6.003: Signals and Systems

From LPs to CDs –
and how 6.003 helps get you there

December 8, 2011
Edison’s Phonograph
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Image by Infrogmation on Wikimedia Commons.
Photo of Pioneer record player removed due to copyright restrictions.
Edison’s Phonograph
Photo of Grado phono cartridge removed due to copyright restrictions.
Edison’s Phonograph

LPs: 100 years of optimization → good fidelity, but

- fragile: easily scratched
- lots of distortions: e.g., wow and flutter
- expensive

CDs: much higher fidelity

- nearly indestructible
- very low distortion
- inexpensive

→ many of these advantages made possible by concepts from Signals and Systems!
Edison’s Phonograph

Image by Dante Alighieri on Wikimedia Commons.
What’s on a CD?

- protective layer (plus label)
- reflective layer (typically aluminum)
- polycarbonate (injection molded)

Image by [Dante Alighieri](https://commons.wikimedia.org/wiki/Author:Dante) on Wikimedia Commons.
Edison’s Phonograph

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What’s on a CD?

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Image by Dante Alighieri on Wikimedia Commons.
What’s on a CD?

Continuous signal (audio)

Discrete storage (pits and lands)

→ sampling!
What’s on a CD?

![Threshold vs Frequency Graph]

- Dadson & King, 1952
- Yeowart, Brian, & Tempest, 1967
- Green, Kidd, & Stevens, 1987
What’s on a CD?

\[ f_s = 44.1 \text{kHz} \]

\[ x_M(t) \quad \xrightarrow{\text{Anti-aliasing CT filter}} \quad x(t) \quad \xrightarrow{\text{Sample and hold}} \quad \hat{x}(t) \quad \xrightarrow{\text{Analog-to-digital converter}} \quad x[n] \]
What’s on a CD?

Ideal anti-aliasing filter

\[ x_m(f) \]

-20 \quad 20 \quad f \text{ (kHz)}
What’s on a CD?

Without anti-aliasing filter

With ideal anti-aliasing filter
What’s on a CD?
What’s on a CD?
What’s on a CD?
**What’s on a CD?**

Given that the sampling frequency $f_s = 176.4$ kHz, the process involves:

1. **Anti-aliasing CT filter**
   - $x_m(t)$
   - $x(t)$

2. **Sample and hold**
   - $x(t)$
   - $\hat{x}(t)$

3. **Analog-to-digital converter**
   - $\hat{x}(t)$
   - $x[n]$

4. **DT filter**
   - $x[n]$
   - $y[n]$

5. **Down-sample**
   - $y[n]$
   - $y_{down}[n]$
What’s on a CD?

\[ \chi(f) \]

CT filter

\[ \tilde{\chi}(f) \]
What’s on a CD?
What’s on a CD?

\[ f_s = 176.4 \text{kHz} \]
What’s on a CD?

![Frequency response graph showing magnitudes and angles at different DT frequencies, highlighting 20 kHz, 24.1 kHz, and 88.2 kHz.]
What’s on a CD?
What’s on a CD?
What’s on a CD?

DT signal after sampling at 176 kHz

After filtering with DT filter

After downsampling
What’s on a CD?

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What’s on a CD?

Audio → bits:
• sampling
• filtering
• DT processing of CT signals
• downsampling

Next issue: how to you build a player?
What’s on a CD?

$\tilde{Y}_{down}(\Omega)$
What’s on a CD?

Spectrum of samples on CD

Upsampled $4 \times \bigcirc$

After filtering with DT filter
What’s on a CD?

Protective layer (plus label)
Reflective layer (typically aluminum)
Polycarbonate (injection molded)

Image by Dante Alighieri on Wikimedia Commons.
What’s on a CD?
What’s on a CD?
Interferometric sensing: 6.003 explanation

What’s on a CD?
What’s on a CD?

Interferometric sensing: 6.003 explanation

[Diagram of interferometric sensing with labels a and b, mirror, and two graphs showing oscillations labeled a and b at time t2]
What’s on a CD?

Interferometric sensing: 6.003 explanation

Interferometric sensing: 6.003 explanation
What’s on a CD?

Interferometric sensing: 6.003 explanation

[Diagram showing two waves, a and b, and the mirror with a and b paths labeled with t and t2]
Interferometric sensing: 6.003 explanation

What’s on a CD?
What’s on a CD?

Focusing with feedback control

- CD
- Laser
- Beam splitter
- Focusing lens
- Cylindrical lens
- Quadrant detector
- Front view of quadrant detector
What’s on a CD?

Focusing with feedback control

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Front view of quadrant detector
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Focusing with feedback control

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- focusing lens
- quadrant detector
- beam splitter
- cylindrical lens
- laser
- front view of quadrant detector
What’s on a CD?

Focusing with feedback control

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Front view of quadrant detector
What’s on a CD?

Focusing with feedback control

- **CD**
- **focusing lens**
- **quadrant detector**
- **cylindrical lens**
- **laser**
- **beam splitter**
- **front view of quadrant detector**
- **A+C-B-D**
- **electromagnetic positioner**
What’s on a CD?

What’s on a CD?

Focusing with feedback

desired focal plane

controller

focusing magnet

A+C−B−D

quadrature sensor
What’s on a CD?

Translating pits to bits
What’s on a CD?

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What’s on a CD?

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Translating pits to bits
What’s on a CD?

Tracking with feedback control
What’s on a CD?

Tracking with feedback control

![Diagram of tracking on a CD with red spots indicating errors and black lines representing tracks.](image-url)
What’s on a CD?

Tracking with feedback control

Diagram of CD track with red markers indicating control points.
Tracking with feedback control
What’s on a CD?

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Tracking with feedback control
What’s on a CD?

Tracking with feedback control

E–F
head positioner
What’s on a CD?

Tracking the tracks with feedback

desired track location → + → controller → track drive motor

E–F → differential sensor → desired track location
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Sampling

$\frac{f_s}{176.4\text{kHz}}$

$x(t) \rightarrow \bar{x}(t)$

Filtering

DT processing of CT signals

Feedback

What’s on a CD?
References:

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