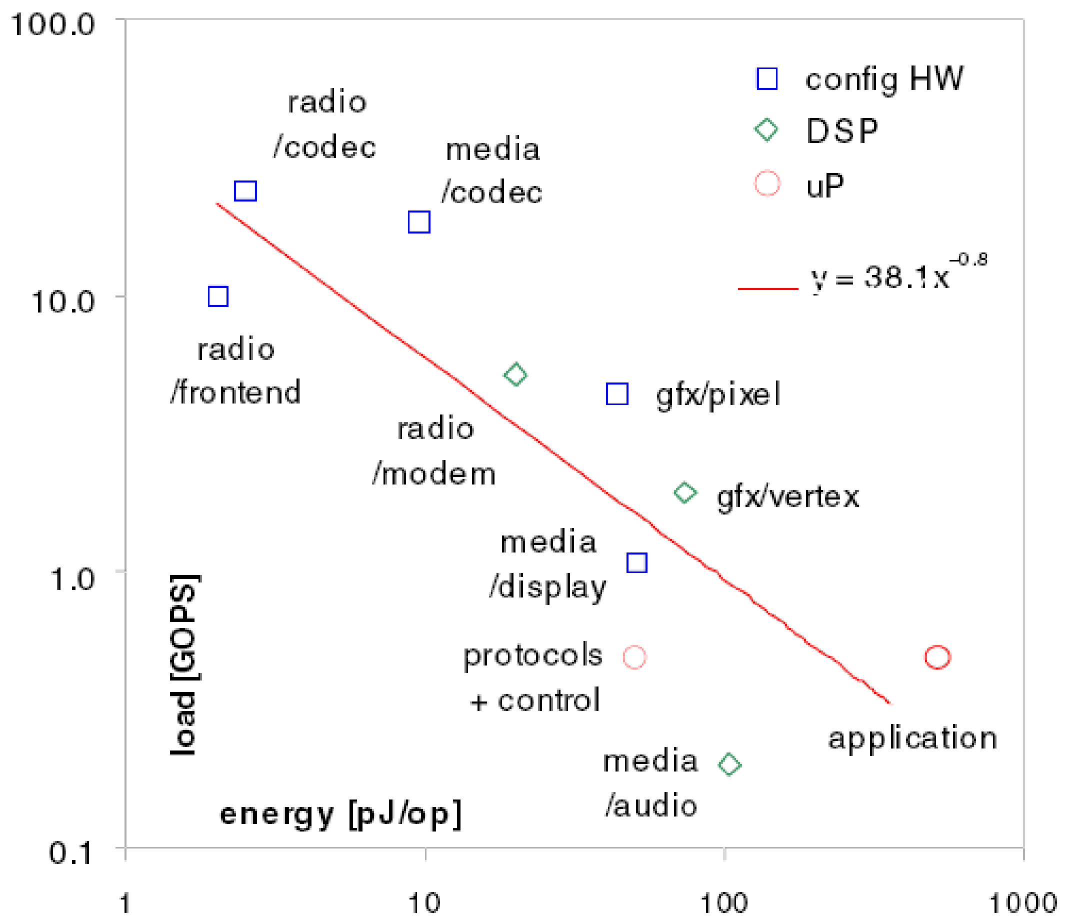


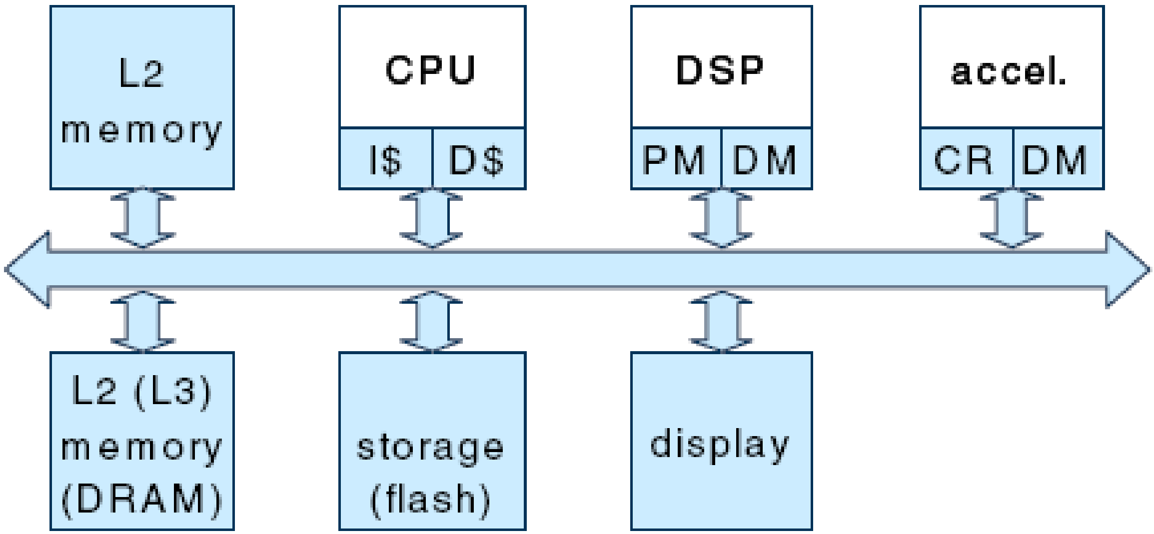
Fig. 4. Workloads [GOPS] versus energy/operation [pJ].

Value of Programming

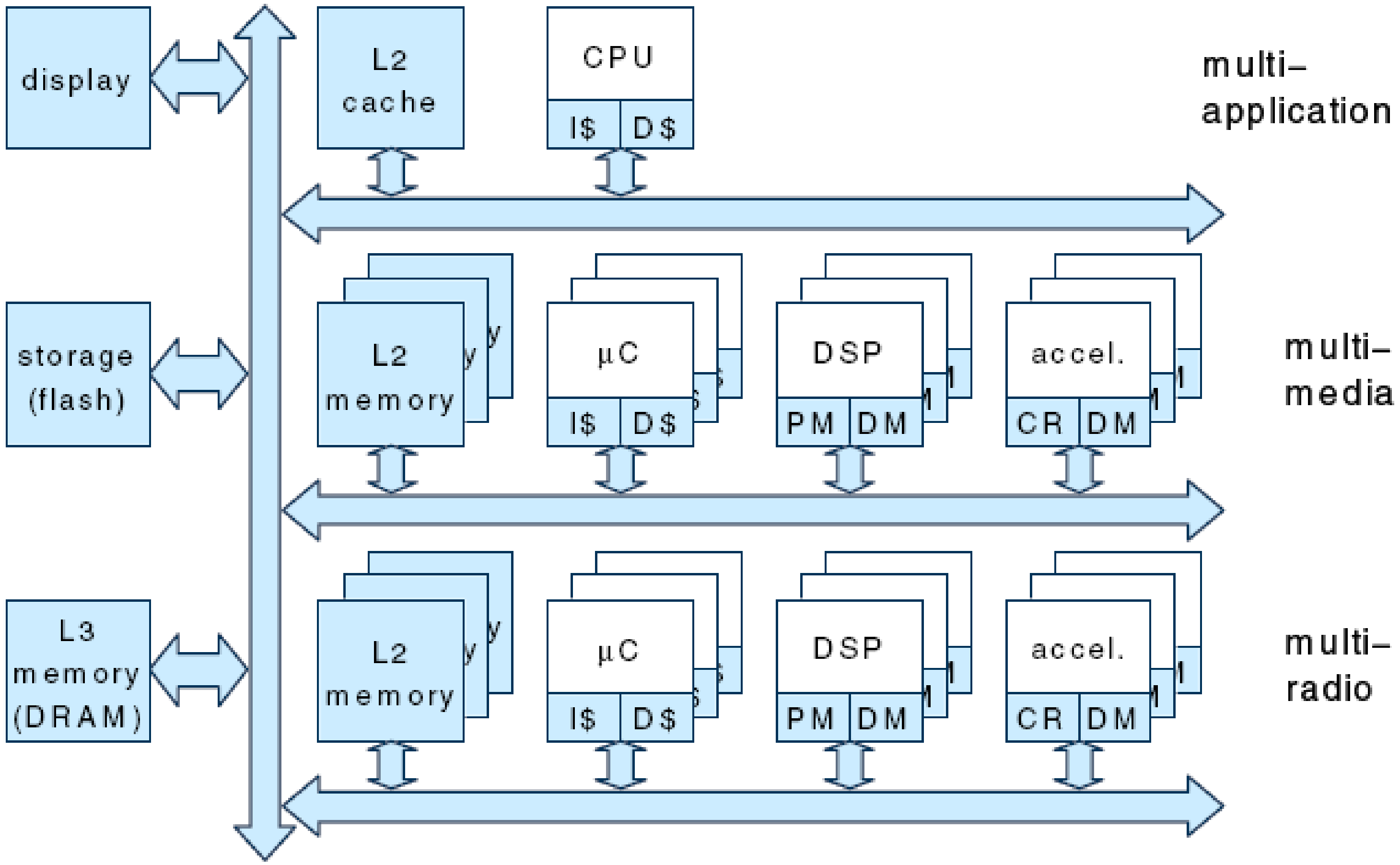
TABLE II
VALUE-AFFORDABILITY OF PROGRAMMABLE SOLUTIONS (EXAMPLES).

	radio	video	3D graphics
very high	protocol stacks		geometry proces.
high	channel estimation		pixel shading
medium	demodulation	motion estimation	
low	turbo decoder (i)fft	entropy (de)coding deblocking	
very low	filters	filters scaling	rasterization pixel blending

2/2.5G Dual-core Architecture



3/3.5G Multi-core Architecture



Cell-phone Chips

TABLE III

PUBLISHED INDUSTRIAL CELL-PHONE CHIPS ("…" DENOTES A SHARED RADIO-MEDIA CORE).

year	ref	source	cmos	total	application		radio		media	
			nm	# cores	core(s)	MHz	core(s)	MHz	core(s)	MHz
1992	[1]	Philips	1000	1	n.a.		KISS-16-V2	…	…	20
2000	[2]	Infineon	250	2	CPU	78	Oak	…	…	78
2001	[9]	Samsung	180	2	ARM9		Teaklite		n.a.	
2003	[6]	Toshiba	130	3	n.a.		n.a.		3x RISC	125
2004	[3]	Nokia	130	2	CPU	50	DSP	…	…	160
2004	[10]	Qualcomm	130	3	ARM9	180	DSP	95	DSP	95
2004	[11]	Renesas	130	2	CPU	216	n.a.		DSP	216
2005	[12]	NEC	130	4	ARM9	200	n.a.		2xARM9 + DSP	200
2006	[13]	ST	130	2	ARM8	156	ST122 DSP	…	…	156
2007	[14]	Infineon	90	2	ARM9	380	TEAKlite	…	…	104
2008	[15]	Renesas et al	65	4	ARM11	500	ARM9	166	ARM11 + SHX2	500
2008	[16]	TI	45	5	ARM11	840	?		C55 + ?	480
2008	[17]	NEC	65	3	ARM11	500	ARM11	250	DSP	500
2009	[18]	Panasonic	45	4	ARM11	486	ARM11	245	2xDSP	216
2009	[19]	Renesas	65	2	CPU	500	n.a.		SHX2	500

Power Management Knobs

TABLE IV

POWER MANAGEMENT KNOBS: f_C DENOTES CLOCK FREQUENCY, V_{DD} AND V_t DENOTE SUPPLY AND THRESHOLD VOLTAGE, AND P_D AND P_S DENOTE DYNAMIC AND STATIC POWER CONSUMPTION.

	knob		throughput	power
stop the clock:	$f_C \downarrow 0$	$\Rightarrow$	$\downarrow 0$	$P_D \downarrow 0$
frequency scaling (FS)	$f_C \downarrow$	$\Rightarrow$	$\downarrow$	$P_D \downarrow$
voltage scaling (VS)	$V_{DD} \downarrow$	$\Rightarrow$	$\downarrow$	$P_D \downarrow$
power down	$V_{DD} \downarrow 0$	$\Rightarrow$	$\downarrow 0$	$P_S \downarrow 0$
forward body bias (FBB)	$V_t \downarrow$	$\Rightarrow$	$\uparrow$	$P_S \uparrow$
reverse body bias (RBB)	$V_t \uparrow$	$\Rightarrow$	$\downarrow$	$P_S \downarrow$

Compact disc players

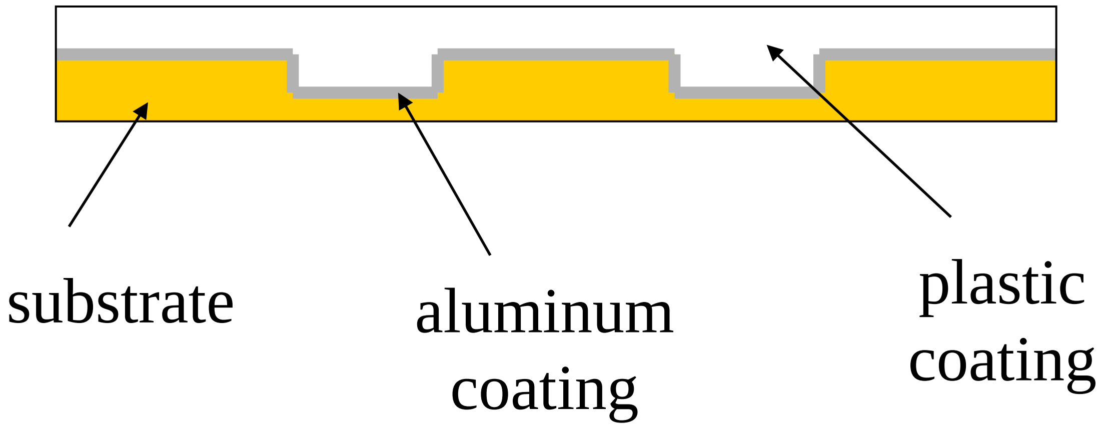
- Device characteristics.
- Hardware architectures.
- Software.

CD digital audio

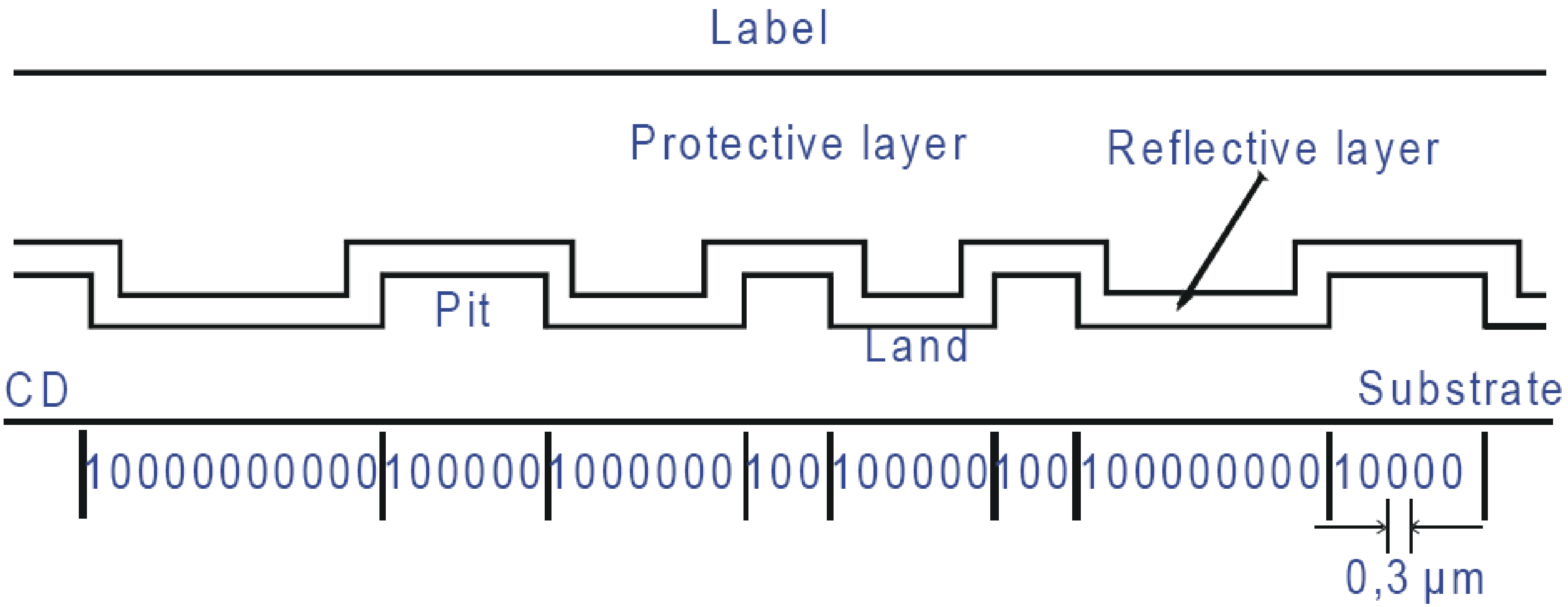
- 44.1 kHz sample rate.
- Quantization: 16 bit samples.
- Pulse coded modulation (PCM)
- Stereo (2 channels)
  - ~1.4 Mbit/s.
- Additional data tracks.
- S/N: ~ 6 dB/bit, 16 bit → 98dB

Compact disc

- Playback time : max 74 min
  - 747 Mbyte
- Data stored on bottom of disc:



CD-DA: pits and Lands

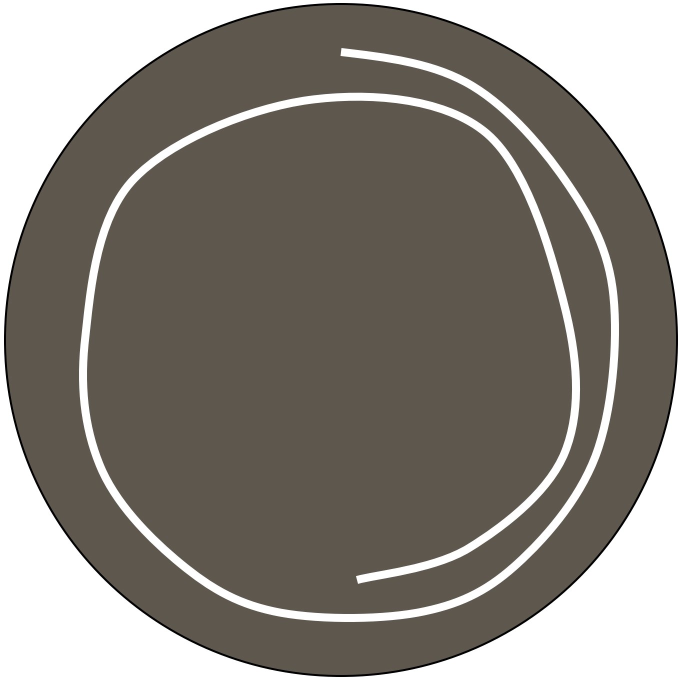


CD medium

- Rotational speed: 1.2-1.4 m/s
- Constant linear velocity (CLV).
- Track pitch: 1.6 microns.
- Diameter: 120 mm.
- Pit length: 0.8 -3 microns.
- Pit depth: .11 microns.
- Pit width: 0.5 microns.
- Laser wavelength: 780 nm.

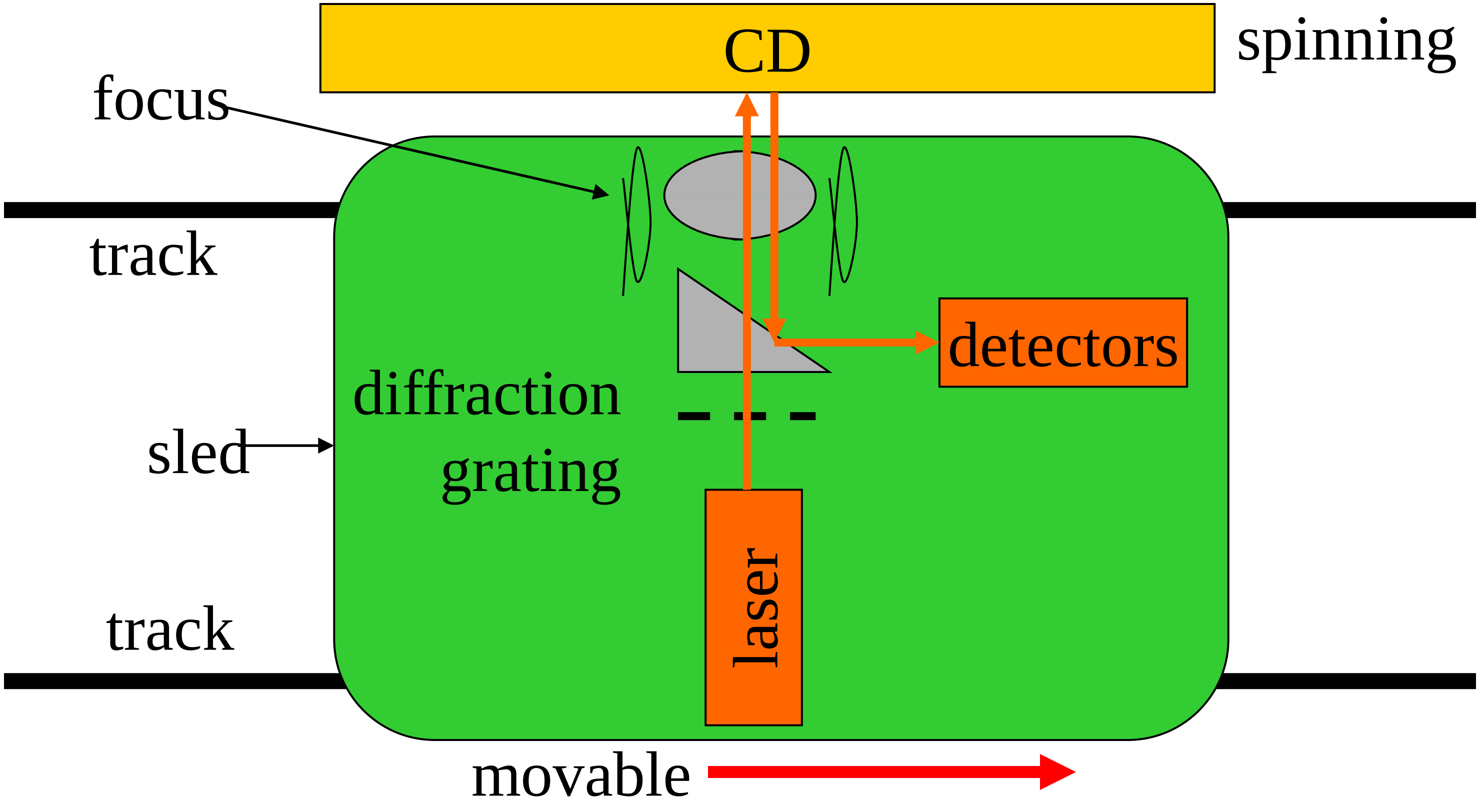
CD layout

- Data stored in spiral, not concentric circle:
- One spiral with approx. 20k turns



CD mechanism

- Laser, lens, sled:

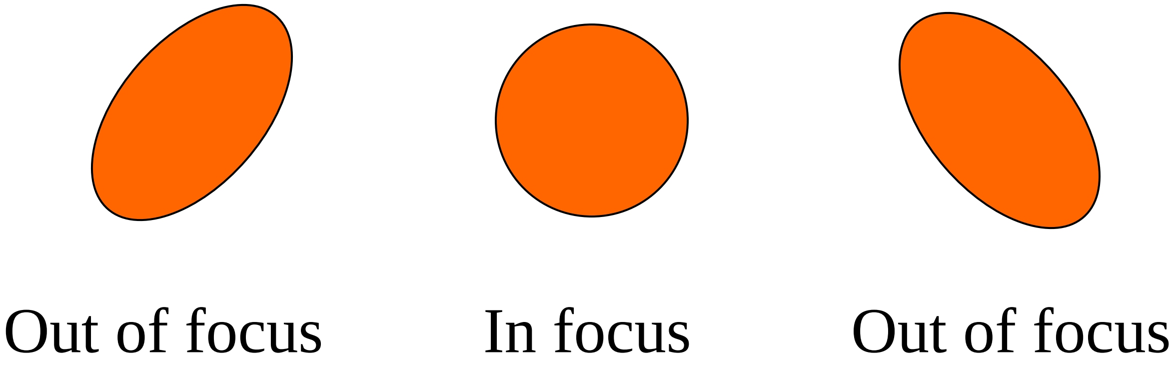


Laser pickup sled

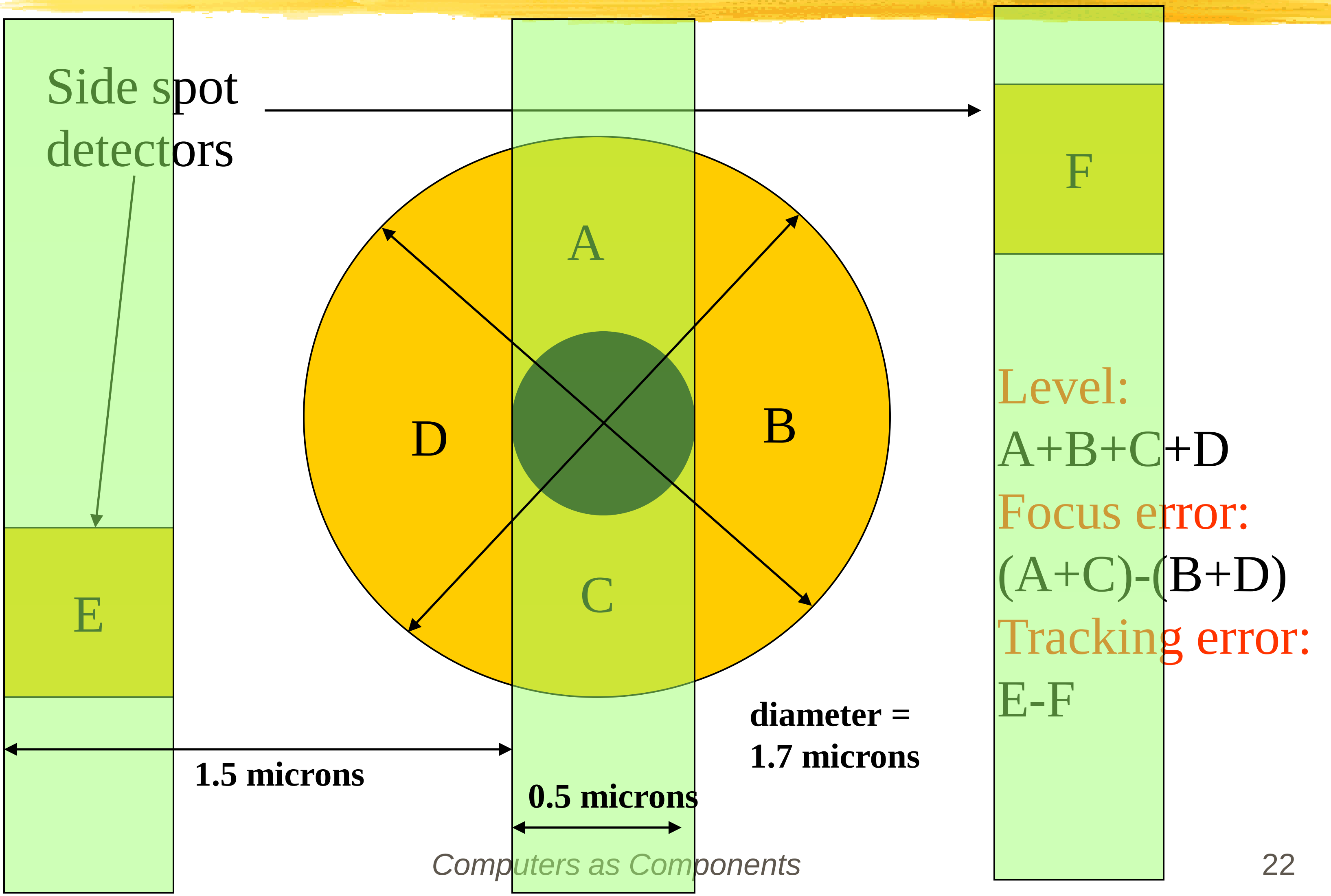
- It is movable
- It is comprised of
  - the laser,
  - a system of lenses,
  - a photodetector, and
  - a motor which moves the sled.

Laser focus

- Focus controlled by vertical position of lens.
- Unfocused beam causes irregular spot:



Laser pickup



Servo control

- Four main signals:
  - focus (laser) @ 245 kHz;
  - tracking (laser) @ 245 kHz;
  - sled (motor): @ 800 Hz;
  - Disc motor.

Optical pickup

EFM (Eight-to-fourteen modulation)

- Fourteen-bit code guarantees a maximum distance between transitions to minimize the transition rate.
- To guarantee pits of specific lengths, the CD standard requires that there are at least 2 and at most 10 zeroes between each pair of 1s.
- The shortest possible pit (or land) thus represents 3 EFM bits (100), and the longest 11 EFM bits (10000000000)
- 256 are chosen from 267 combinations that satisfies the constraints

EFM

Example from the code conversion table

data bits	channel bits
00000000	01001000100000
00000001	10000100000000
...	...

EFM

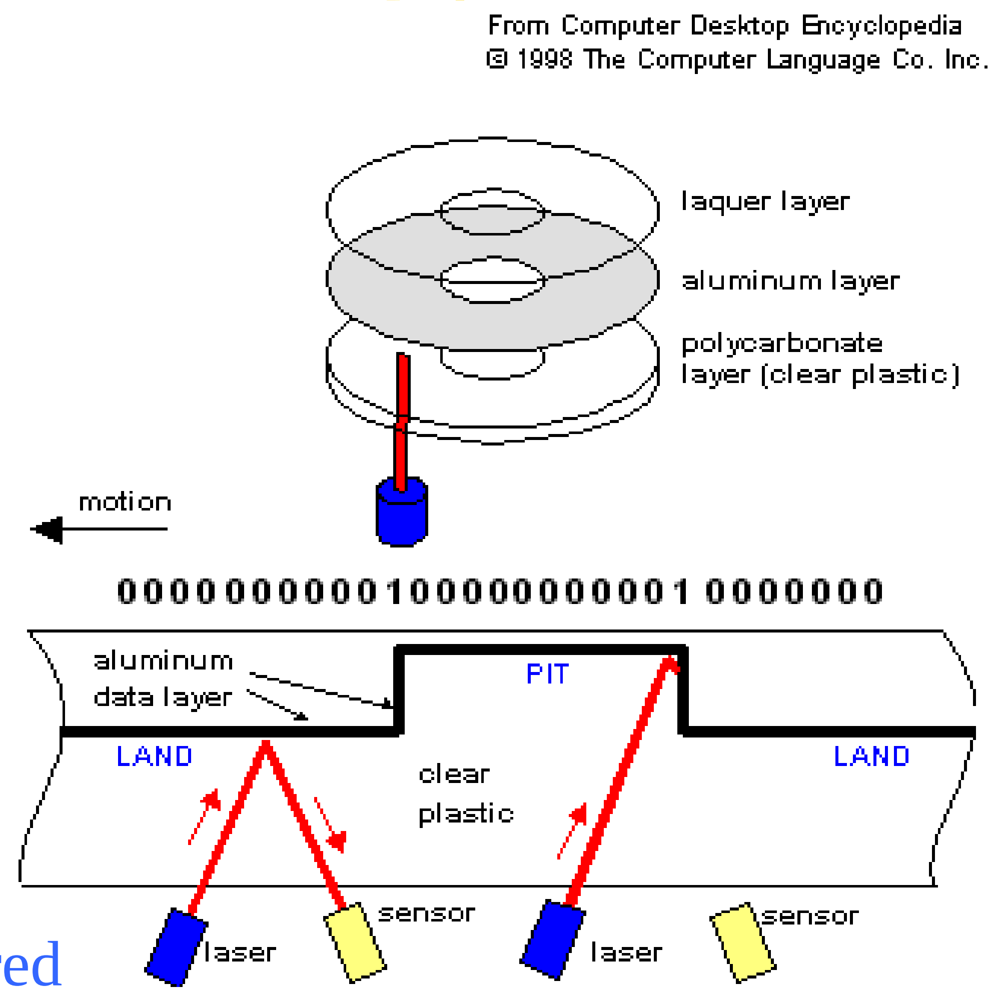
Concatenation of independent 14 bit values could lead to a violation of:

- minimum distance of 2 bits between Ones
- maximum distance of 10 bits between Ones
- => three additional ***merging (filling) bits***

CD-DA: Eight-to-Fourteen Modulation Example

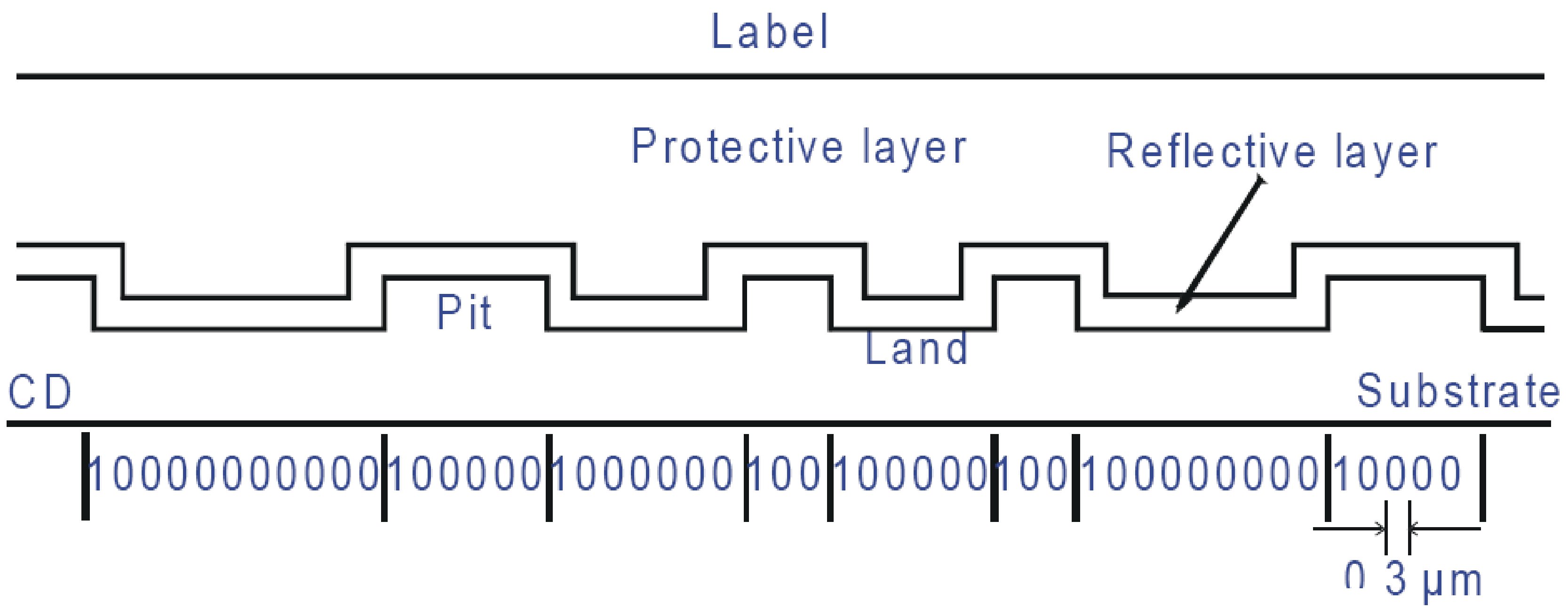
Audio Bits		0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1
Modulation Bits		0 1 0 0 1 0 0 0 1 0 0 0 0 0	1 0 0 0 0 1 0 0 0 0 0 0 0 0
Filling Bits	0 1 0	1 0 0	
Channel Bits	0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0		
On the CD-DA	l p p p l l l p p p p l l l l l l p p p l l l l l p p p p p p p p p		

CD-DA: pits and lands



780 nm = infrared

CD-DA: pits and lands



Reading: Laser focused onto reflective layer

- **Lands** - almost totally reflecting the light
- **Pits** – scattering the light

Error correction

- CD interleaves Reed-Solomon blocks to reduce effects of large data gaps (scratches and other bursty errors).
- The time required to complete Reed-Solomon coding depends greatly on the number of erasure bits

CIRC encoding

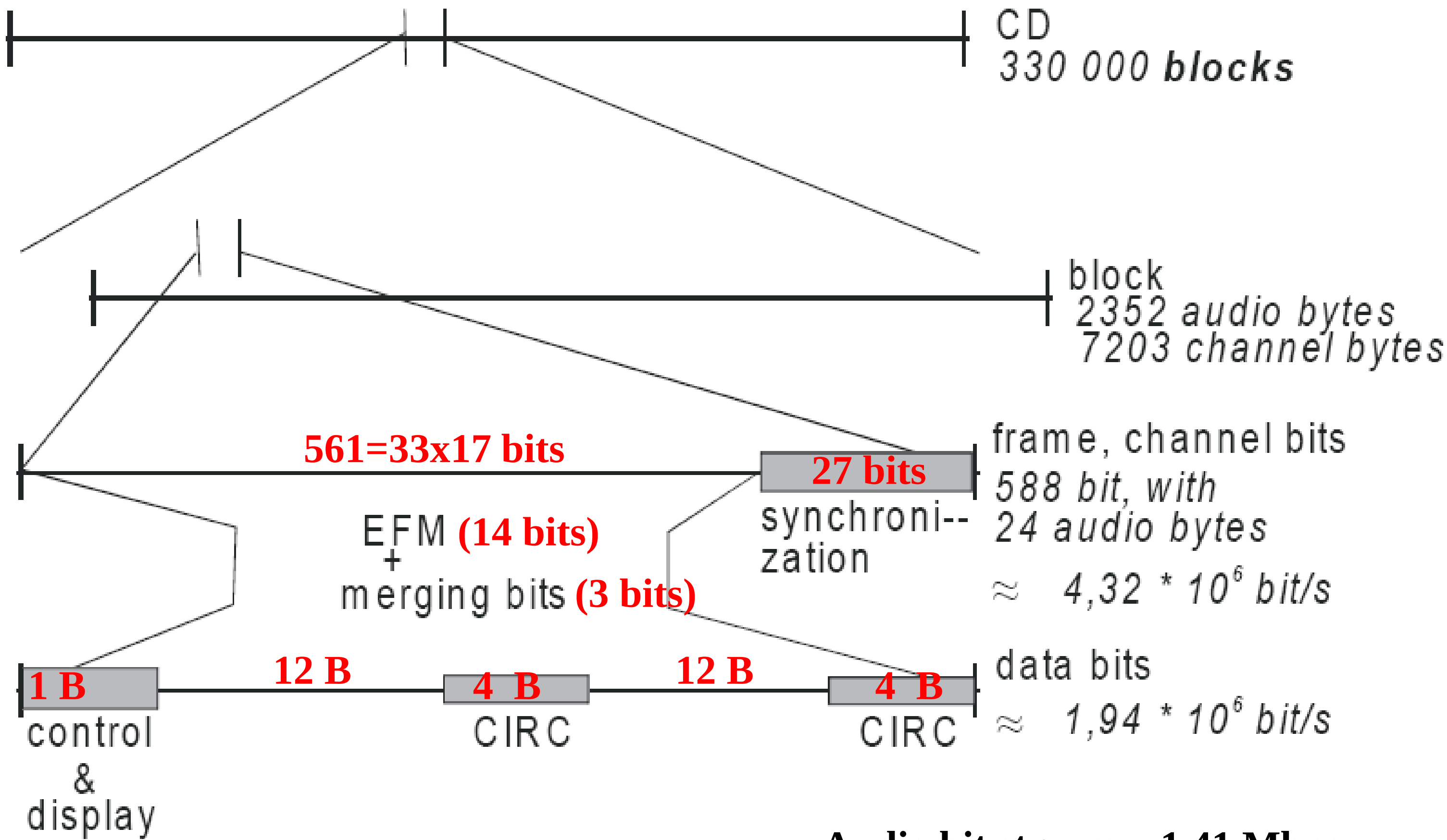
- Cross-interleaved Reed-Solomon coding.
  - Interleaves to reduce burst errors.
- Each 16-bit sample split into two 8-bit symbols.
  - Pulse coded modulation (PCM)
- Sample split into two symbols.
- Six samples from each channel (=24 bytes=192 bits) are chosen to make a frame, which is encoded as a 224 bits.
- It will be eventually encoded as 588 bits

CIRC encoding

Each frame consists of

- **Data**
  - two groups of 12 audio data bytes each (actual data)
- **Error detection and correction code**
  - two groups of four parity bytes
  - Computed according to the Reed-Solomon code
- **Control&display byte**
  - Together with control&display bytes of other frames it forms the subchannel stream.
  - Example: subchannel byte for track start identification
- **Synchronization pattern**
  - Start of a frame
  - 12 x “1” + 12 x “0” + 3 merging bits = 27 bits

CD ROM: Structure



Audio bit stream ~ 1.41 Mbps

33=24+9

CD ROM: Data Streams

Audio bit stream ~ 1.41 x 10^6 bit/s:

- 44,1 kHz sampling frequency ~ 1411200 bit/s
- 16-bit stereo PCM
- uniform quantization

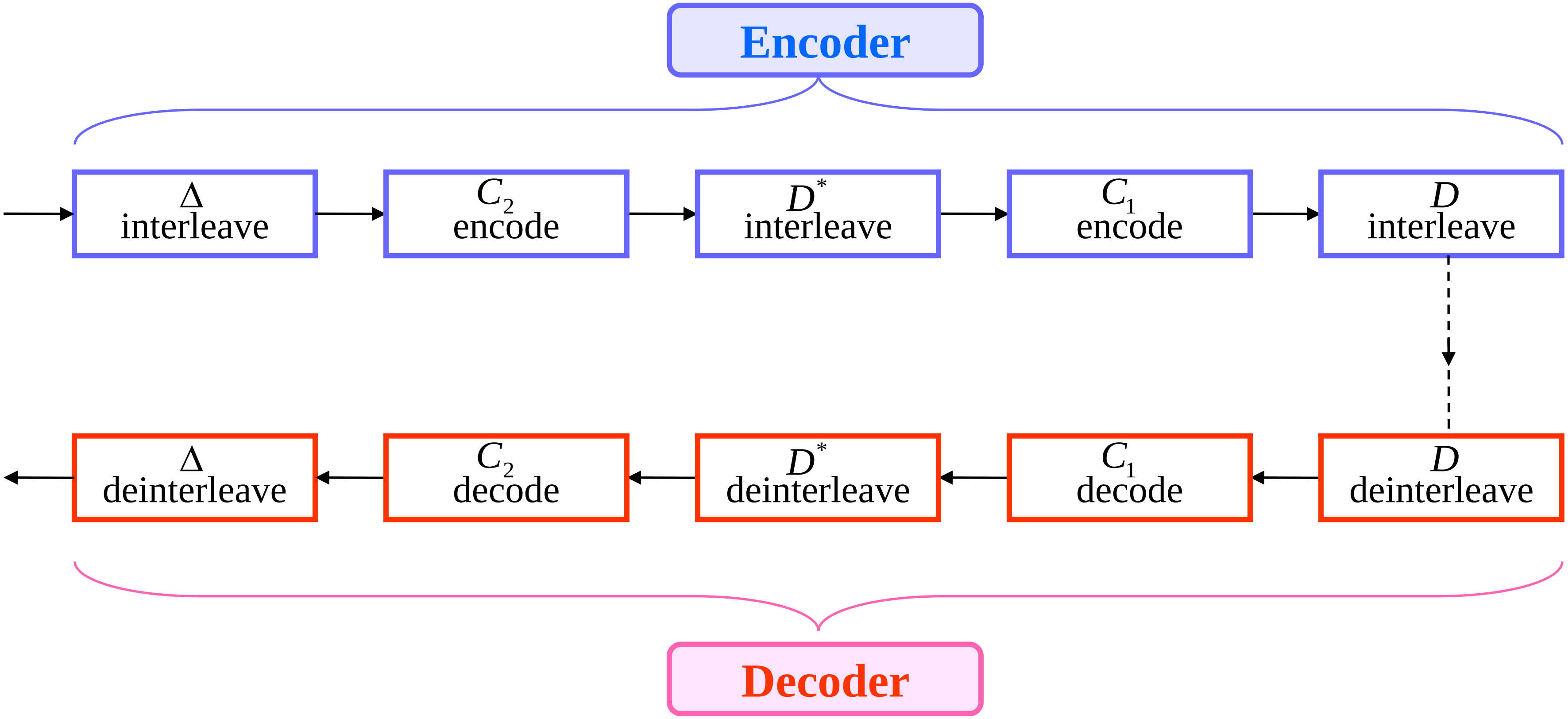
Data bit stream ~ 1.94 x 10^6 bit/s:

- Audio bit stream
  + parity bytes
  + control&display byte

Channel bit stream ~ 4.32 x 10^6 bit/s:

- Data bit stream
  + EFM
  + merging bits
  + synchronization pattern

CIRC encoder

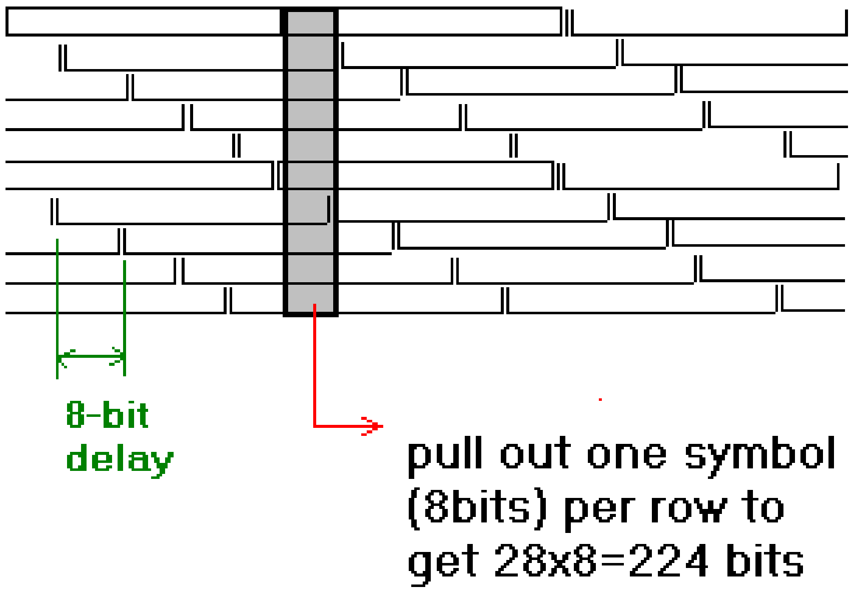


CIRC coding

- CIRC includes the use of first C2 then C1 encoders.
- The C1 level of CIRC is meant to correct small, random errors.
- The C2 level corrects larger errors and burst errors.
- Interleaving is used between the C2 (28,24) and C1 (32,28) encoders.

Interleaving to disperse errors

- Codewords of first code are stacked like bricks
- 28 rows of vectors over GF(256)
- Extract columns and re-encode using second Reed-Solomon code



Decoding

- (EFM decoding) As each frame is read from the disc, it is first decoded from fourteen channel bits (the three merging bits are ignored) into eight-bit data bytes.
- (C1 decoding) Then, the bytes from each frame (twenty-four data bytes and eight error correction bytes) are passed to the first Reed-Solomon decoder C1, which uses four of the error correction bytes and is able to correct one byte in error out of the 32 (28+4) bytes.
- If there are no uncorrectable errors, the data is simply passed along. If there are errors, the data is marked as being in error at this stage of decoding.

Decoding

- (Deinterleaving) The 24 data bytes and four remaining error correction bytes are then passed through unequal delays before going through another Reed-Solomon decoder C2.
- These unequal delays result in an interleaving of the data that spreads long error bursts among many different passes through the second decoder.
- The delays are such that error bursts up to 450 bytes long can be completely corrected. The second Reed-Solomon decoder uses the last four error correction bytes to correct any remaining errors in the twenty-four data bytes.
- At this point, the data goes through a de-interleaving process to restore the correct byte order.

Error correction

- With audio CDs, CIRC can correct burst errors up to 3874 consecutive erroneous bits or **symbols** (2.5 mm track length) and can well conceal 13,282 error bits (8.7 mm) and marginally conceal 15,500 bits.
- The CD standard requires a **block error rate (BLER)** [the number of data blocks that have any bad symbols at the initial C1 error correction stage] of less than 220 per second averaged over 10 seconds (50 would be typical).

What actually goes on the disc?

- CD player processes 7,350 frames per second
- So CD player reads 7350x 588= 4,321,800 bits per second of music produced
- To get 74 minutes of music, we must store

  74x60x4321800 = 19,188,792,000 bits

  = 2.39 GB

bits of data on the compact disc!

CD formats

- CD-DA: read book
- CD-ROM: yellow book
- CD-RW: orange book

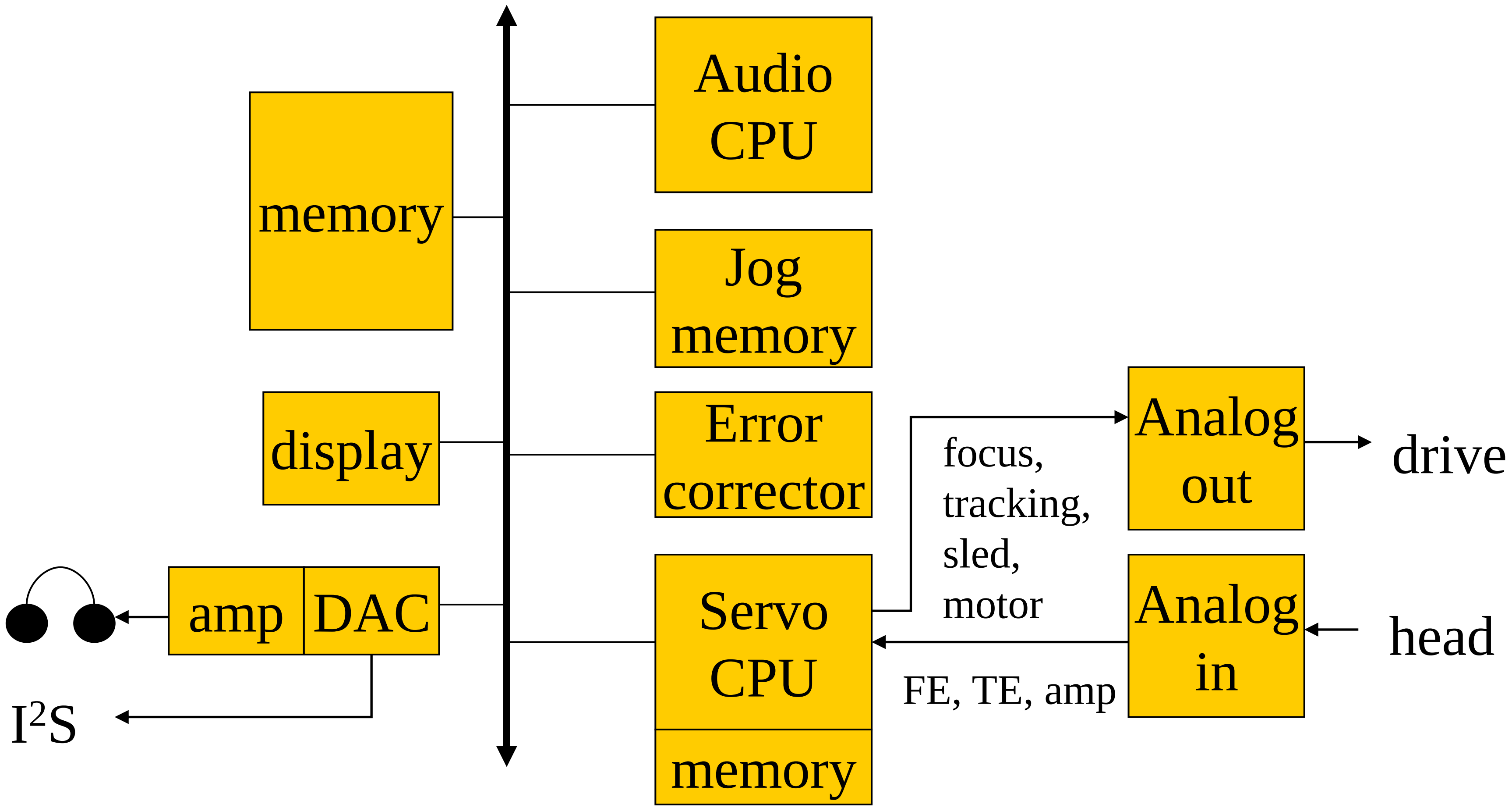
MP3

- Decoding is easier than encoding, but requires:
  - decompression;
  - filtering.
  - ~10% of ARM7 CPU
- Basic CD standard for data discs.
- No standards for MP3 disc file structure: player must understand Windows, Mac, Unix discs.

Jog/skip memory

- Read samples into RAM, play back from RAM.
- Modern RAMs are larger than needed for reasonable jog/skip.
- Jog memory saves some power.

CD/MP3 player



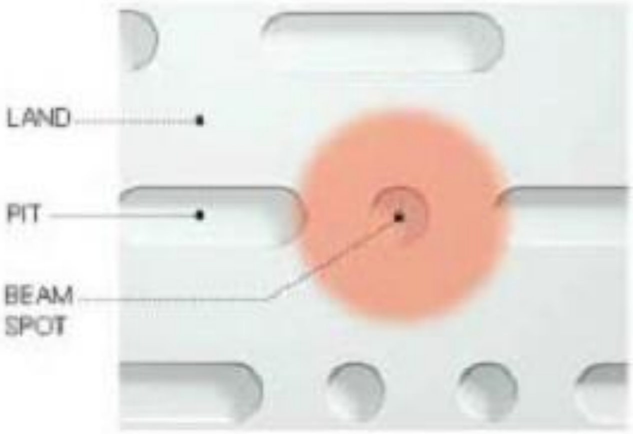
DVD format

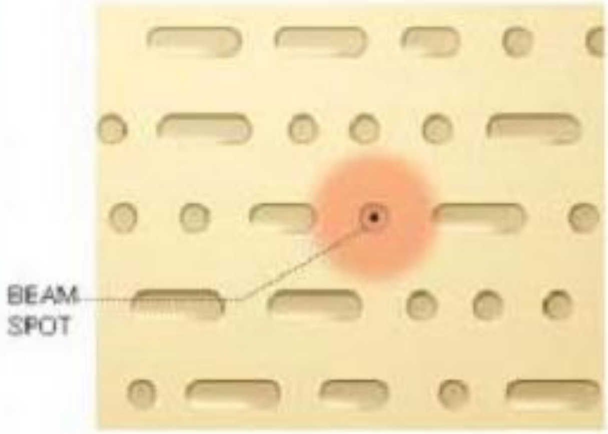
- DVD: Digital versatile disc
- Similar to CD (IR: 780 nm), but:
  - shorter wavelength laser (red: 650 nm);
  - tighter pits
    - Spacing: 0.74 microns from 1.6 microns
    - Pit minimum: 0.4 micron from 0.83 micron
  - EFM plus: 8 bits to 16 bits
  - two layers of data: a dual-layer disc has two layers of data, one of them semi-transparent so that the laser can focus through it and read the second layer.

CD and DVD

CD laser spot of 1.6 microns (µm) from 780-nanometer laser. Tracks are 1.6 µm apart.

DVD laser spot of 1.1 µm from 650-nanometer laser. Tracks are 0.74 µm apart.





Rainbow colors

Rainbow Colors Spread According to Their Wavelengths:

(nanometer=1 billionth of a meter)

- Red 780-622 nm
- Orange 622-597 nm
- Yellow 597-577 nm

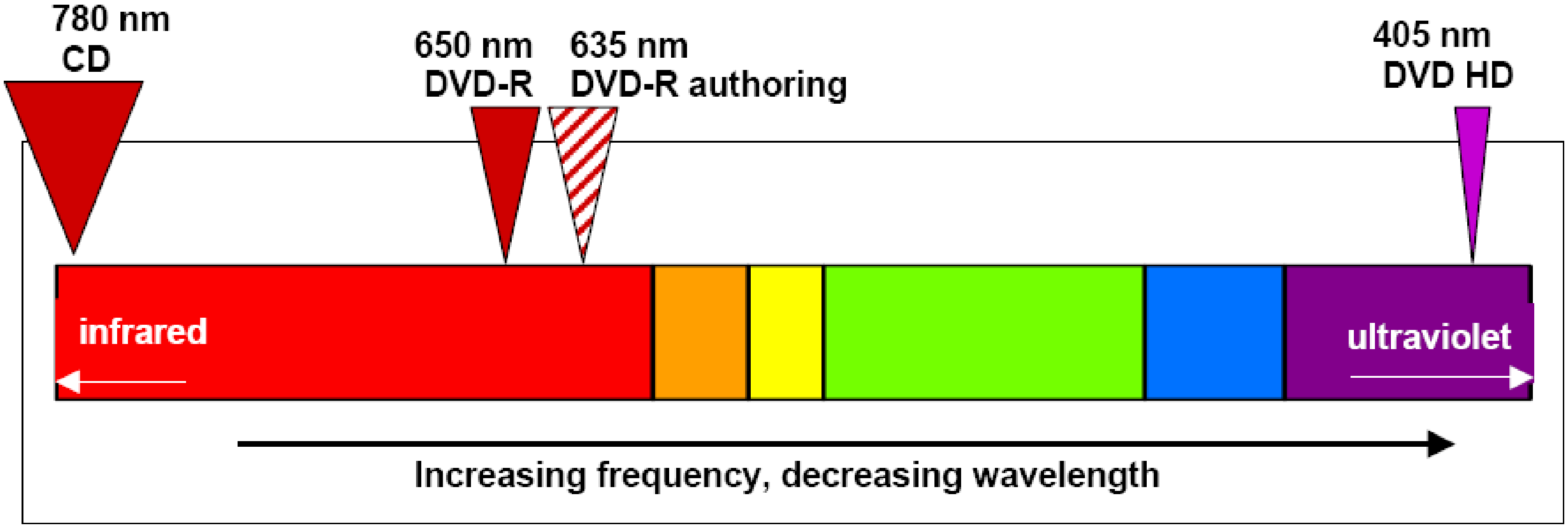
Green 577-492 nm

- Blue 492-455 nm
- Violet 455-390 nm

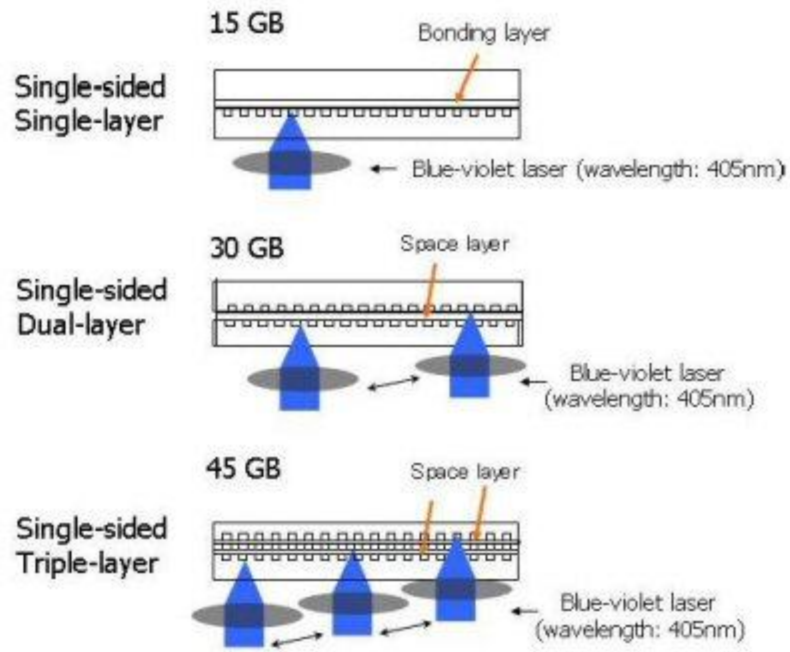
Infrared for CD=780nm; ruby-red for DVD= 650 nm

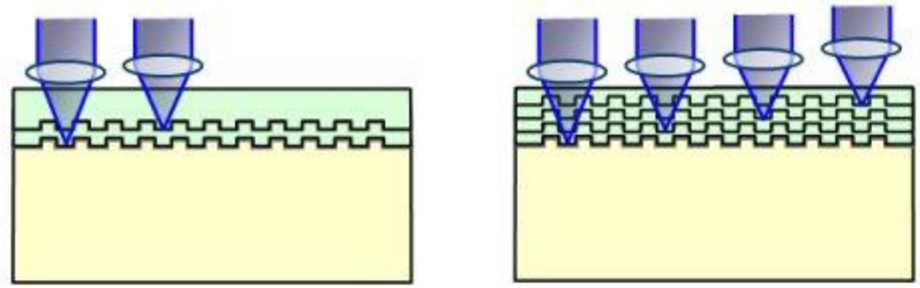
Blue-violet laser for DVD HD = 405 nm

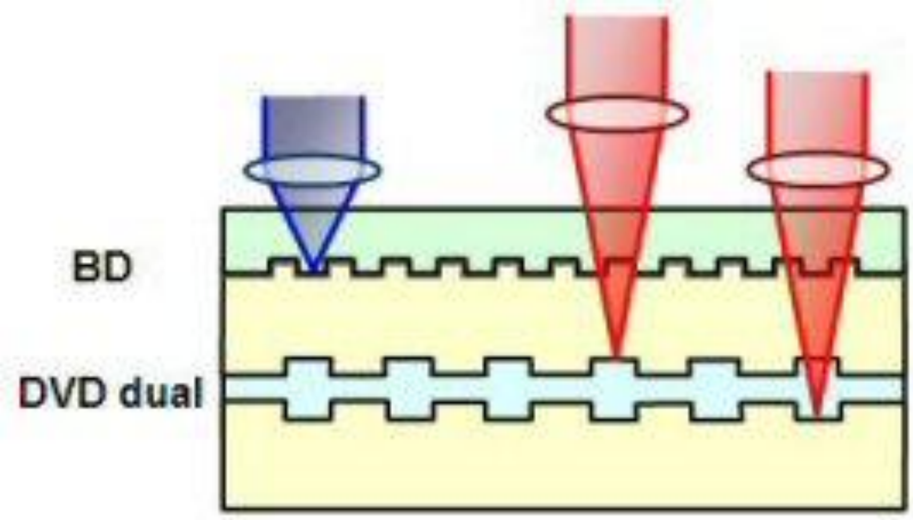
DVD


780 nm
CD
650 nm
DVD-R
635 nm
DVD-R authoring
405 nm
DVD HD
infrared
ultraviolet
Increasing frequency, decreasing wavelength

Multi-layer structure







Audio on DVD

- Alternatives:
  - MP3 on data DVD (stereo).
  - Audio track of video DVD (5.1).
  - DVD audio (5.1).
  - SACD (5.1).

MPEG audio standards

- Layer 1:
  - Lossless compression of subbands + optional simple masking model
- Layer 2:
  - More advanced masking model.
- Layer 3:
  - Additional processing for lower bit rates.

MPEG audio rates

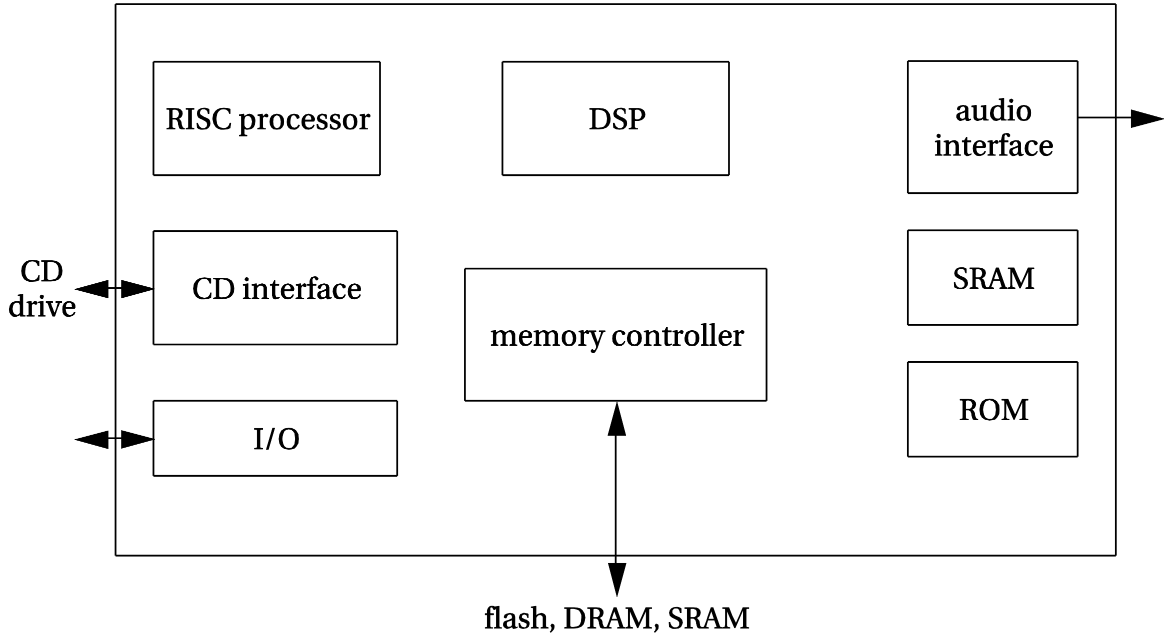
- Input sampling rates:
  - 32, 44.1, 48 kHz.
- Output bit rates:
  - 23, 48, 64, 96, 112, 128, 192, 256, 384 kbits/sec.
- Output can be mono, dual-channel (bilingual, etc.), stereo.

Other audio standards

- Dolby Digital (AC-3):
  - Uses modified discrete cosine transform.
- ATRAC (MiniDisc):
  - Uses subband + modified DCT.
- MPEG-2 AAC.

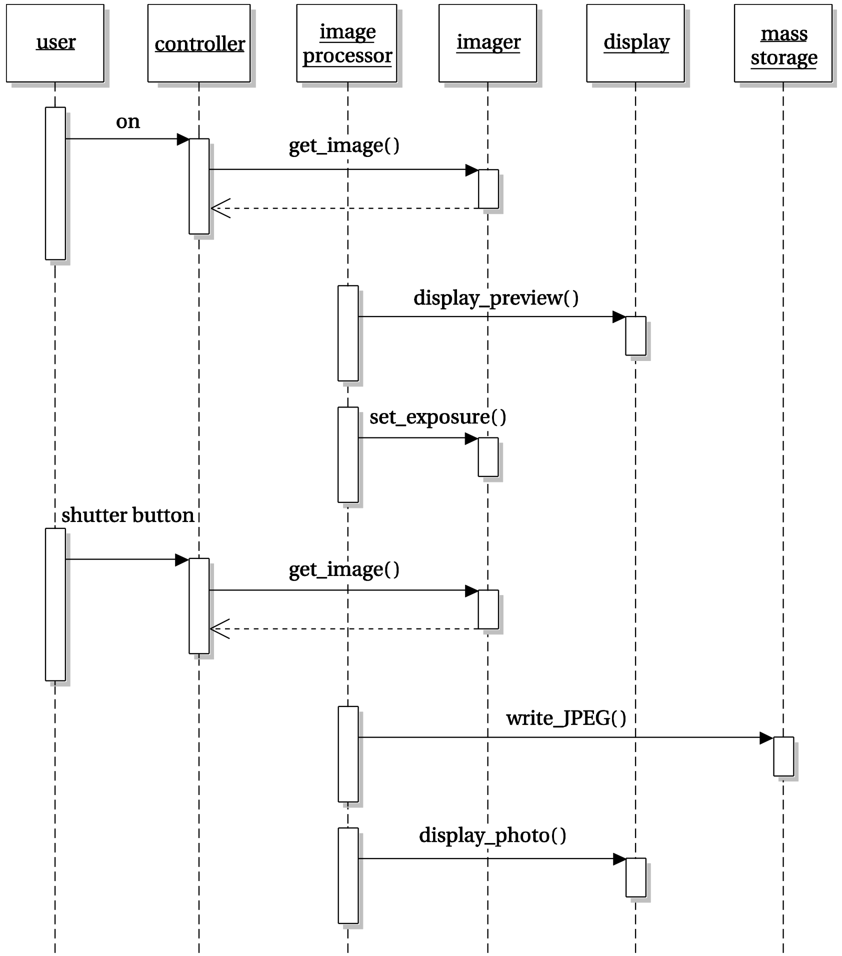
Audio players

- Audio players may use flash, hard disk, or CD for mass storage.
- File system must be compatible (FAT).



Digital still cameras

- DSC must determine exposure before taking picture.
- After taking picture:
  - Improve image quality.
  - Compress.
  - Save as file.



Digital still camera architecture

- DSC uses CPU for general-purpose processing, DSP for image processing.
- Internal memory buffers the passes on the image.
- Display is lower resolution than image sensor.
  - Image must be downsampled.

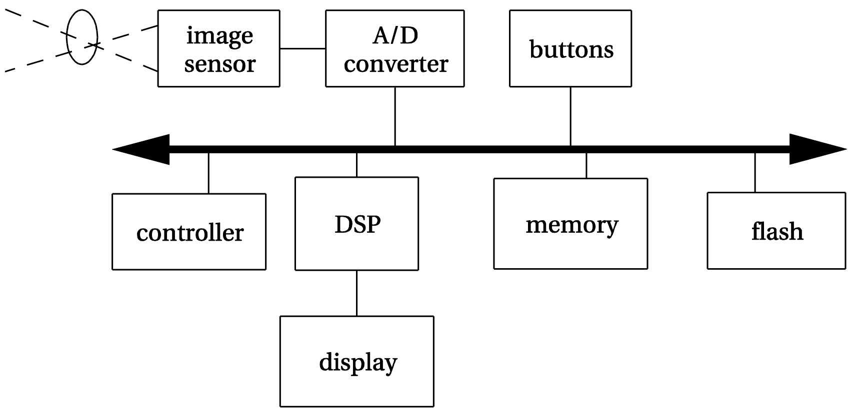
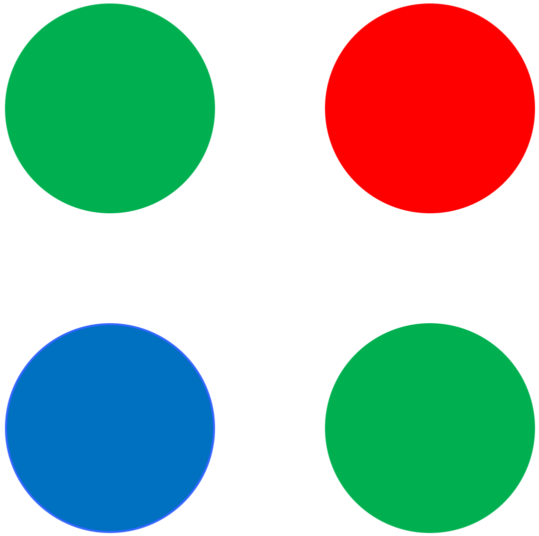


Image capture

- Before taking picture:
  - Determine exposure.
  - Determine focus.
  - Optimize white balance.



Bayer pattern

Image processing

- Must perform basic processing to get usable picture:
  - Bayer->RGB interpolation.
- DSCs perform many functions formerly performed by photoprocessors for film:
  - Image sharpening.
  - Color balance.

File management

- EXIF standard gives format for digital pictures:
  - Format of data in a file.
  - Directory structure.
- EXIF file includes:
  - Image (JPEG, etc.)
  - Thumbnail.
  - Metadata (camera type, date/time, etc.)