A Short History of Motion Picture Projection Technology

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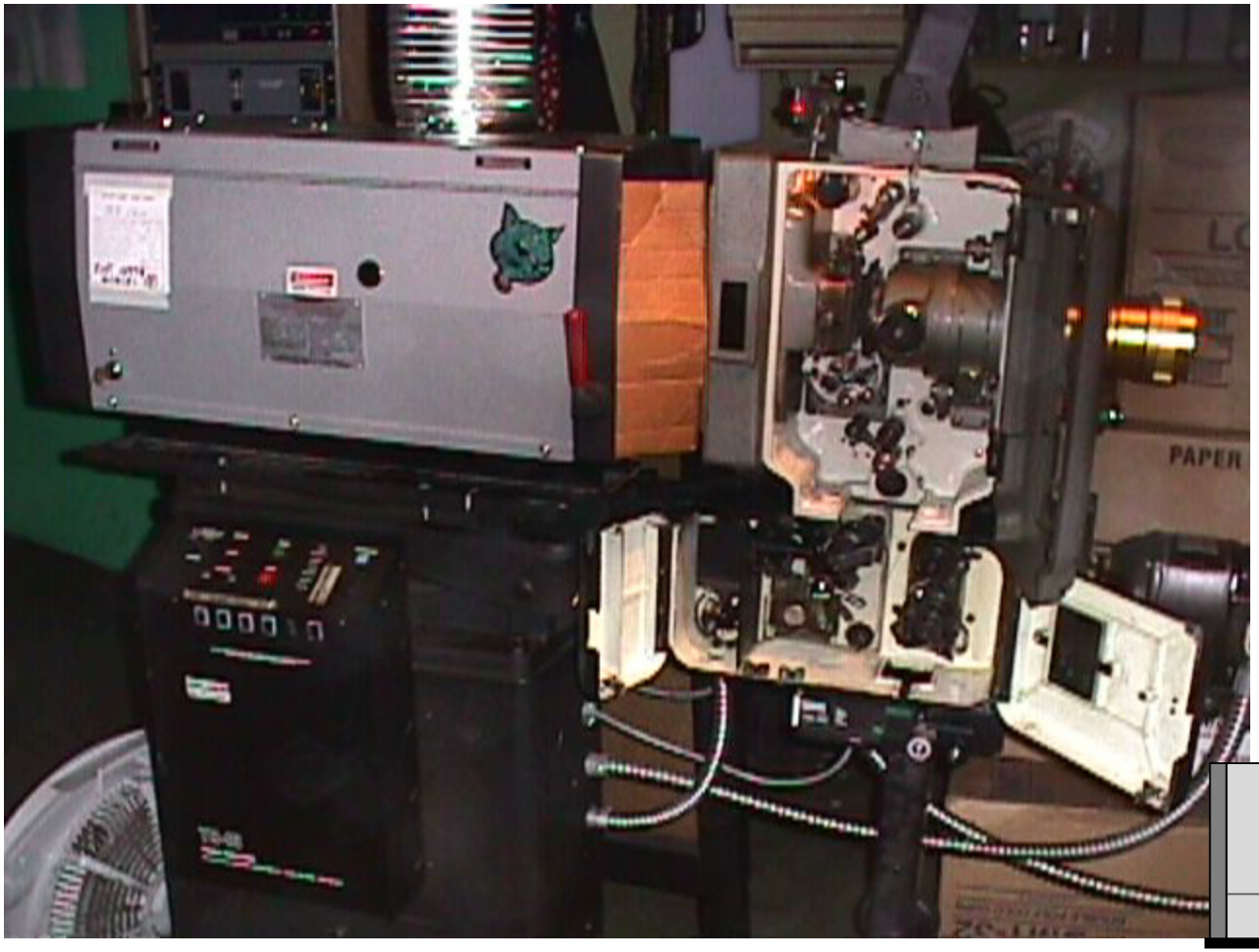
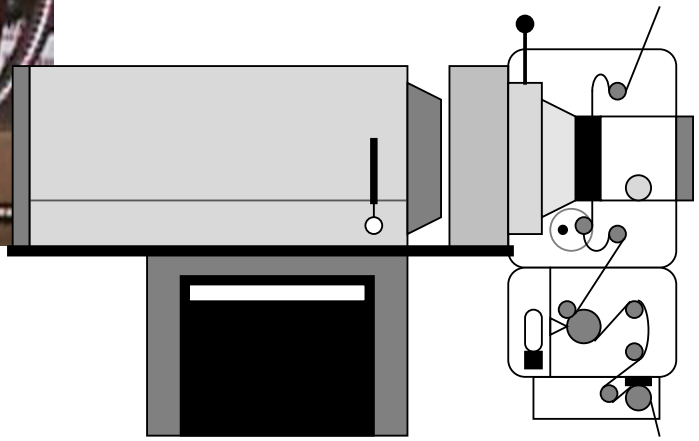
Outline

- A tutorial on commercial 35mm projection
  - The optical path
  - The sound path
  - Film handling
- A history of film projection
  - Origins and film
  - Picture development
  - Sound development
  - The future?

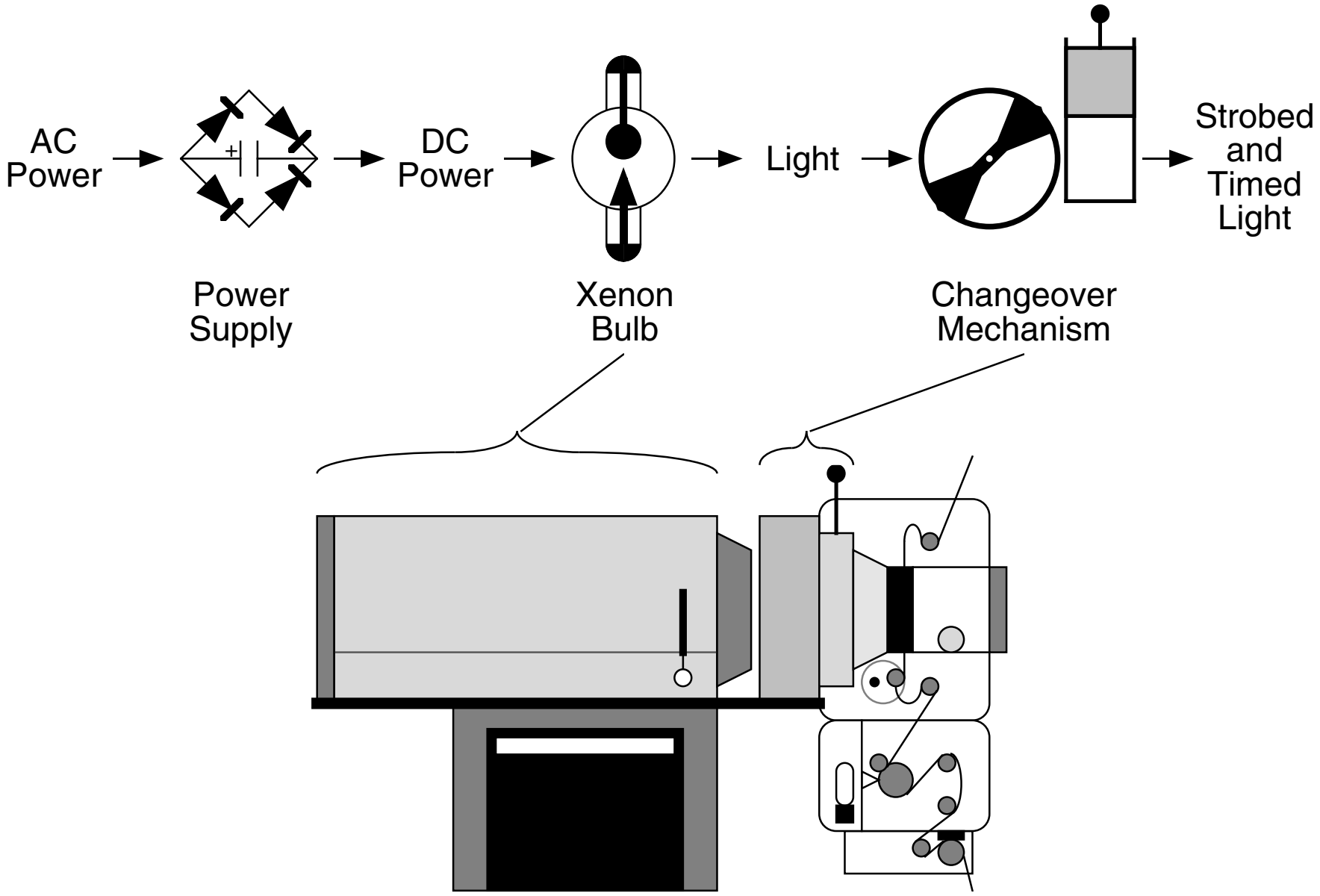
A Professional 35mm Projector



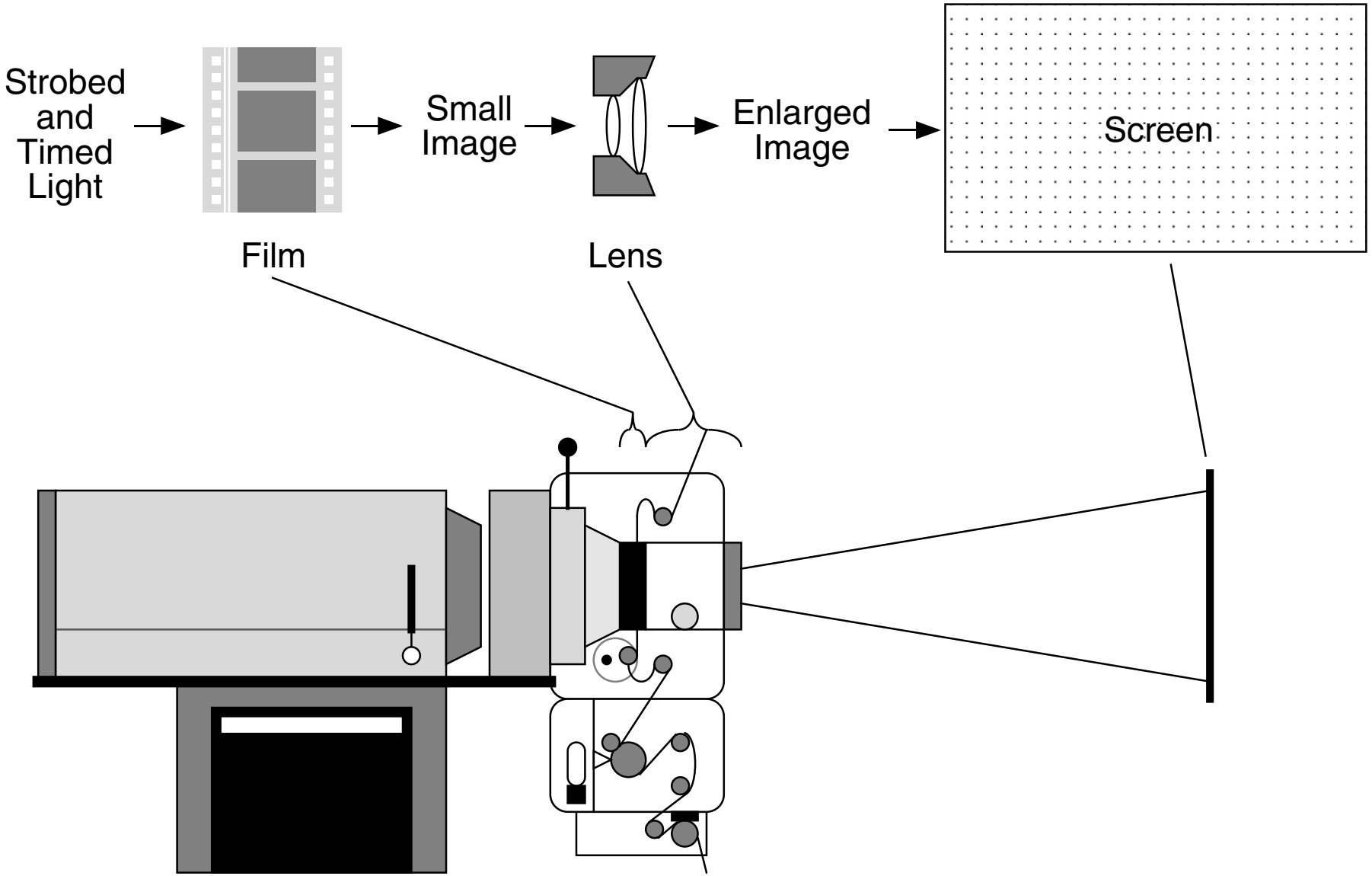
The key parts of this projector are represented schematically below.



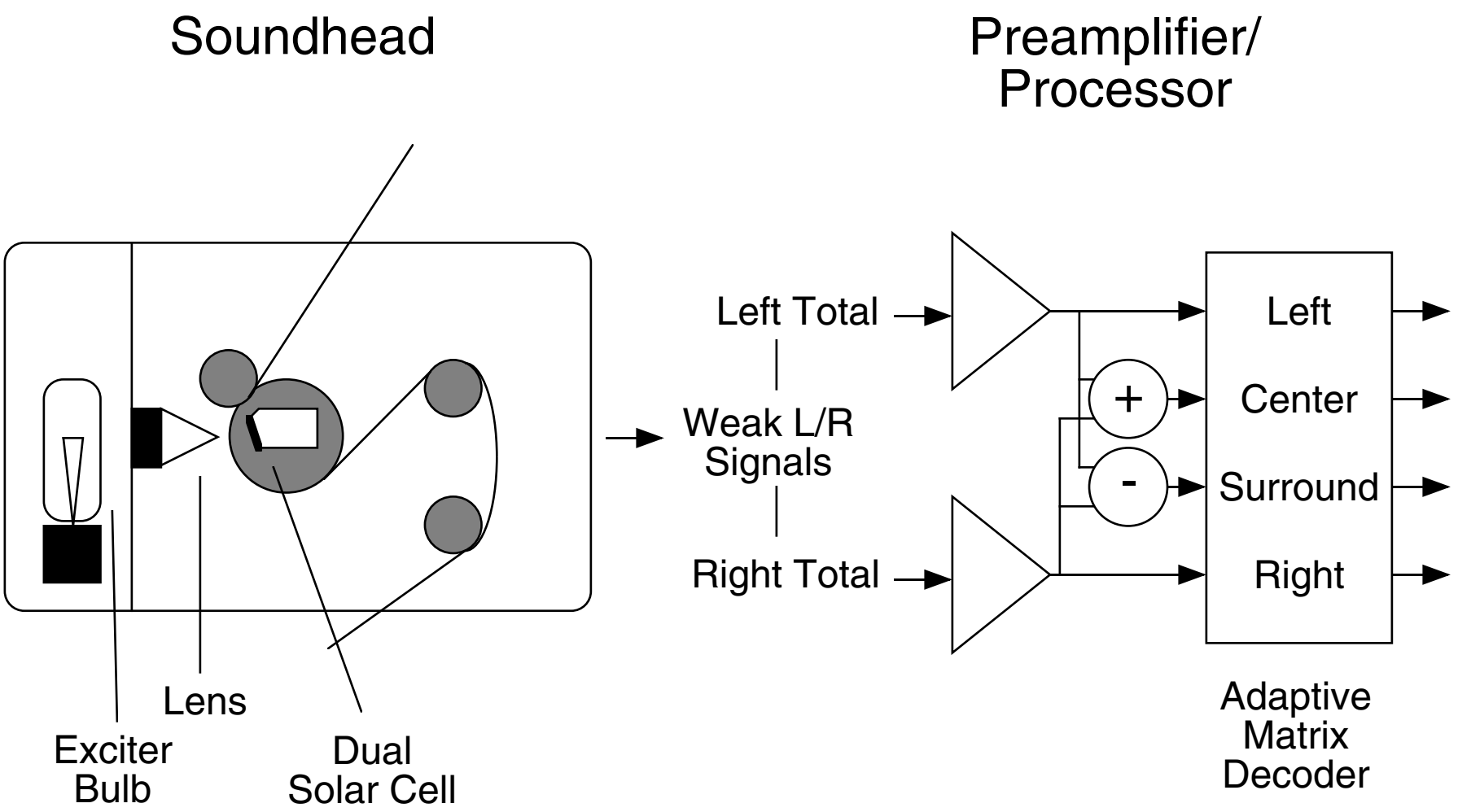
Projector Optical Path I



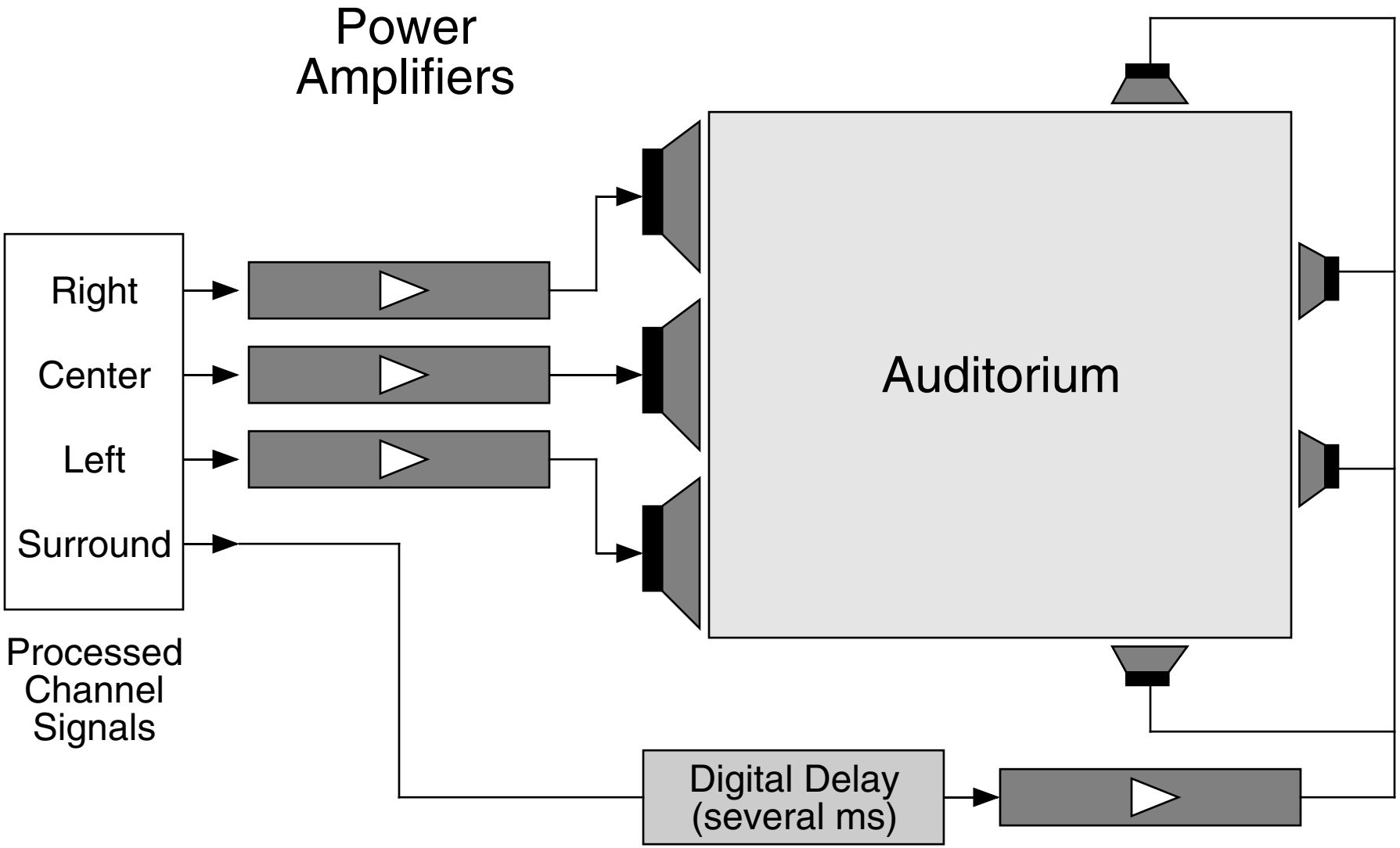
Projector Optical Path II



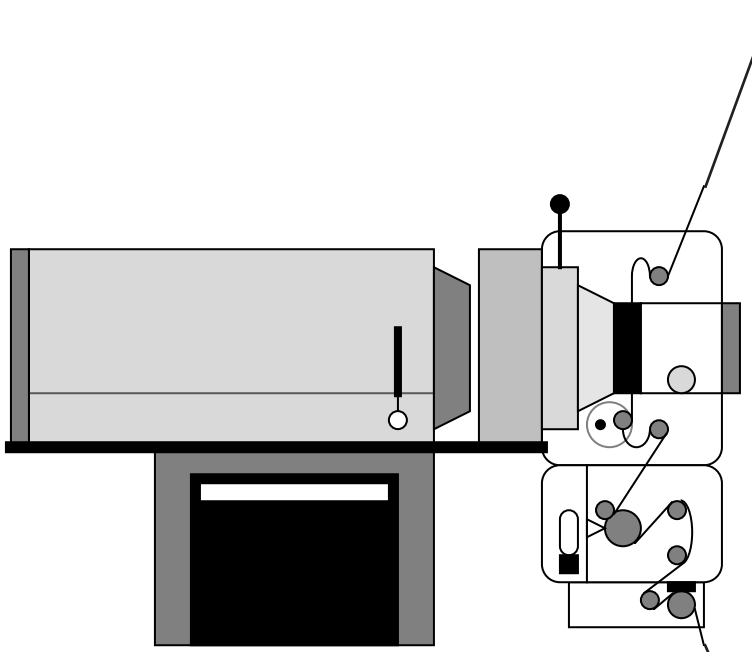
Projector Sound Path I



Projector Sound Path II



Projector Film Path



Platters

Optical Head

Sound Head

Automation Sensor

Basic Projection History I

- Edison invented the first practical camera/projector (~1896)
  - — Others were invented elsewhere, but failed quickly
  - — Key development: 35mm *flexible* film stock, developed with Eastman Kodak

- Film has always been the heart of the system
  - — Convenient 35mm size has been the primary format from the start
  - — Initially cellulose nitrate
    - Reasonably strong and transparent
    - Tends to decay over long periods of time
    - Flammable and sometimes EXPLOSIVE!
  - — Switched to cellulose triacetate (“safety film”) in the 1940’s
    - Melts instead of burning
  - — Now generally use polyester-based stock (since 1970’s-1990’s)
    - Just slightly better than acetate film in most respects
    - Thinner and stronger than old films — projector breaks first!

Basic Projection History II

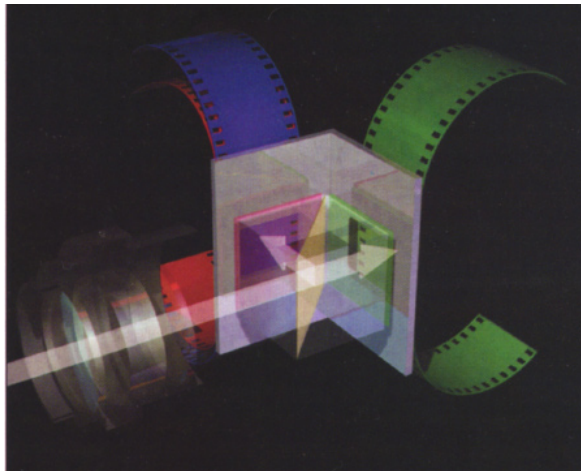
- Arc lamps have always been the primary light source
  - — Come close to simulating daylight colors (high color temperature)
  - — Nearly emulates a point source, so it's easier to focus across a picture
  - — First used carbon arc "bulbs" (very maintenance-intensive)
  - — Switched to Xenon arc bulbs in the 1940's

- Film handling has changed slowly
  - — 4 perforations per frame sprocket drive has been standard since the start
  - — 18–22 fps initially, standardized to 24 fps prior to sound introduction in 1920's
  - — Manual changeover between two projectors was used for features
    - Projectionist must switch projectors every ~20 minutes
    - Films still have pairs of projectionist cues at upper right near reel ends
    - Still used at some theaters, like the Stanford, that rotate films daily
  - — Now platters are used to hold entire features
    - Much less labor intensive
      1. Film arrives in cans, like those at right
      2. Original reels are be spliced together with trailers & leaders
      3. Projectionist now just needs to start the feature!
    - No rewinding between shows
    - Trailer changes can be done right on the platter
    - Automation cues can control house lights, sound, etc.

Color Film

- First attempt: Red gunshots in *The Great Train Robbery* (~1900)

- Partial color attempts (~1910–1920's)
  - — Additive color processes
    - 2 or 3 colors were shot onto alternating frames of film using filters
    - Projectors combined together while playing — but misalignment was common
  - — 2-color processes
    - Strips of 2 colors combined onto the same film stock

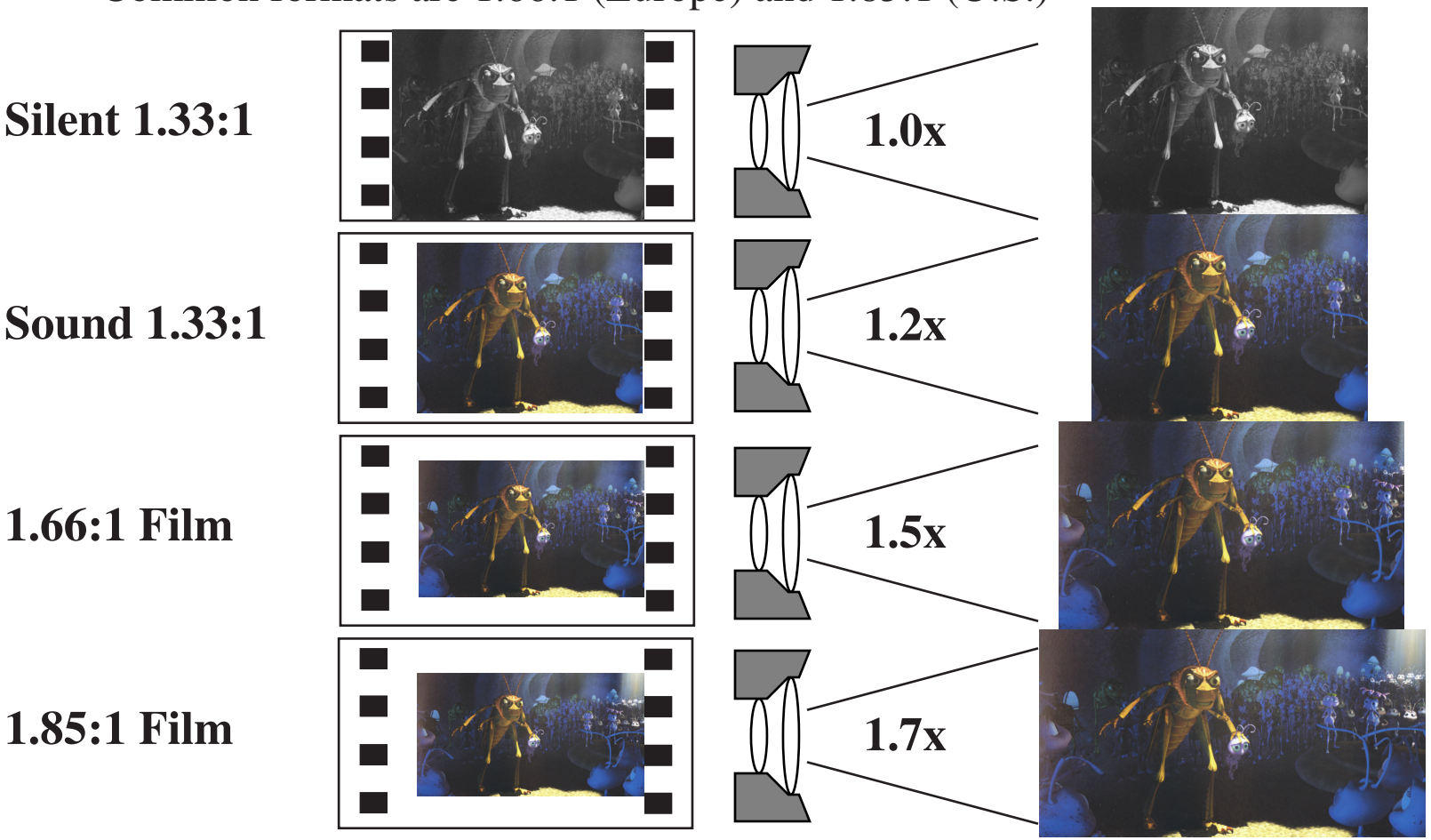


- Technicolor 3-strip process (1930's–present)
  - — Film shot to red, green, and blue films simultaneously
    - Color selection done using beam splitting and filtering
    - Shot to 3 film stocks (each basically B/W)
  - — Prints made by literally printing 3 complement colors onto film
  - — Walt Disney was the first to use it in *Flowers and Trees* (1932)
  - — Color is very stable — but misalignment of 3 original negatives is possible over time

- Composite color films (1950's–present)
  - — C/M/Y emulsions are sandwiched together right in the negative film
  - — More complex film processing, but can result in more realistic color with good film
  - — Early composite prints tended to decay unevenly over time

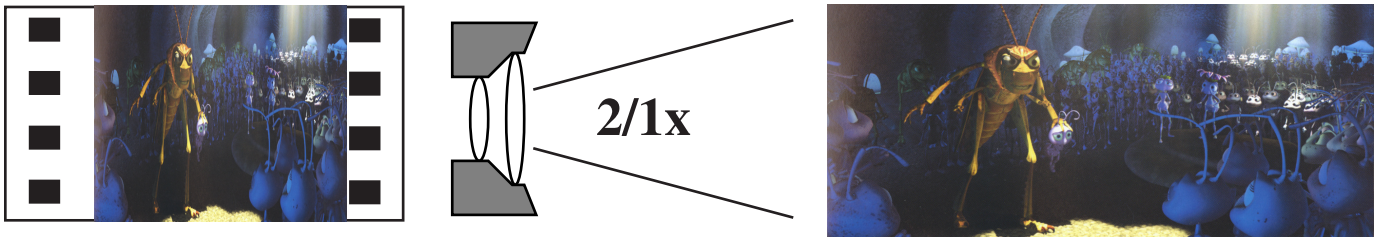
Widescreen I

- Came about in 1950's as an answer to television
- "Shorter" picture formats
  - — Adding sound had reduced the height of the film image a bit, so why not more?
  - — Common formats are 1.66:1 (Europe) and 1.85:1 (U.S.)



Widescreen II

- Cinemascope
  - — Twentieth-Century Fox introduced this in the mid-1950's
  - — Compresses picture 2:1 horizontally, uses full frame vertically
  - — 2.35:1 aspect ratio in its current form



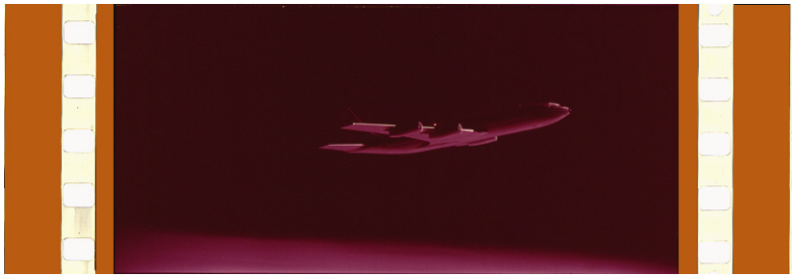
- 70mm film
  - — 2.2:1 aspect ratio on 2x-wide film, 5-perforation format
  - — Ultra-high resolution, but EXPENSIVE, especially due to 6-channel *magnetic* stereo
  - — 70mm projectors can always also show 35mm prints

- Other formats
  - — Interlocked projectors (expensive and generally impractical)
    - Used today only for some specialized applications
  - — VistaVision, sideways 8-perf on 35mm film at 2.35:1
    - Used today for visual effects work (a "poor man's 70mm")
  - — IMAX film, sideways 15-perf on 70mm film at 1.37:1
    - Common ultra-large format at museums and similar venues

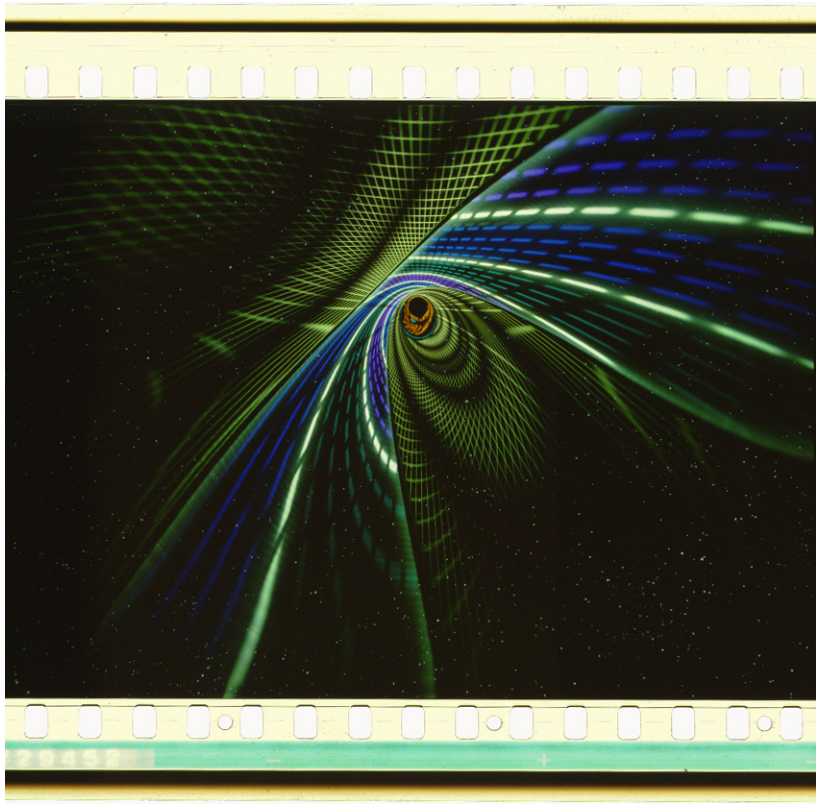
Large Format Comparison

35mm Scope

Standard 70mm



IMAX 70mm



Sound History I: Analog Mono

- Organ music (1900's – early 1930's)
  - — Organist played a score timed to synchronize with a silent movie
  - — Still happens at the Stanford theater!

- Vitaphone and other manually synced formats (1928 – mid 1930's)
  - — First started with *The Jazz Singer* and *Steamboat Willie* (both in 1928)
  - — Projectionist played recorded music / effects at the appropriate time
    - Speech was typically impossible to do well because sync was not close enough
  - — "Vitaphone" was a record-based version of this technology

- Monaural Optical Sound-on-Film (mid 1930's – 1980's)
  - — Sound printed right on the film, alongside the picture, like an oscilloscope trace
    - Picture had to shrink and shift slightly to make room for the soundtrack
    - Prints cost no more than silent ones
  - — ~40 Hz – 8 kHz frequency range set by size of early read heads and film speed
  - — First read by phototubes, and later by silicon solar cells
  - — Became a **STRONG** standard very quickly

Sound History II: Analog Stereo

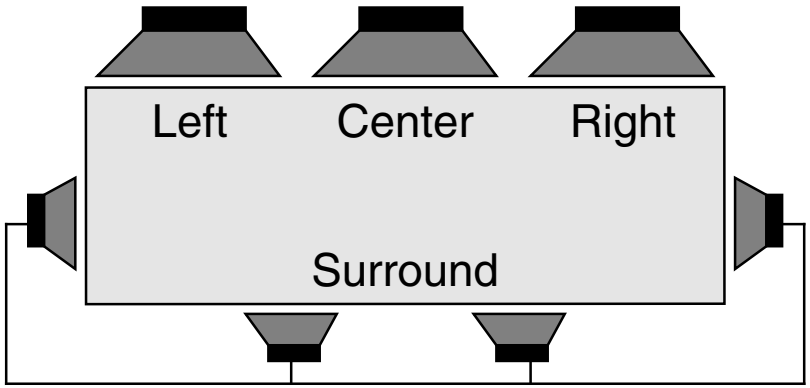
- Disney's *Fantasia* (1940) was presented using a custom stereo setup
- CinemaScope magnetic stereo (mid-1950's)
  - — 4-channel stereo introduced along with the scope widescreen format
    - Recorded using optional magnetic tracks in place of the normal optical ones
  - — Prints were too expensive, so it died quickly
- 70mm magnetic stereo (late-1950's – 1980's)
  - — 6-channel stereo
    - Two different speaker formats used (1950's-60's and 1970's-80's)
  - — Very expensive process to add iron oxide magnetic tape tracks to the film edges
  - — Prints did not wear well in projectors, and decayed quickly
- Dolby "A" Stereo (1977)
  - — "4-channel" stereo
    - Uses dual-channel optical tracks to encode 4 channels through matrix encoding
  - — Dolby noise reduction and compression used to improve quality and frequency response
- Dolby "SR" Stereo ("Spectral Recording," 1987)
  - — Evolutionary enhancement to noise reduction technology used in Dolby "A"

Sound History III: Digital

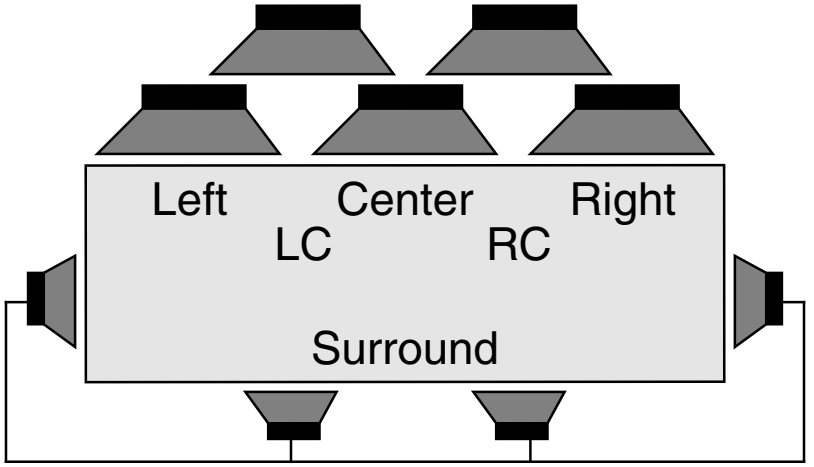
- SRD: Dolby Digital (1992, http://www.dolby.com)
  - — Discrete 6-channel stereo sound
  - — Printed as a dot pattern between the soundtrack side sprocket holes on film
    - Limited area requires high compression rates (about 10:1)
    - Encoded primarily as compressed-mantissa FP frequency-domain information
  - — Adopted as standard sound for DVDs and ATSC digital TV standard
- DTS: Digital Theater Sound (1993, http://www.dtstech.com)
  - — Also discrete 6-channel stereo sound
  - — Actual sound is recorded on a set of CD-ROM or DVD discs
    - Synced to picture with timecode and serial # printed on film
    - Off-film format allows lower compression rates (less than 3:1)
    - Can also be used easily with 70mm and IMAX film formats
- SDDS: Sony Digital Dynamic Sound (1994, http://www.sdds.com)
  - — 8-channel stereo format, with no home theater equivalent
  - — Printed semi-redundantly and offset on both edges of the film using cyan emulsion layer
    - Front channels will play normally even through film damage clear across the film
    - Compression rates similar to DTS format
- Dolby EX surround extension (1999)
  - — Extra center rear surround, matrix encoded in left/right surround pair of any digital track

Sound Formats: Speakers

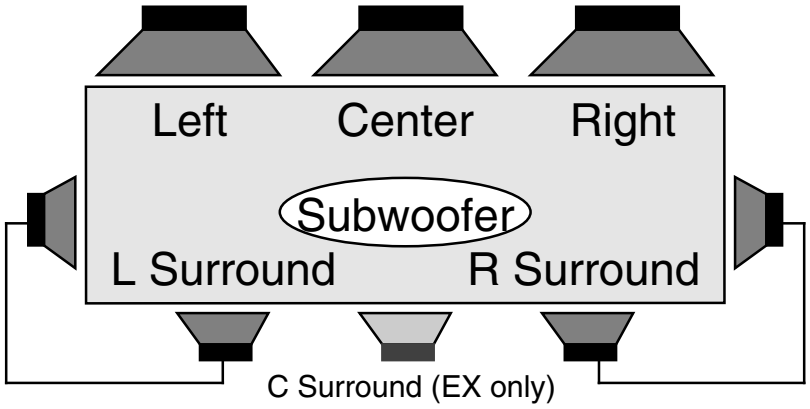
Analog Optical Stereo



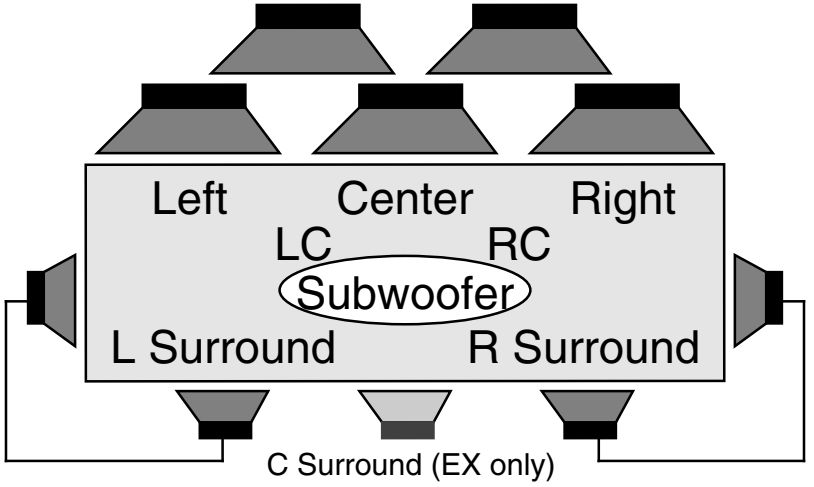
Early 70mm Magnetic



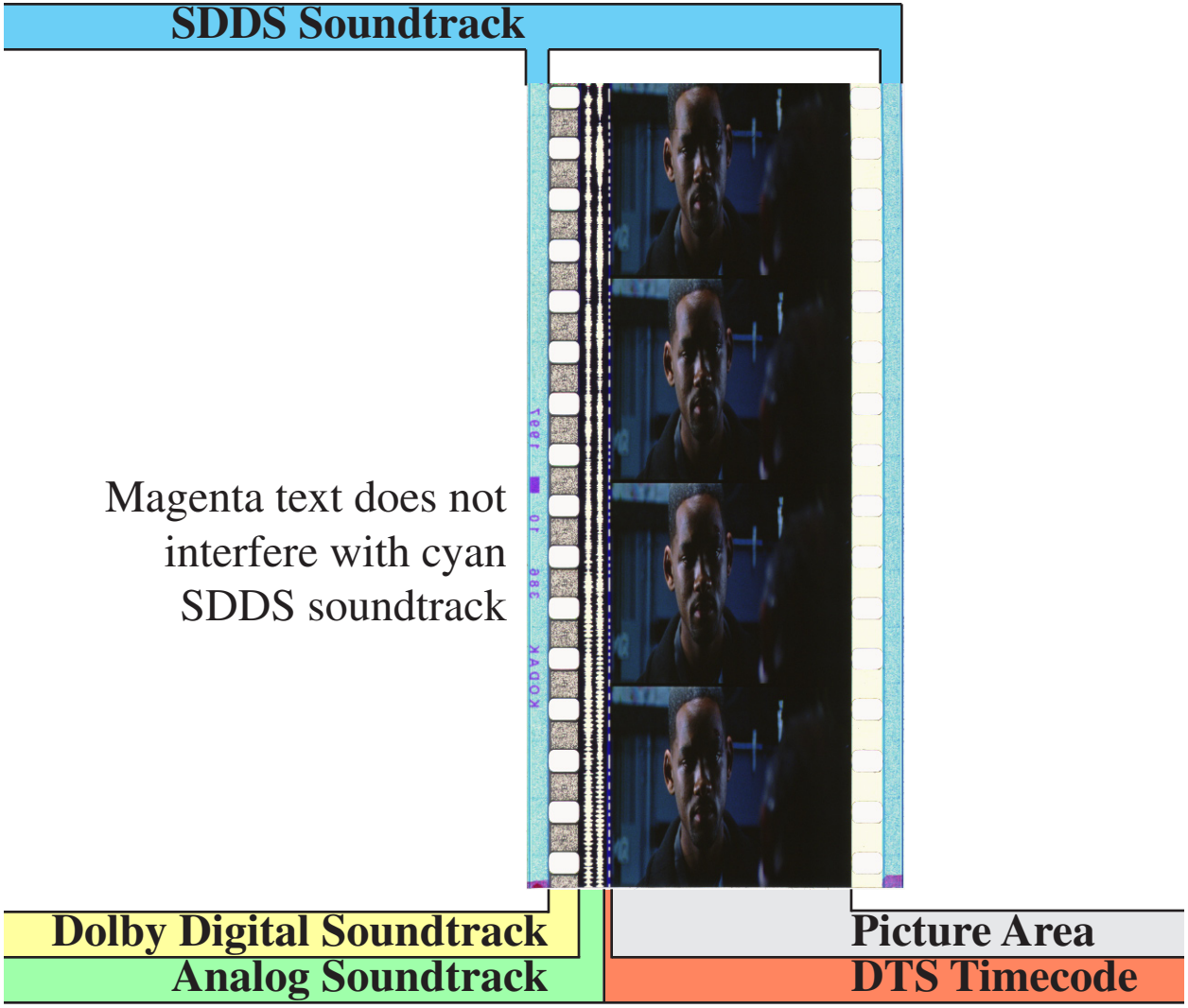
Later 70mm Magnetic, Dolby Digital, DTS



SDDS

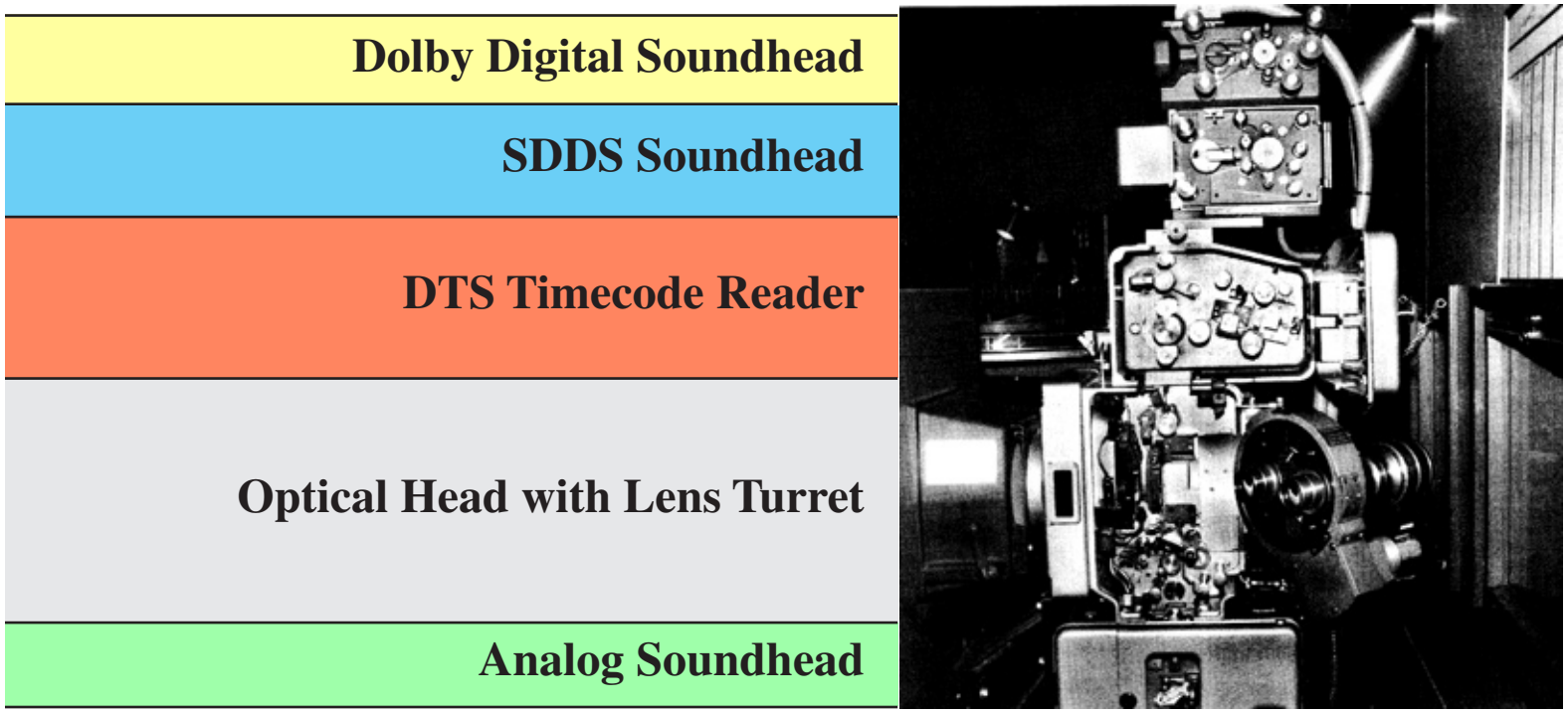


Sound Formats: On 35mm Film



Sound Formats: Readers

- Digital soundheads are mounted on top of the projector



- Analog sound is printed 19 frames before the picture
  — Allowed sound & picture to synchronize before delay circuits were practical

- Digital sound is synchronized with the analog sound
  — It is read early and digitally delayed for an appropriate sync time

The Future: All-Digital Projection

- A few theaters have been using this technology (since 1999)
  - — George Lucas first pushed it into use with Star Wars Episode I
    - Limited resolution at the time: only about 1,024x768
  - — Has only expanded slowly since this time
- Only a part of projectors are different from 35mm:
  - — Projector has a conventional lamphouse
  - — Optical head is similar to a conference room LCD/DLP projector
  - — All *moving* projector parts are eliminated, keeping maintenance down
  - — Currently TI's DLP is the dominant projection technique (http://www.dlp.com)
    - Array of microscopic mirrors that pivot to reflect light through/away from lens
    - Reflective technology allows high contrast ratio (dark blacks)
  - — Sony is pushing high-resolution LCD-based technology (SXRD project, www.sony.net)
    - Just like an LCD screen, but with a MUCH bigger "backlight"
- Digital film *storage* is also a key component:
  - — Started out with ad hoc, uncompressed video data on high-density tapes
  - — First "standard" digital format only established in 2005 (http://www.dcimovies.com)
  - — Current "standard" is Motion JPEG-2000 on RAID arrays (50-300 GB/film)
    - Only limited compression since artifacts are obvious on a big screen
  - — Copy protection of stored digital data is key issue for studios
    - Slows standards development and limits distribution formats (drive? disc? tape? Internet?)

The Problems of Digital

- The current business problem
  - — *Studios* **want** digital, because they will save ~$3K per 35mm print costs
    - Wide releases can require over 6,000 prints = nearly $20M just on film prints
    - More flexible: Doesn't take several weeks to make prints, so can "expand" instantly
  - — But theater *operators* are ambivalent
    - Will save money on projectionists and maintenance in the long run . . .
    - . . . but each theater will cost $100K or more to convert, and . . .
    - . . . there's still no guarantee that today's projectors won't be obsolete tomorrow
    - Projectionist unions are fighting to prevent job loss (fewer needed, plus different skills)
  - — Solution will probably require studios to help underwrite conversion costs
    - Alternate model: Sponsors could buy projectors in exchange for ads
- A technical comparison against film
  - — Digital has a more stable picture
    - No shuttering of light between frames
    - No frame jitter
  - — Digital "prints" never get scratched or dirty during playback
    - Big advantage, since one looooooong scratch can ruin an entire 35mm print
  - — Additional "sideband" information can easily be included
    - Multiple soundtracks, in different languages
    - Optional subtitles/captions
    - Much like features in today's DVDs
  - — But film still has higher resolution . . .

Format Resolutions

Format	Aspect Ratio	Film Area (mm)	Approximate Resolution†
NTSC/DVD Video	1.33:1	—	720 x 480
Max. HDTV Resolution	1.85:1	—	1,920 x 1,024
DLP Projection**	*Any**:1	—	2,048 x 1,080
Silent	1.37:1	25 x 18	3,300 x 2,400
Academy Sound	1.37:1	21 x 16	2,800 x 2,100
US Flat Widescreen	1.85:1	21 x 11	2,800 x 1,500
CinemaScope	*2.35*:1	21 x 18	2,800 x 2,400
VistaVision Wide	2.35:1	38 x 16	5,000 x 2,100
Standard 70mm	2.20:1	48 x 23	6,500 x 3,000
IMAX 70mm	1.37:1	71 x 53	9,500 x 7,000

† This estimate is based on "average" modern film stocks with approximately 3,400 dpi / 133 dpmm resolution.
* Different anamorphic lenses can be attached to the projector to emulate various film aspect ratios.
** Typical resolution numbers for 2006. Smaller projectors vary from 1,280x720 to 1,600x1,200, while 4,096x2,160 has been suggested