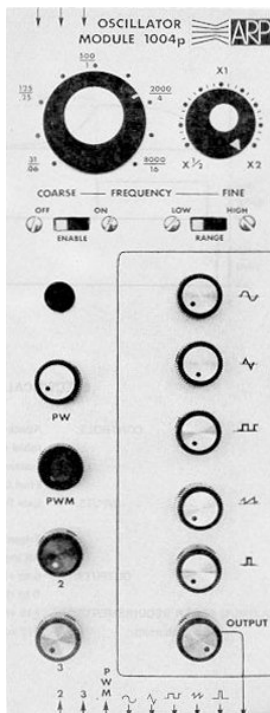


# The Big MAT Book:

## Courseware for Audio & Multimedia Engineering

### Volume 3: Audio Hardware

Stephen Travis Pope  
Graduate Program in Media Arts & Technology &  
Dept. of Music  
University of California, Santa Barbara



**MEDIA ARTS & TECHNOLOGY PROGRAM**

**CREATE**



Front cover: Oscillators from various analog synthesizers

Inside flap: Moog 55 synthesizer

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# The Big MAT Book: Courseware for Audio & Multimedia Engineering

## Overview

Volume 1: Multimedia Engineering

Volume 2: Audio Software

Volume 3: Audio Hardware

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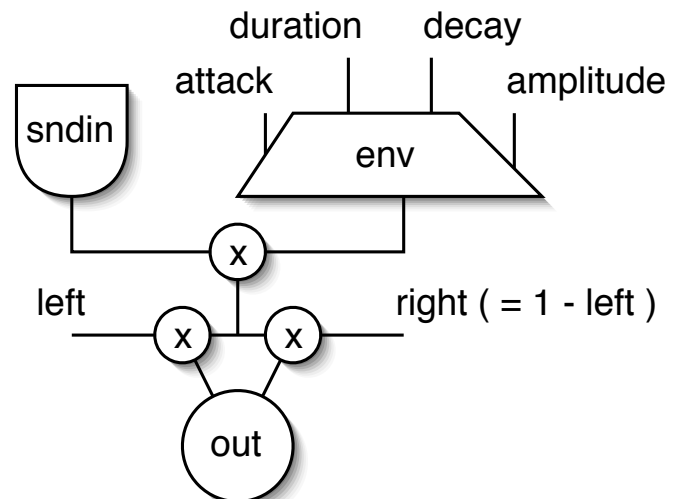
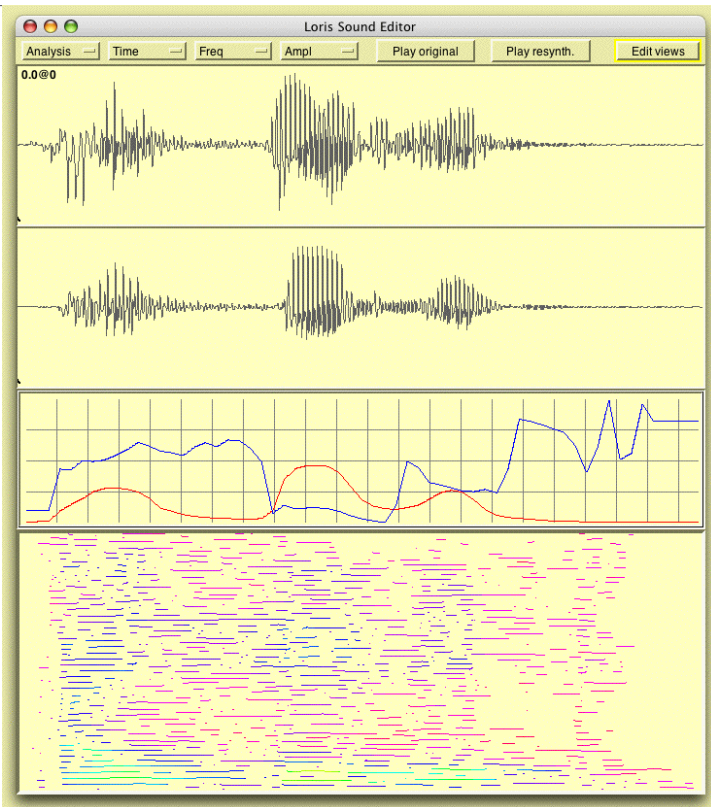
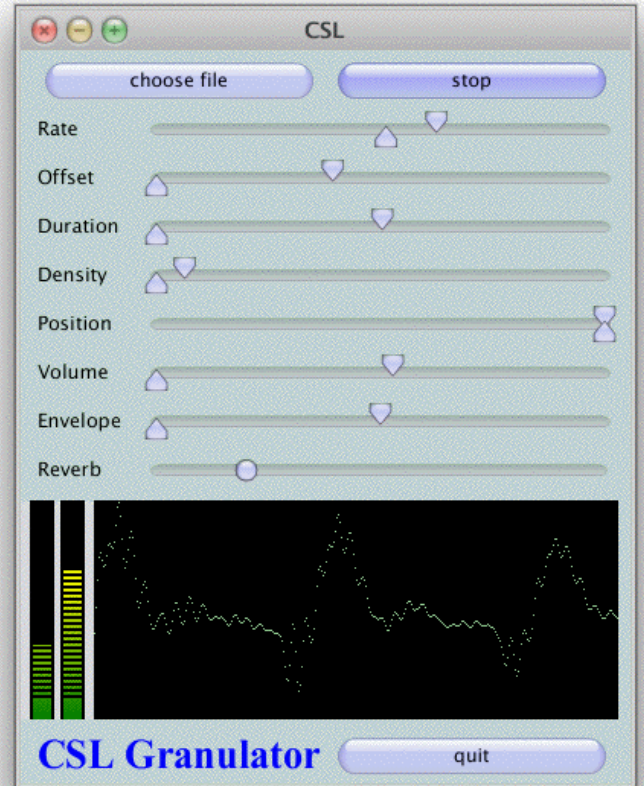
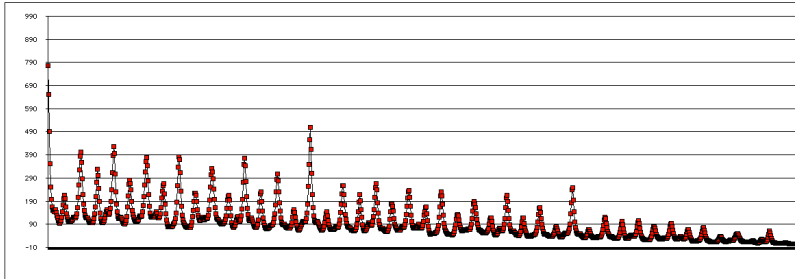
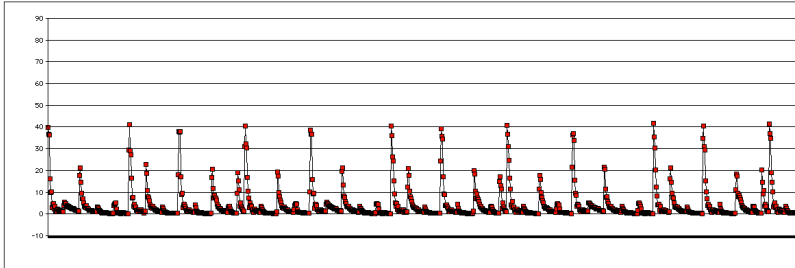
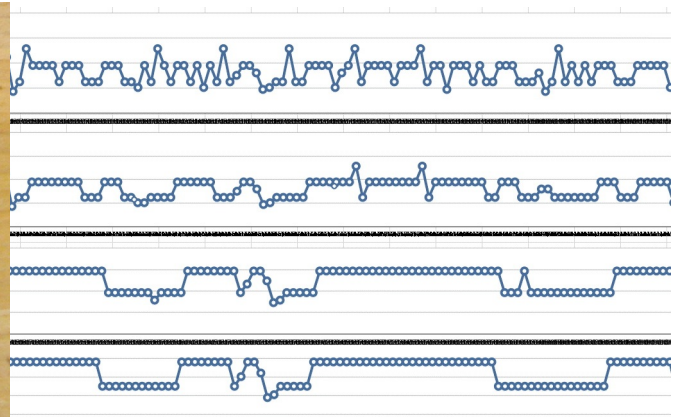
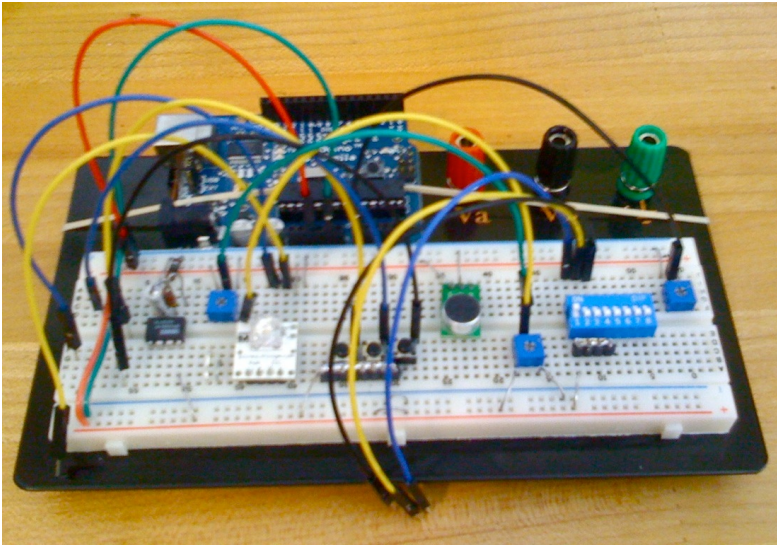
- 1. Survey of Media Engineering & Technology .....1
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# Introduction to the Series “Courseware for Audio & Multimedia Engineering”

Multimedia engineering is a broad and complex topic. It is also one of the fastest-growing and most valuable fields of research and development within electronic technology. The book before you is an anthology of curriculum materials developed over the space of 12 years at the University of California, Santa Barbara for students in UCSB’s *Graduate Program in Media Arts and Technology*.

The *BigMATBook* consists of the presentation slides for twelve ten-week courses, amounting to over 600 hours of presentation time. For each of the twelve courses, the presentation slides are accompanied by the tables of contents of the course readers, and an overview of the example code archives. These resources are available from the HeavenEverywhere web site; see

<http://HeavenEverywhere.com/TheBigMATBook>

The multimedia engineering courses included here cover theory and practice, hardware and software, visual and audio media, and arts as well as entertainment applications. Some of the courses (the first two chapters) are required of all MAT graduate students, and thus must target less-technical and also non-audio-centric students. The bulk of this material, though, consists of elective courses that have somewhat higher-level prerequisites and assume basic knowledge of acoustics and some (minimal) programming experience in mainstream programming languages.

The *BigMATBook* courses borrow liberally from R&D publications by my friends and colleagues, especially Roger Dannenberg, Julius O. Smith, D. Gareth Loy, F. R. Moore, Perry Cook, Adrian Freed, George Tzanetakis, Ross Bencina and Dan Overholt. I want also to express my deepest thanks to my MAT and Music Dept. colleagues JoAnn Kuchera-Morin, Curtis Roads, Clarence Barlow, Matthew Wright, and Matthew Turk, and to the many students who helped these courses evolve, either as course participants or teaching assistants (you know who you are).

Stephen Travis Pope ([stephen@HeavenEverywhere.com](mailto:stephen@HeavenEverywhere.com))

Santa Barbara, California—September, 2009 (updated January, 2014)

# Introduction to Volume 3: Audio Hardware

Volume three of *TheBigMATBook* is dedicated to the engineering and aesthetics of sound recording and reproduction equipment and musical content. We address the fundamentals of the design of audiophile-class components and recording studio equipment. The topics include the components of the studio signal chain, from microphones through mixing consoles to monitor loudspeakers. We address the various processing stages, recording formats, post-production, and encoding for distribution.

## Audiophile engineering topics

- Principles of high fidelity sound reproduction
- Critical listening and audio system evaluation
- Audio components: electronics, transducers, and interconnects
- Room acoustics, design, and treatment
- Audiophile, pro-audio, and recording studio systems
- Audiophile recording techniques and equipment
- Digital audio formats and content distribution
- Multi-channel formats and surround sound
- System measurement, evaluation, and comparison

## Recording studio design topics

- Introduction
- Studios and Control Rooms
- Power and Wiring
- Microphones and Pre-amps
- Mixing Consoles and Channel Strips
- Storage Formats and Media
- Monitoring and Playback
- Processing and Signal Conditioning
- Mixing and Mastering
- Computers and Digital Audio Workstations

# MAT 242A Audiophile Engineering (Spring, 2007)

## Overview

This course will focus on the engineering and aesthetics of audiophile sound recording and reproduction equipment and musical content. Students will read articles from the research and commercial literature, will learn the fundamentals of the design of audiophile-class components, and will carry out several formal listening experiments. Grading will be on the basis of written papers, technical projects, and/or a final examination, at the students' choice.



## Course Topics

- Principles of high fidelity sound reproduction
- Critical listening and audio system evaluation
- Audio components: electronics, transducers, and interconnects
- Room acoustics, design, and treatment
- Audiophile, pro-audio, and recording studio systems
- Audiophile recording techniques and equipment
- Digital audio formats and content distribution
- Multi-channel formats and surround sound
- System measurement, evaluation, and comparison



## Prerequisites

Basic knowledge of acoustics and some familiarity with stereo equipment. (No specific electronic or musical skills are assumed.) Upper-division undergraduates are welcome with permission of the instructor.

## Course Materials

Robert Harley, "The Complete Guide to High-End Audio," 3rd edition, Acapella Publishing, ISBN 0-9640849-4-5 (available from <http://www.hifibooks.com>, Amazon.com, and elsewhere, not in the UCSB book store), plus a two-part course reader (available at the UCSB book store).

## Instructor

- Stephen T. Pope ([stp@mat.ucsb.edu](mailto:stp@mat.ucsb.edu))

## Meeting time and place

- T/Th 12:00 - 1:50 PM, Music 2215

## Electronic Resources

- Course Web Site  
See <http://create.ucsb.edu/242>
- Email Mailing List  
See <http://www.mat.ucsb.edu/mailman/listinfo/242> to join

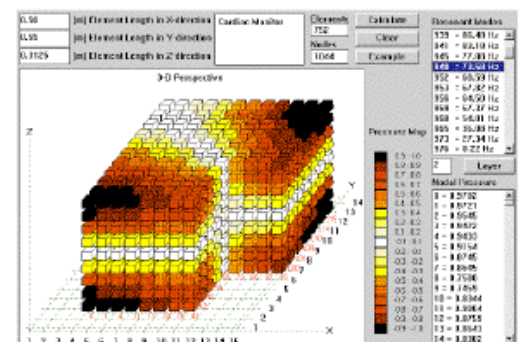
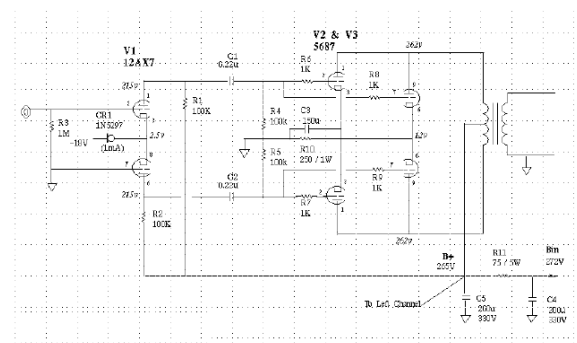


Figure 10. Pressure distribution of the 200Hz mode.

# **MAT 242A: Audiophile Engineering Reader Contents**

## **Volume 1**

### **General Reference**

*Reviews of Acoustical Patents* -- JAES  
*Can you really hear it? Psychoacoustics in Action* -- JAES 55(12): 2007  
*The Faults of Recording Media* -- The Anstendig Institute  
*Stereo: A Misunderstanding* -- The Anstendig Institute  
*Digital Recordings, A Tragedy Unrivaled in the History of Art* -- The Anstendig Institute

### **Formats, CODECS & Networking**

*New Media for Music* -- JAES, 6/03  
*SACD One Year Later* -- Stereophile, 11/00  
*Understanding S/P-DIF and AES/EBU* -- Audio Electronics 3/98  
*A Suggested Explanation for (Some of) the Audible Differences between High SampleRate and Conventional Sample Rate Audio Material* -- dCS, Ltd, 1997  
*A/D Conversion Techniques* -- Steve Hendrix  
*Dithering Around* -- Pro Audio Review, 4/99  
*AAC: Life Beyond MP3* -- HiFi News, 10/00  
*Lossless Compression for DVD Audio* -- AES 9th Regional Conf.

### **Spatial and Surround Sound**

*High-Quality Multichannel Audio Coding: Trends and Challenges* -- JAES 6/00  
*History of Spatial Coding* -- JAES 6/03  
*Stereo vs 5.1: Is it More or Less?* -- Stereophile, 8/01

### **Hardware Theory**

*Tubes do something special* -- Stereophile, 9/00  
*The Cool Sound of Tubes* -- IEEE Spectrum, 8/98  
*Op-Amp Spectral X-Contamination* -- Stereophile, 6/01  
*Reflections, Echoes, & Music* -- Stereophile, 11/01  
*Audio Power Amplification* -- JAES 54(4): 2006  
*What should I look for in a loudspeaker?* -- W. R. Dudleston, Legacy

### **Testing**

*Friend or Foe? Designers on Measurement* -- Ultimate Audio, 1999  
*Fundamentals of Modern Audio Measurement* -- JAES, 9/99  
*Measuring Loudspeakers (3 parts)* -- Stereophile, 11/98-1/99  
*Auditory Models for Gifted Listeners* -- JAES, 11/00

## **Audiophile Content**

*Bob Ludwig Interview* -- Stereophile 10/00

*I Want More (Tom Jung interview)* -- Stereophile 11/99

*Hard Disk Classical Music Recording* -- Pro Audio Review, 5/99

*Recording Deep River (excerpt)* -- Stereophile, 3/04

## **Tweaking**

*Optimizing your Audio System* -- Audio Electronics 3/98

*Tweaks!* -- Audio Musings 3/98

*Digital Room and Speaker Correction: The Big Picture* -- RegOnAudio

*Digital Correction for Audio, Part 1* -- RegOnAudio

*Loudspeaker Placement* -- Bodhan Raczynski

*Cinemusic Room Treatments* -- RPG

## **Volume 2**

### **Systems**

*Recommended Systems* -- TAS, 6/02

*The Hot 100* -- Stereophile, 11/02

### **Source: LP**

*Wilson Benesch Full Circle Turntable* (\$3900) -- Stereophile 11/98

*Koetsu Signature Platinum Phono Cartridge* (\$5500) -- UltimateAudio, 3/98

### **Source: CD/SACD/DVD-A**

*Technics DVD-A10 DVD/Audio* (\$1200) -- Stereophile, 11/00

*Sony SCD-XA777ES Multichannel SACD/CD* (\$3000) -- Stereophile, 1/02

*Esoteric DV-50 Universal Player* (\$5500) -- Stereophile 8/03

*MBL 1611/1621* (\$31,000) -- Stereophile, 12/99

*Burmeister Reference 970/969* (\$33,000) -- Stereophile, 12/99

### **Source: DACs**

*MSB Link DAC III* (\$700) -- Stereophile, 9/00

*Digital Audio Labs CardDeluxe PC Soundcard* (\$600) -- Stereophile, 9/00

*Mark Levinson 360 DAC* (\$4500) -- Stereophile, 12/99

*dCS Purcell D/D convertor* (\$5000) -- Stereophile, 1/01

*Slim Devices Transporter WiFi D/A Processor* -- Stereophile 2/07

### **Preamplifiers**

*Conrad-Johnson Premier 17LS pre* (\$4500) -- Stereophile, 5/01

*Mark Levinson 32 Reference Pre* (\$15,000) -- Stereophile, 1/00

*Boulder 2002/2010 Phono/preamplifier* (\$65,000) -- Stereophile 7/02

*Krell Evolution 202 preamplifier & 600 monoblock* (\$45,000) -- Stereophile 12/06

## **Amplification: Tube**

*Antique Sound Labs Explorer 805 DT SET (\$3000) -- Stereophile, 3/04*

*Music Reference (RAM Labs) RM-200 (\$3450) -- Stereophile, 4/02*

*Audio Research Reference 1 Pre and VT200 Power (\$8500 + \$9000) -- Stereophile, 11/98*

## **Amplification: Solid State**

*Headroom "Max" amplifier (\$1333) and Sennheiser HD600 'phones -- UltimateAudio, 3/98*

*Rotel RB-1090 2-channel power stage (\$2000) -- Stereophile, 1/00*

*Halcro DM88 Monoblock (\$40,000) -- Stereophile, 10/02*

## **Amplification: Integrated**

*NAD C370 (\$700) -- Stereophile, 1/02*

*Krell KAV-300i (\$2350) -- Stereophile 7/96*

## **Speakers**

*Polk Audio RT25i (\$320) -- Stereophile, 9/01*

*PSB Image 4T (\$650) -- Stereophile, 2/01*

*Magnepan MG3.6/R (\$3750) -- Stereophile, 8/00*

*Quad ESL-989 Electrostatic (\$8000) -- Stereophile, 11/02*

*Avantgarde Series Two (\$11,000) -- Stereophile, 9/00*

*B&W Nautilus 801 (\$11,000) -- Stereophile 1/99*

*Rockport Antares (\$41,500) -- Stereophile, 8/02*

*Wilson X-1 Grand Slamm Series II (\$77,000) -- Fi, 6/98*

## **Interconnection**

*Speaker Cables under \$8/m -- What HiFi?, 5/98*

*Our Favorite Audio Cables -- Listener, 3/01*

*Alpha-Core interconnects (\$78/m) and speaker cables -- Stereophile, 10/01*

*Nirvana S-X Ltd. (\$2200/m) -- Stereophile, 8/00*

*Nordost Valhalla interconnects and speaker cables (\$4200/m) -- Stereophile, 11/01*

## **Power and Accessories**

*Nine Power Conditioners Surveyed -- TAS, 10/03*

*AC Outlet Replacement -- Stereophile, 3/04*

*Acoustic Sciences Studio Traps (\$315) -- Stereophile, 12/98*

## **Processors**

*TacTRCS2.0 digital EQ/preamp and software (\$4300) -- Stereophile, 9/01*

## **Integrated/Disk-based Systems**

*Sonos ZP80 & ZP100 WiFi Music System -- Stereophile 10/06*

*Linn Knekt Kivor Hard Disk System (\$20,000) -- Stereophile, 12/01*

*Meridian Digital Theater System (\$73,000) -- Stereophile, 2/00*



# MAT 242: Special Topics in Digital Multimedia: Audiophile Engineering

Prepared by Stephen Travis Pope (stp@mat.ucsb.edu)  
UCSB, Spring, 2007

MAT 242A

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## MAT 242A Topics

- Principles of high fidelity
- Critical listening, system evaluation
- Audio components
  - Sources, electronics, transducers, and interconnects
- Room acoustics, design, and treatment
- Audiophile, pro-audio, and recording studio systems
- Audiophile recording techniques and equipment
- Digital audio formats and content distribution
- Multi-channel formats and surround sound
- System measurement, evaluation, and comparison

MEDIA ARTS & TECHNOLOGY PROGRAM

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## Lecture 1 Outline

- Goals
- Logistics
- Materials
- Course Overview
- Assignments
- Topic 1



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## Goals for MAT 242

- Critical listening
- Component, system, and content evaluation
- Technical features of current state of the art components and content
- Pros/cons of different distribution formats
- Look into the future

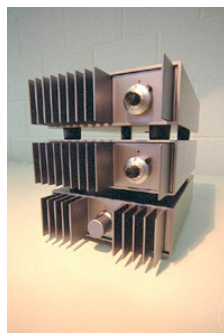
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## Logistics

- Instructor
  - Stephen T. Pope
    - stp@mat.ucsb.edu
    - http://create.ucsb.edu/~stp
- TA
  - Alex Kouznetsov
    - alex@create.ucsb.edu
- Meeting time
  - Tues/Thurs, 12:00 - 1:50 PM
  - CREATE class room (Music 2215)



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## Materials

- Text books
  - Required: Robert Harley, *The Complete Guide to High-End Audio* (Acapella Publ., 3rd Edition)
  - Recommended: F. Alton Everest, *The Master Handbook of Acoustics* (TAB Books, 1994) and/or John L. Hood, *Audio Electronics* (Newnes Publ., 1995)
  - Two-volume reader for MAT 242A at the UCSB bookstore
  - Presentation slides (bookstore or on-line)

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## Other Materials

- Augmented by readings from the Journal of the Audio Engineering Society, Pro Audio Review, Stereophile, and other sources
- Web site: <http://create.ucsb.edu/242/>
- Mailing list: 242@mat.ucsb.edu, <http://zydeco.mat.ucsb.edu/mailman/listinfo/242>
- HiFi Link list: <http://create.ucsb.edu/~stp/hifi.links.html>  
(Comments/corrections/additions are welcome!)

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## Topics

- Principles of high fidelity
- Critical listening, system evaluation
- Audio components
  - Sources, electronics, transducers, and interconnects
- Room acoustics, design, and treatment
- Audiophile, pro-audio, and recording studio systems
- Audiophile recording techniques and equipment
- Digital audio formats and content distribution
- Multi-channel formats and surround sound
- System measurement, evaluation, and comparison

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## Course Schedule

- **Week 1:** Principles of high fidelity sound reproduction
  - Critical listening and audio system evaluation
- **Week 2:** Audio system measurement, evaluation, and comparison
  - Frequency and phase responses, types of coloration and distortion
- **Week 3:** Audio electronics – source components
  - Analog and digital source chains
- **Week 4:** Digital audio formats and content distribution
  - CD, DVD, SACD, digital broadcast, Internet sound distribution
  - Multi-channel formats and surround sound

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## Course Schedule

- **Week 5:** Audio electronics – amplification components
  - Preamplifiers, switchers, attenuators, power amplifiers
- **Week 6:** Audio electronics – transducers and interconnects
  - Loudspeakers, enclosures, and crossovers
  - Cables and interconnects
- **Week 7:** Room acoustics, design, and treatment
  - Acoustics of listening rooms, performance spaces, and recording studios
  - Audio accessories and treatments
- **Week 8:** Audiophile, pro-audio, and recording studio systems
  - Audiophile recording techniques and equipment
- **Week 9:** Wrap-up, final listening session

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## Assignments/Grades

- Options: written papers, technical project, or exam
- Default option: Three short written papers:
  - 1) Critical listening exercise
    - Select a recording or piece and listen to the changes over several systems and formats - Due week 4
  - 2) Product review/comparison
    - Compare/contrast two or more components - Due week 7
  - 3) Advanced paper
    - Open technical topic - Due finals week

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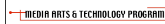
# MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 1: Principles

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## Topic 1: Principles of high-fidelity sound reproduction

- HiFi: what/why/how/since-when?
- Critical listening and audio system evaluation
- Reading: Harley Chpts. 1-3. App. A
- Exercise: Select 1 or more music samples for critical listening


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## Topic 1 Readings

- General
  - Reviews of Acoustical Patents – JAES
  - Can you really hear it? Psychoacoustics in Action
  - The Faults of Recording Media – Anstendig
  - Stereo: A Misunderstanding
  - Digital Recordings, A Tragedy Unrivaled in the History of Art
- Spatial and Surround Sound
  - High-Quality Multichannel Audio Coding: Trends and Challenges
  - History of Spatial Coding
  - Stereo vs 5.1: Is it More or Less?

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## Why hi-fi?

- Sound projection via electro-mechanical systems
  - Broadcast
  - Recording
  - Augmentation
- Capture of
  - Timbres
  - Dynamics
  - Spatial image
  - "Emotion"
- The desire for high-fidelity of reproduction



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## A bit (well, several bits) of history

- 1870s: Telephony
- 1880s: Sound reproduction (wax cylinders)
- 1920s: Tubes, Jazz, 12-tone music
- 1930s: Radio Broadcast, TV, electrical (wire) recording
- 1940s: Multi-way speakers, musique concrete, elektronische Musik
- 1950s: Stereophony (on LPs), tape recording, computer music, FM broadcasting, 1-piece stereo HiFi "consoles"
- 1960s: "HiFi" as a concept, commercial analog synthesizers, multi-track recording, solid-state audio electronics, emergence of "high-end" audio

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## More History

- 1970s: Stereo FM radio, Quad LPs, 16/44 DACs, separate stereo "components," audio OpAmp ICs
- 1980s: CDs, DAT, THX theater sound, pluriphony, walkman, true 16-bit DACs, 20-bit DAT, digital synthesizers, PCs, computer networks, MIDI
- 1990s: 5.1-channel home theater, MP3/WWW, HDCD, integrated audiophile components (again)
- 2000s: AAC/MPEG-4, portable/wireless players, SACD, DVD/A, iTunes/store, Internet broadcasting, recommender systems


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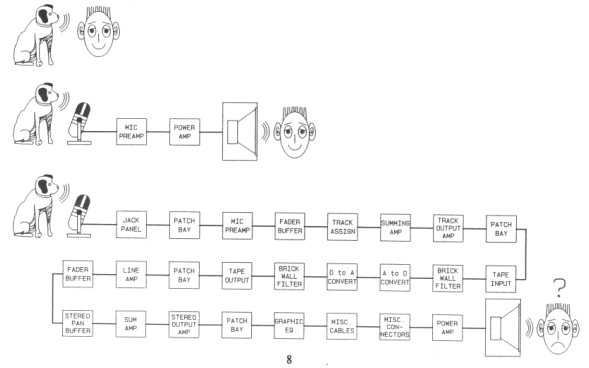
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## What is "audiophile"

- **Standard definitions**
  - Designed by ear, not by measurement
  - Built and tested by hand
  - Expensive
  - Small-label brands
  - Minimalist, maximalist
  - Audiophile content
  - Built for critical listening
- **Focus on the system, not the components**
  - Source chains, processing, transducers, interconnects, stands, room treatments
- **Relation to ProAudio, TheaterSound, etc.**

## In Pictures



## The state of the art

- Not one but many!
- 7.1-channel 24/192 gear and DVD/SACD content
- Good-sounding 5.1-channel AAC over medium-bandwidth WAN channels
- Excellent playback of HiFi-mastered vinyl
- Audiophile-quality digital broadcast
- Pocket-sized system with 50 GB (~25 days) of storage and flexible VBR (up to 16/44) encoding
- Audiophile systems from \$2000 - \$450,000
- Increasing cross-over with studio and theater sound

## Example: SOTA in Speakers (\$800 - 125,000)



## Name-dropping (brands I've listened to)

- **Respected less-expensive brands**
  - NAD, Naim, Adcom, Cambridge, Musical Fidelity, Marantz, Music Hall, PSB, Monster, Polk
- **Good "mid-level" Audiophile**
  - Rotel, Denon, Sonic Frontiers, Proceed, Parasound, Rega, Madrigal, AudioQuest, B&W, NHT, Thiel, Legacy
- **Absolute (cost-no-object)**
  - Krell, Mark Levinson, Conrad Johnson, Classé, Linn, Bel Canto, VPI, B&W, Wilson, Martin Logan, JM Lab, Purist Audio, Kimber, Nordost

## My personal biases

- **Solid-state for amplification**
  - Audiophile integrated amps
- **Tubes for low-level sources**
- **2-3-way simple dynamic speakers**
- **Silver interconnects**
- **Bi-wiring**
- **Room treatment & stands**
- **Many sources**
- **Stereo rather than home theater**

## How to listen

- Aspects of sound and instruments
- Transients (what to choose?)
- Decay
- Spectral elements
- Listening to the spatial image
- Listening for problems (image analogy)
- Hearing the music!

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## HiFi Resources

- Magazines
- Web Sites
- Link Lists
- News Groups
- Events and Shows
- Other Media

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## Assembling an audiophile system

- Decisions of principle
  - What do you listen to (or intend to listen to)?
  - What sources and format do you want?
  - What can you afford?
- Balance of investment
  - 20-30% Sources
  - 20-30% Amplification
  - 30-50% Speakers
  - 10-25% Interconnects
  - 0-25% Treatments

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## Readings

- Recommended Systems – TAS, 6/02
- The Hot 100 – Stereophile, 11/02

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## Decisions

- Sources
  - CD, DAT, SACD, DVD, Cassette, LP, Radio, MP3, streaming, computer, home studio, etc.
- Projection format
  - Channels and geometry: 2, 4, 5.1, 7.1, 8
- New/used
  - Dealer relationship vs. WWW
- 1-step or incremental
  - As a tool or as a hobby
- Many more...



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## Listening

- Experimental design
  - A/B/A
- Choosing content (sonic memory)
  - Make your own sampler CD or take your favorites with you.
- Audiophile values
  - Clarity/detail, dynamics, sound stage, involvement
- Turning it on and off
- All the pretty adjectives

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## Characterizations

- Time-domain
  - Transients, pace, rhythm, timing
- Spectral-domain
  - Weight/balance of the octaves
  - Deep bass and high treble extension
  - Mid-range and vocal timbres
- Spatial-domain
  - Sound stage, size/volume, involvement
- Others
  - Detail, clarity, involvement, musicality

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## Assignment

- Select 3-6 musical selections for critical listening tests; listen to them carefully over as many systems as you can.
- Prepare to discuss them. Why are they a good choice for system evaluation? How are they recorded and mastered?
- Prepare some ideas for the first paper.
- Do the reading for weeks 1 and 2.

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## What's Next?

- Audio System Measurement (medium-heavy tech)
- Critical listening exercises (your selections and mine)
- Readings
- Quizzes

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## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 2: Measurement

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## Topic 2: Measurement of Audio Systems

- Features of audio signals
- Amplitude-domain effects
- Time-domain effects
- Frequency-domain effects
- Other distortions
- Measurement and evaluation
- Intro. to electronics

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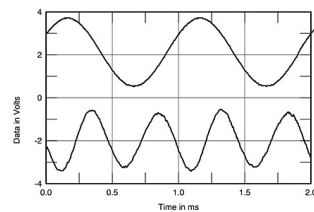
## Topic 2 Readings

- Testing
  - Friend or Foe?
  - Fundamentals of Modern Audio Measurement
  - Measuring Loudspeakers (3 parts)
  - Auditory Models for Gifted Listeners
- Hardware Theory
  - Tubes do something special
  - The Cool Sound of Tubes
  - Op-Amp Spectral X-Contamination
  - Reflections, Echoes, & Music
  - Audio Power Amplification
  - What should I look for in a loudspeaker?

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## Audio Signals



- Sound waves and transducers
- The time domain
- The frequency domain
- Space and multichannel systems
- Inter-domain effects

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## Representations of Audio

- Transducers, feature-extraction, and representation domains
- Continuous-time vs. sampled signals
- Continuous-range vs. quantized signals
- Representations of spatial sound
- Standard representations

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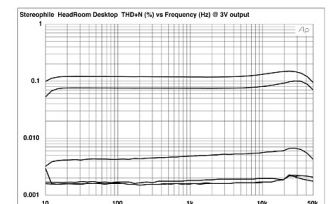
## Limitations of Transducers

- Time-domain effects
  - Latency, slew
- Frequency response & limits
  - Freq/phase extension
- Amplitude effects & limits
  - Clipping, hysteresis, zero-crossing
- Electrical properties

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## Amplitude-domain effects

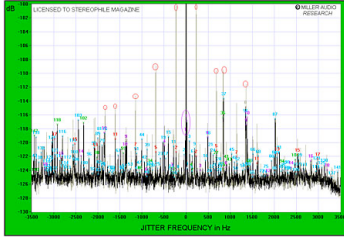


- Gain linearity
- Amplitude features
  - Limits
  - Sensitivity
- Signal-to-noise ratio and dynamic range
- Directionality
- Distortions vs. level

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## Time-domain Effects



- Delays and latency
- Latency jitter
- Slew rate and time/frequency effects

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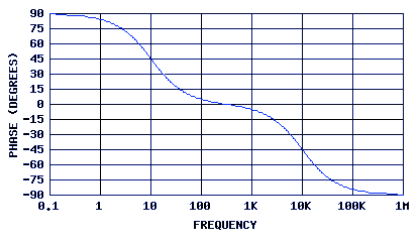
## Frequency-domain Effects

- Frequency response
- SNR vs. frequency
- Harmonic distortion
- Intermodulation distortion

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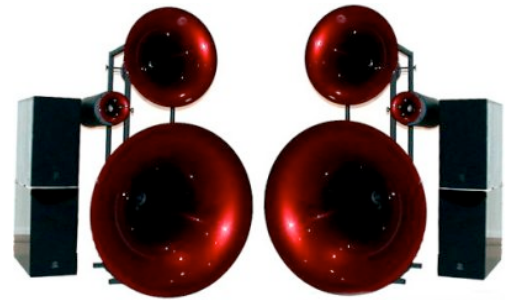
## Phase-domain Effects



- Group delay and time/frequency effects
- Phase vs. frequency
- Special impact of filters

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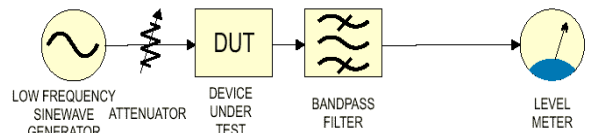
## System Measurement

- Source/filter/listener model
- Sources
  - Constant
  - Swept
  - Bursts
  - Multi-tone
- DUT considerations
- Measurement devices

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## Measurement Examples

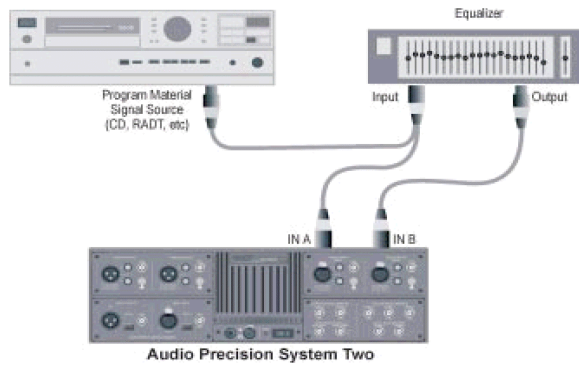


- Examples (see [AudioPrecision.com](http://AudioPrecision.com))
- Amplitude Linearity

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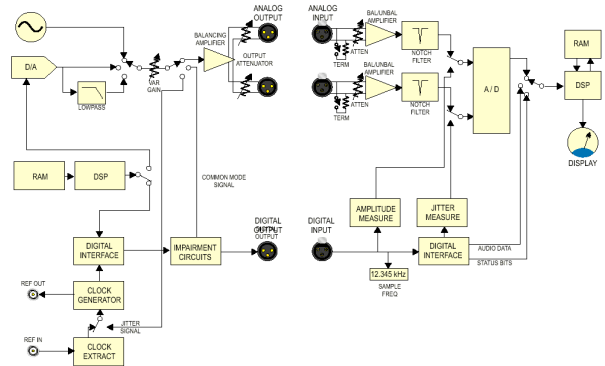
## Simple Test Setup



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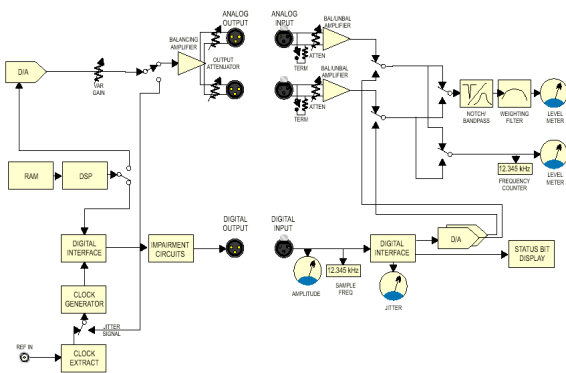
## Mixed-signal Measurement



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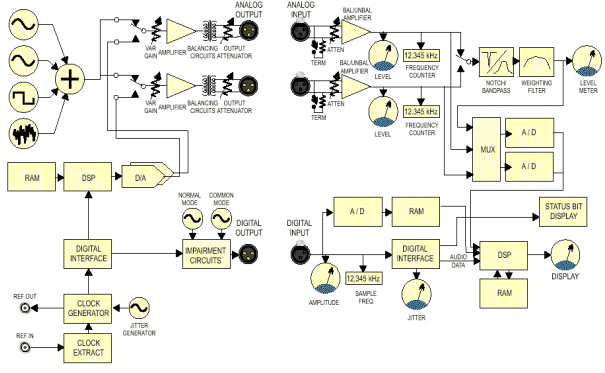
## Dual-domain Measurement



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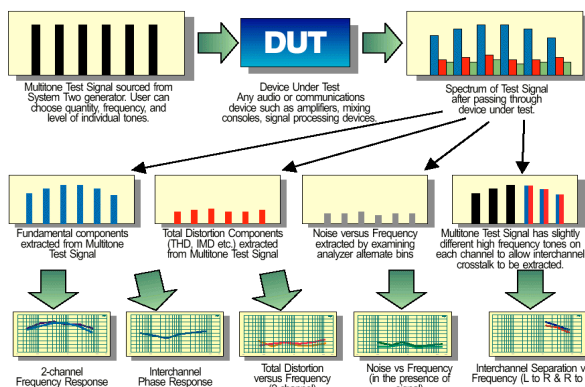
## Dual-domain Measurement



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## Multi-tone Measurement



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## Time/Phase/Amplitude

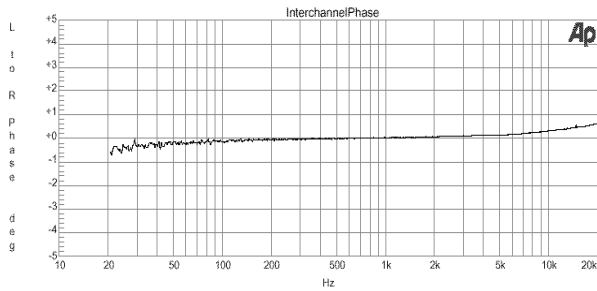
- Phase
- Crosstalk
- Time/frequency measurements

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## Interchannel Phase

Audio Precision CD Interchannel (Relative) Phase - Glide Tone



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## Interchannel Crosstalk

Audio Precision CD Crosstalk Left (Ch A) to Right (Ch B)

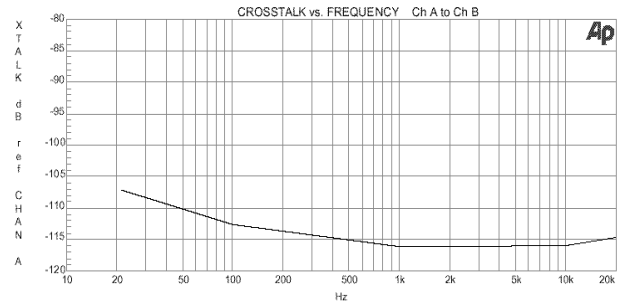


Figure 31 is a graph of left-to-right separation using the CD left channel only signals.

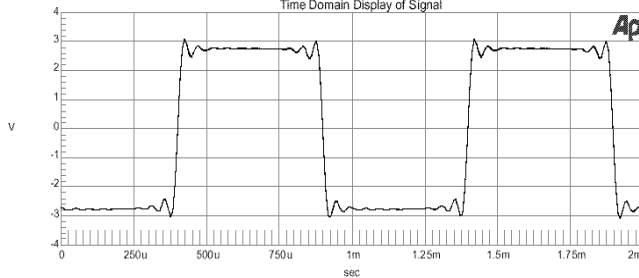
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## Band-limited Square Wave

Audio Precision Waveform Display

Time Domain Display of Signal



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## Time/Phase Accuracy

Audio Precision CD Triggered O'scope mode

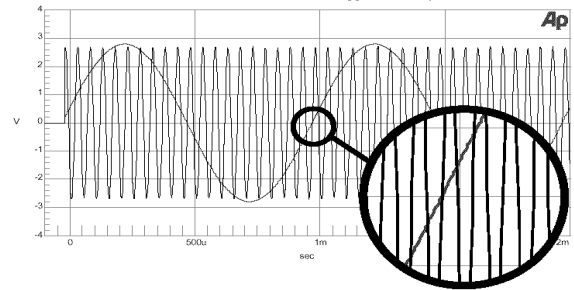


Figure 36 Two different frequencies (1k and 10k) on different channels from the Philips disc track 74. The zero cross of both signals should coincide with no offset when phase vs. frequency and interchannel phase is correct.

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## Phase Response

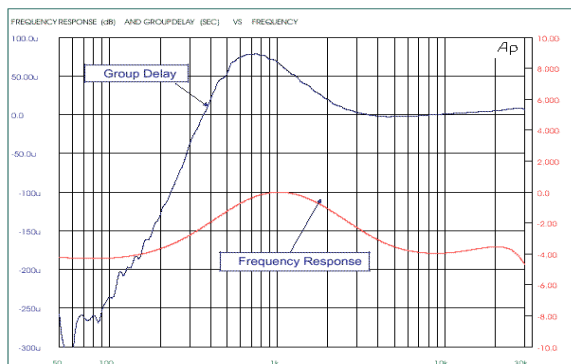


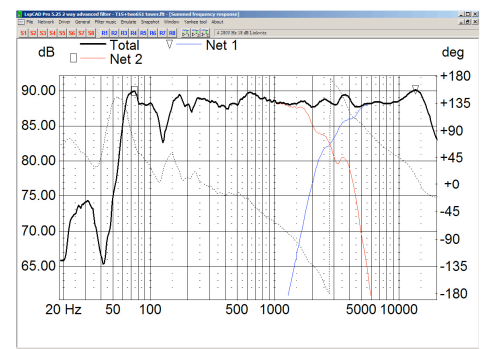
Figure 1 Final results of the group delay procedure showing group delay &amp; frequency response versus frequency of a simple equalizer.

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## The Frequency Domain

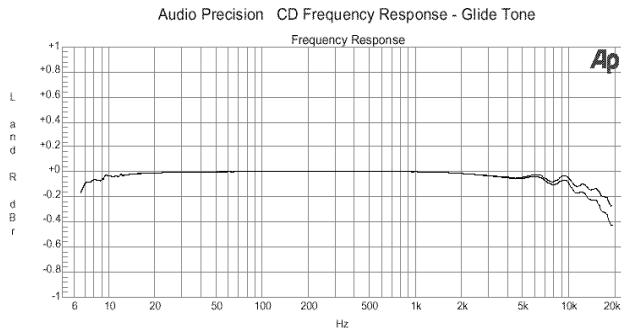
- Response
- Noise
- Phase



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## Swept Frequency Response

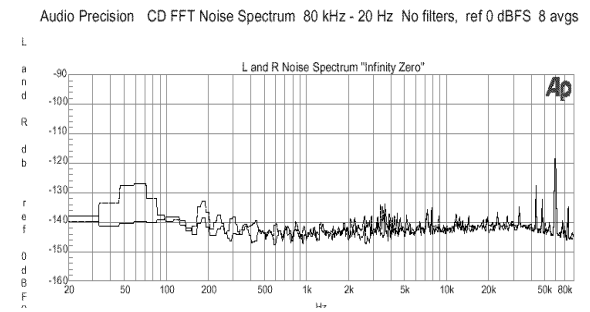


- Range and scale of spectrum

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## Noise Spectrum



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## THD vs. Frequency

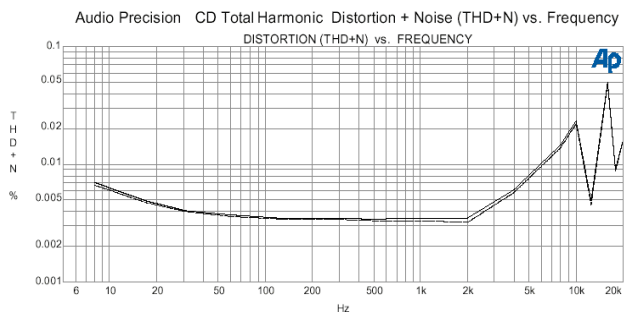


Figure 14 Distortion vs. Frequency graph (THDFREQ.at2)

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## SNR vs. Frequency

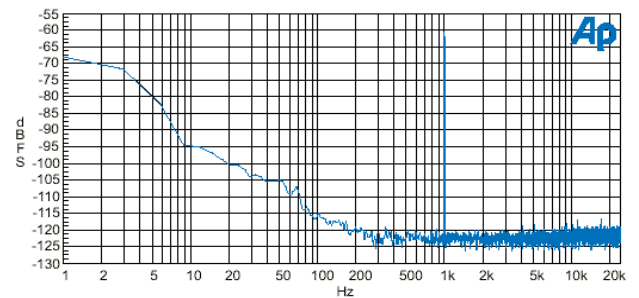
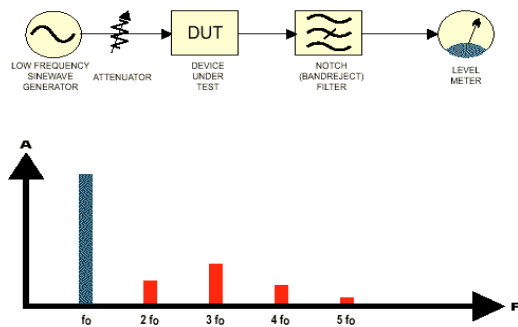


Figure 17. FFT of signal-to-noise test output, logarithmic axis.

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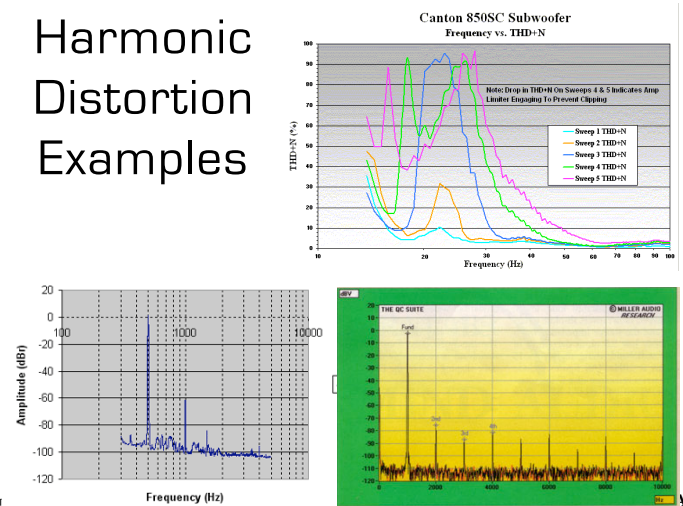
## Harmonic Distortion



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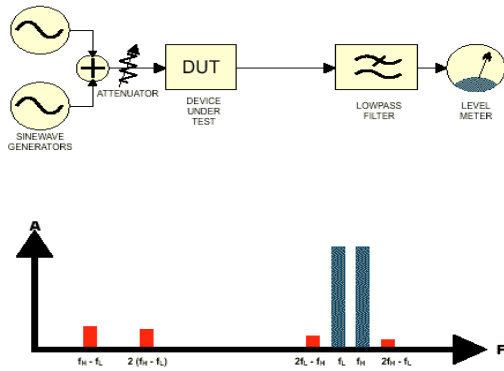
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## Harmonic Distortion Examples



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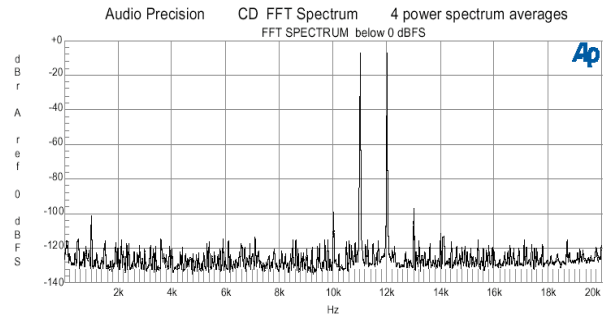
## Intermodulation Distortion



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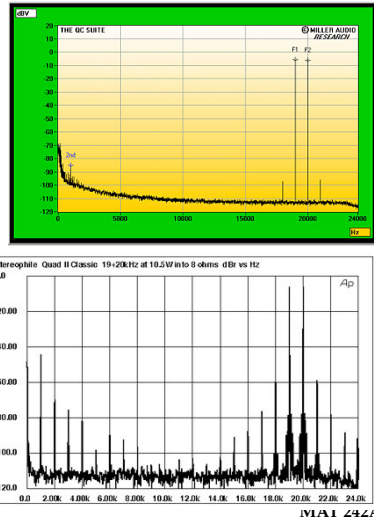
## Intermodulation Distortion



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Examples  
Above: good  
Below: bad



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## Source Measurement

- All above
- Test content considerations
- Special considerations for digital sources

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## Digital Converter Linearity

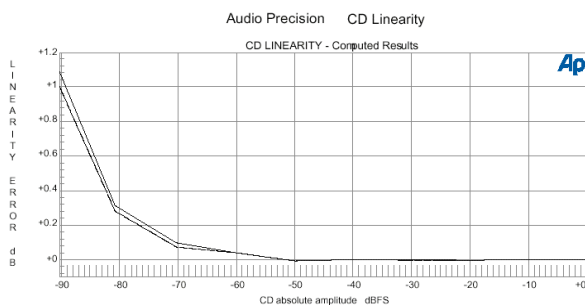
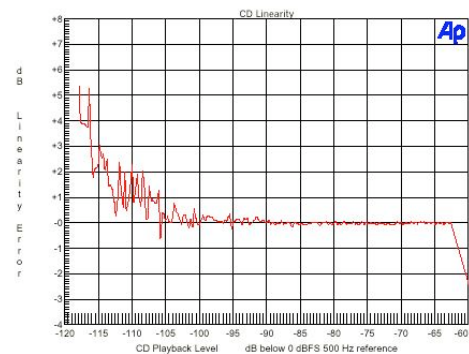


Figure 23 Graph of Analog Level meter controlled sweep from Linarty at 2 Horizontal axis (first column) data has been replaced with the actual values and Compute Linearity done.

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## Example



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## Aliasing Filter Response

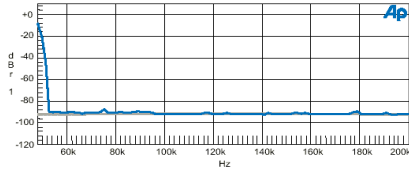


Figure 5. Anti-alias filter stopband attenuation.

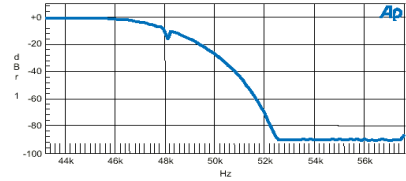


Figure 6. Anti-alias filter transition region.

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## Aliasing Filter Response

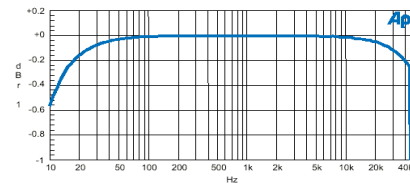


Figure 7. Frequency response in the ADC passband.

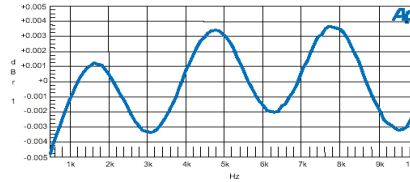


Figure 8. Anti-alias filter ripple.

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## Jitter Representation

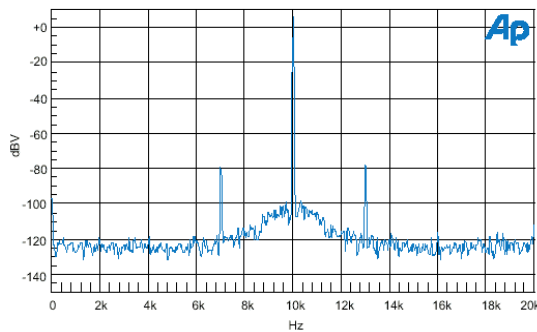
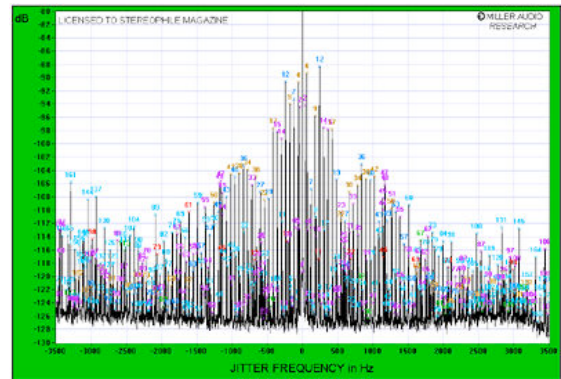


Figure 15. Jitter-modulated sidebands.

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## Example



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## Measurement in Equipment Reviews: Stereophile Magazine Examples

- Sources: use standard material, time-domain effects
- Amplification: performance under varying loads
- Speakers: response, impedance, of-axis, etc.
- Interconnects: how to measure?
- Other components
- Examples: Halcro DM88 amplifier (state of the art)

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## Example: Freq. Response

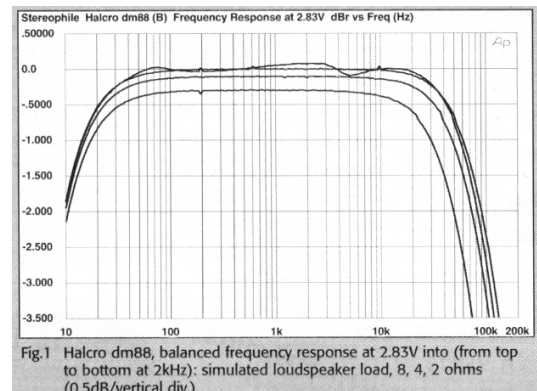


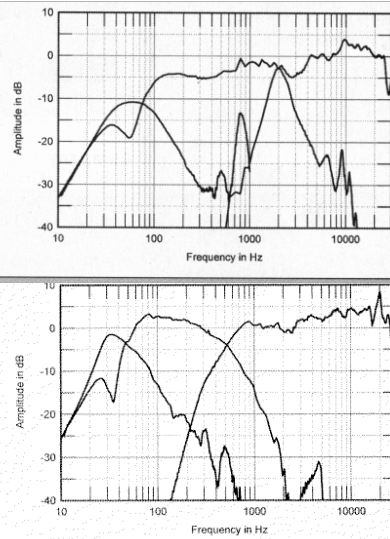
Fig.1 Halcro dm88, balanced frequency response at 2.83V into (from top to bottom at 2kHz): simulated loudspeaker load, 8, 4, 2 ohms (0.5dB/vertical div.).

- Ruler-flat, even under a real load

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## Speaker Freq. Response



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## Distortion Waveform

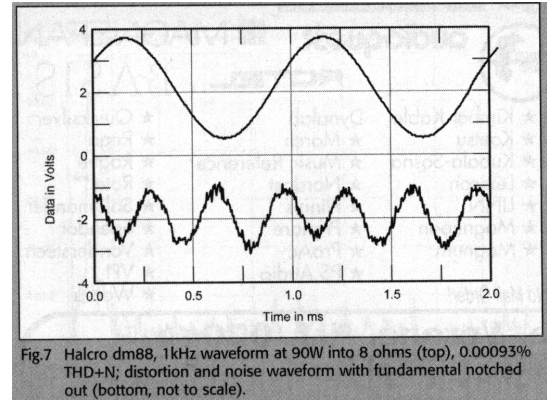


Fig.7 Halcro dm88, 1kHz waveform at 90W into 8 ohms (top), 0.00093% THD+N; distortion and noise waveform with fundamental notched out (bottom, not to scale).

- Mostly 3rd harmonic (i.e., solid-state amp)

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## Same at Full Power

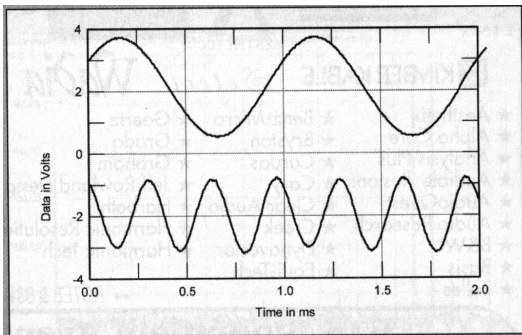


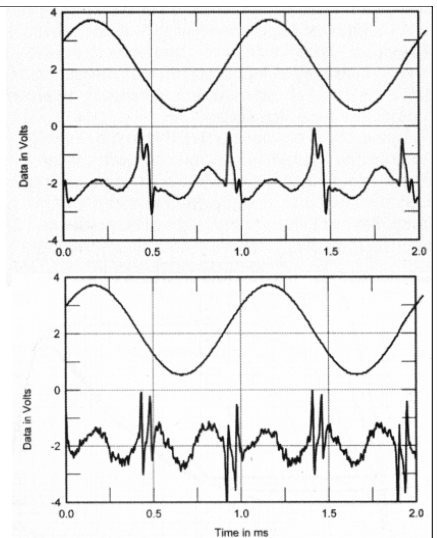
Fig.8 Halcro dm88, 1kHz waveform at 196W into 4 ohms (top), 0.0038% THD+N; distortion and noise waveform with fundamental notched out (bottom, not to scale).

- Even "cleaner" 3rd harmonic with some low freq

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## THD + Noise



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## Small-signal Square Wave

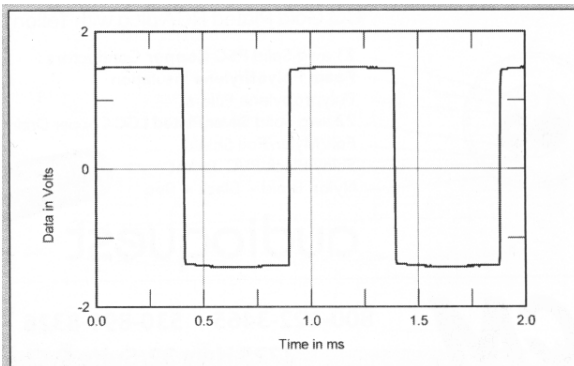


Fig.3 Halcro dm88, small-signal 1kHz squarewave into 8 ohms.

- At 1 kHz, look for overshoot, ringing

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## Small-signal Square Wave

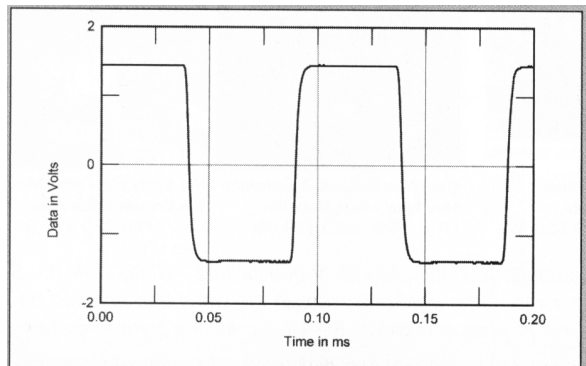
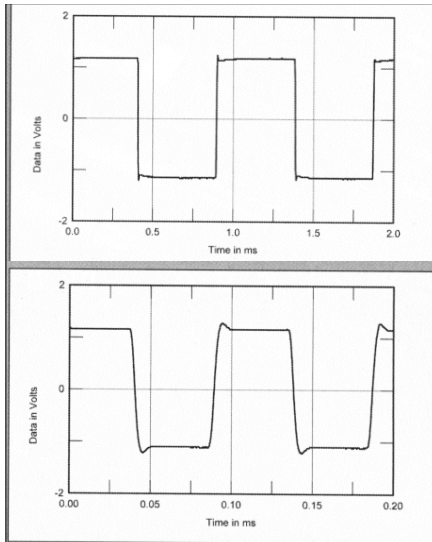


Fig.4 Halcro dm88, small-signal 10kHz squarewave into 8 ohms.

- At 10 kHz, look at transition, steady-state

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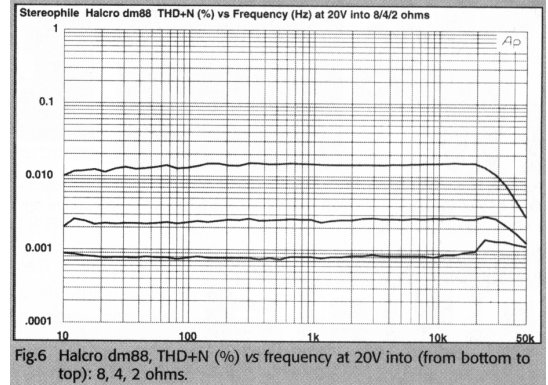


Small  
Squares  
(with  
overshoot &  
ringing)

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## THD vs. Frequency



Look at extreme frequency ranges

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## THD vs .Power

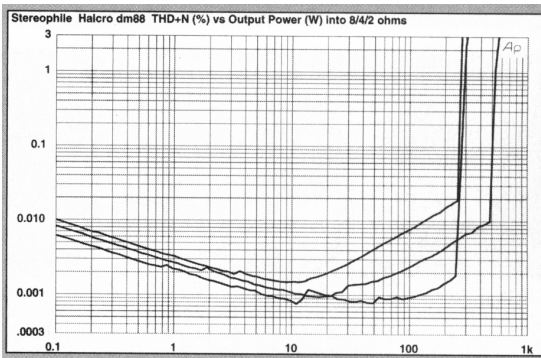


Fig.5 Halcro dm88, distortion (%) vs 1kHz continuous output power into (from bottom to top at 100W): 8, 4, 2 ohms.

Low-power value, slope at rated power

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## Harmonic Dist. Spectrum

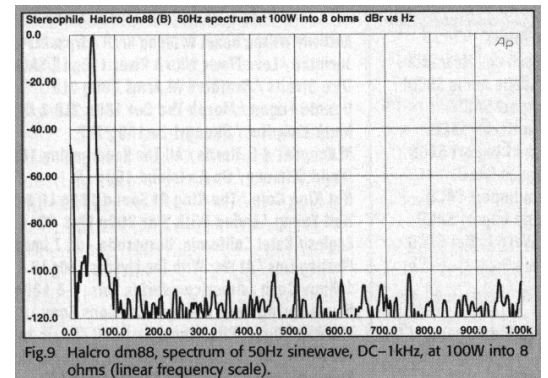
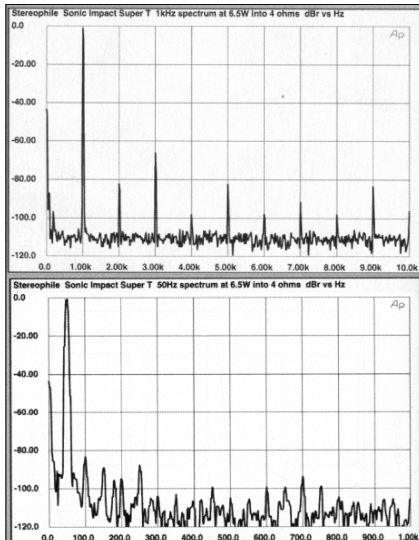


Fig.9 Halcro dm88, spectrum of 50Hz sine wave, DC-1kHz, at 100W into 8 ohms (linear frequency scale).

Look at level and even/odd balance

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Depressing  
THD  
Spectra

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## Intermodulation Spectrum

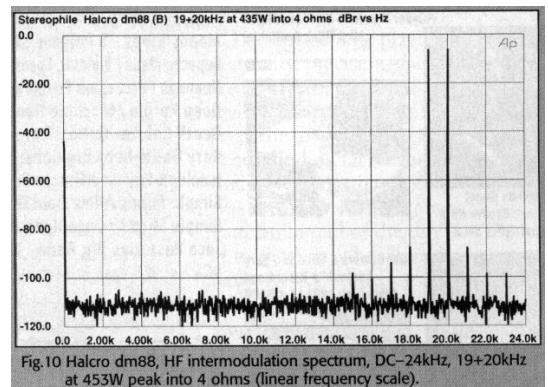


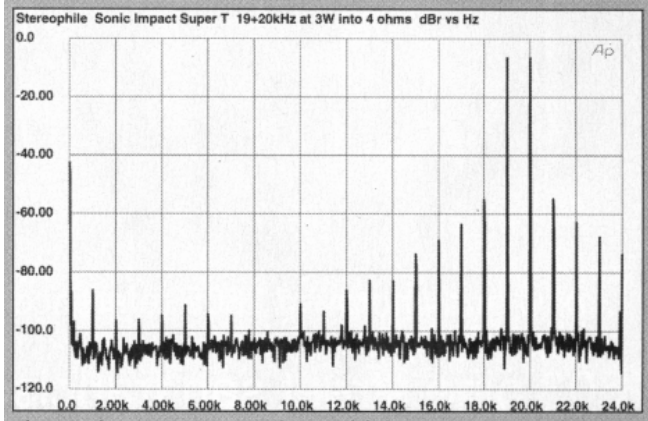
Fig.10 Halcro dm88, HF intermodulation spectrum, DC-24kHz, 19+20kHz at 453W peak into 4 ohms (linear frequency scale).

19 + 20 kHz, look at side-bands and 1 kHz

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## Bad Day at IM



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## Electronics

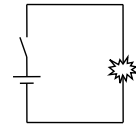
- Voltage and Current
- Batteries and Resistors
- Capacitors and Inductors
- Transformers
- Circuits and systems

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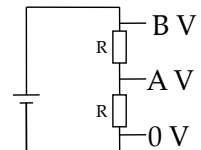
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## Simple Circuits

- Flashlight



- Voltage Divider
  - Water valve analogy

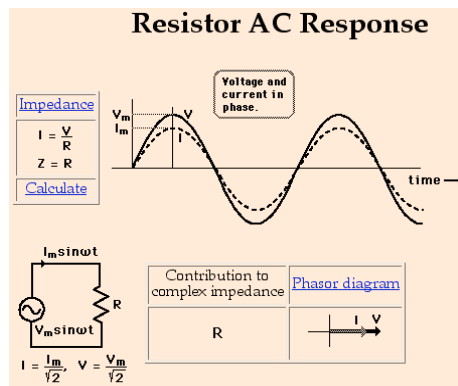


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## Resistors

- $I \propto V$
- Analogies for circuits: plumbing, acoustical systems



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## Capacitors

- $I \propto \Delta V$

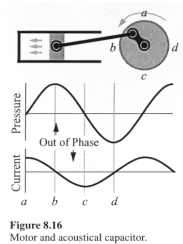
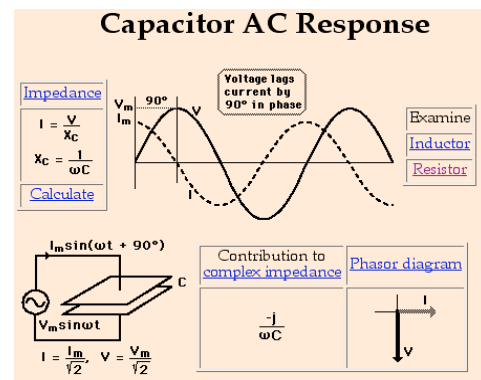
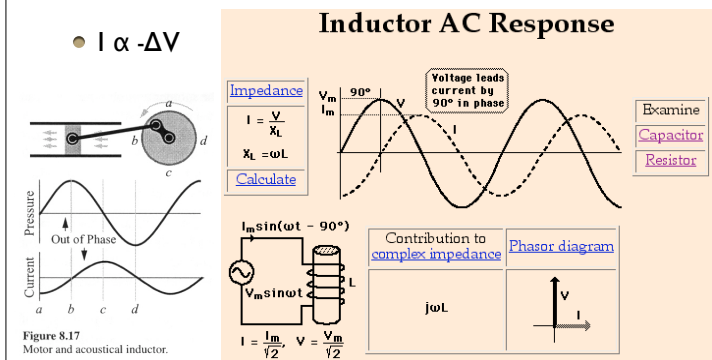


Figure 8.16 Motor and acoustical capacitor.

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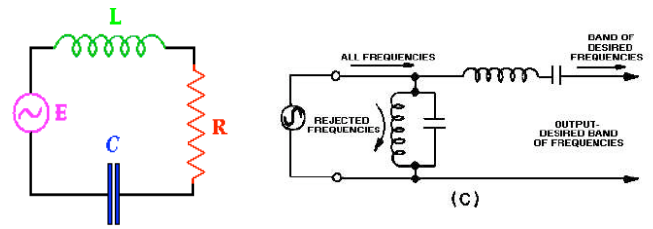
## Inductors



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## RC, RL, and RLC Circuits



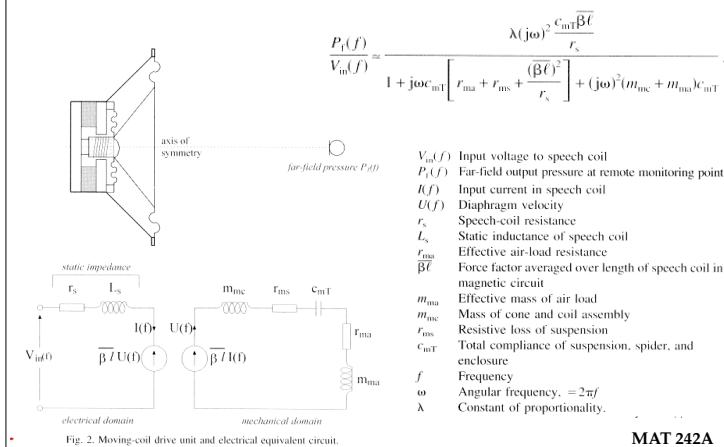
- Web examples

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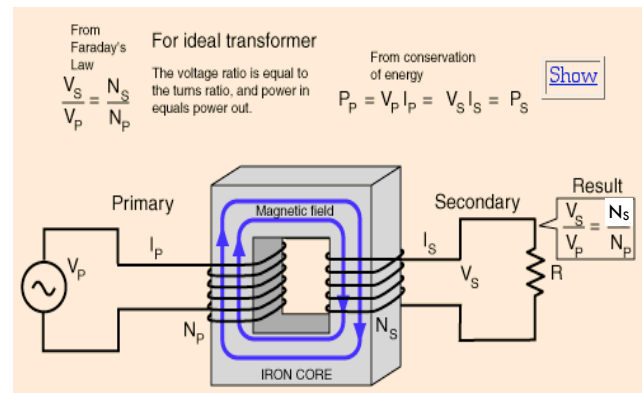
## Acoustical Circuit & Transfer Fcn



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## Transformers

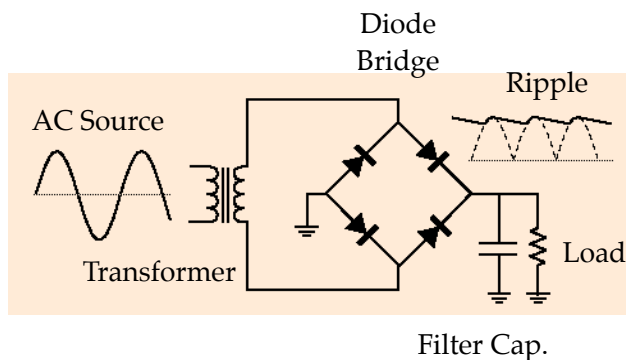


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## Power Supplies



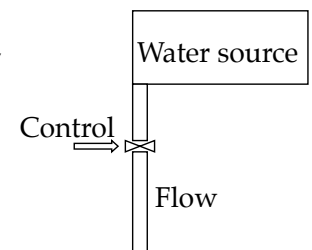
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## Tubes and Transistors

- The valve analogy

- Reservoir
- Control
- Output

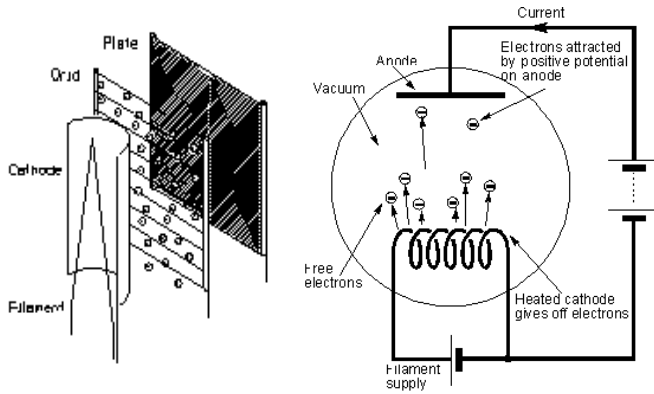


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## Tube (simplified)



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## Tube (Detailed)

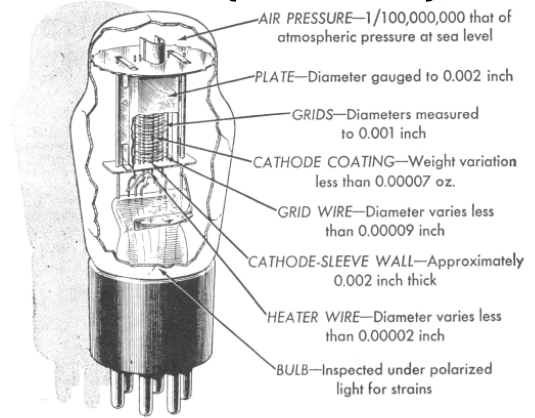


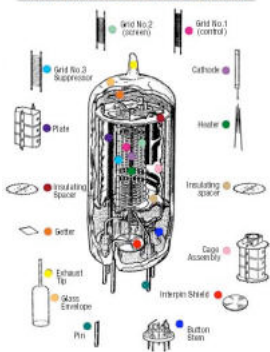
Fig. 9.  
The internal details of a vintage RCA multi-grid tube.

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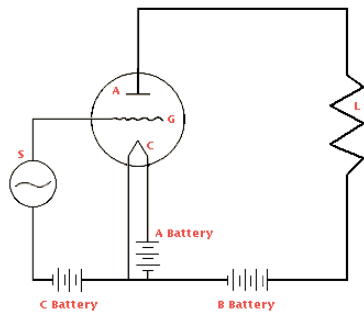
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## More about Tubes

Inside a miniature tube (this is a pentode)



A simplified schematic circuit diagram of a triode amplifier. The triode contains a cathode C, an anode A, and a control grid G. The triode, batteries A, B, and C, and a load resistor L serve to amplify the voltage in the AC source S.



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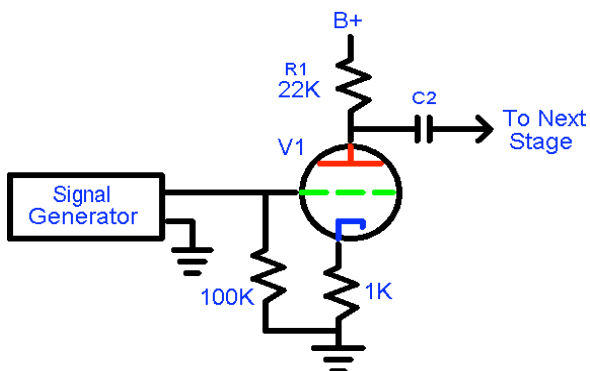
## Tube Flavors

- **Tube structure**
  - Extra grids capture "bounced" electrons
  - Triode -> tetrode, pentode
- **Tube packaging**
  - Multiple circuits in 1 envelope
- **Tube diodes, rectifiers**
  - For power supplies

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## A Basic Tube Amplifier



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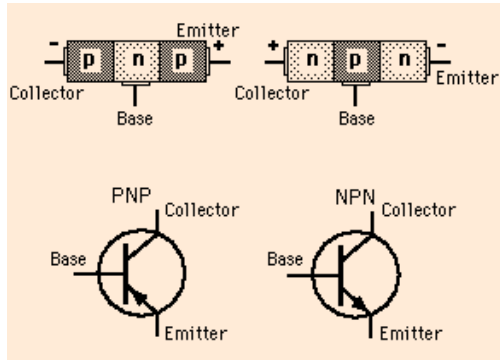
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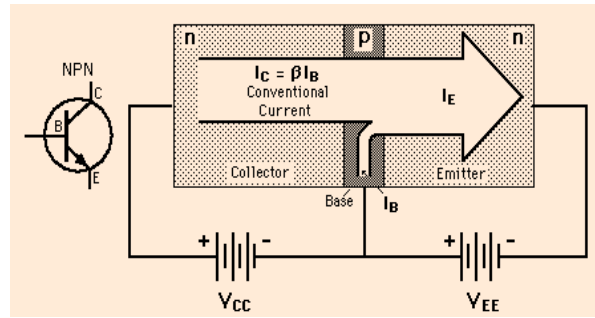
## Transistors



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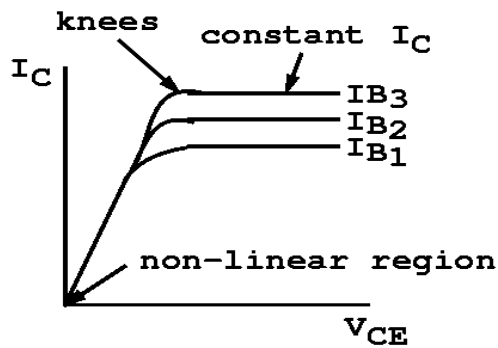
## Transistor current control



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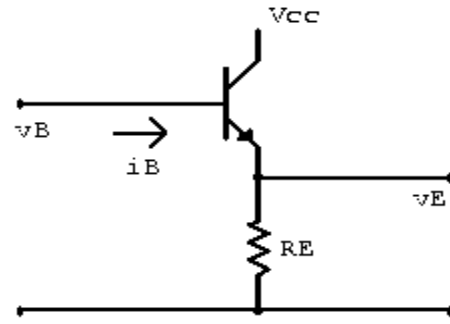
## Transistor Transfer function



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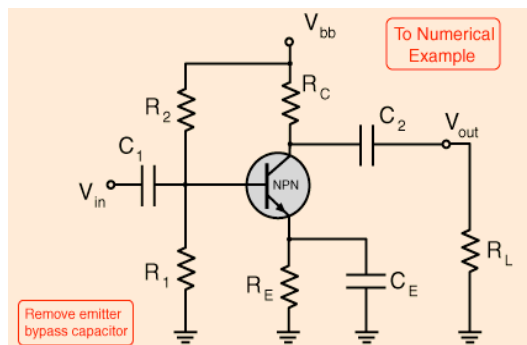
## A Simple CE Amplifier



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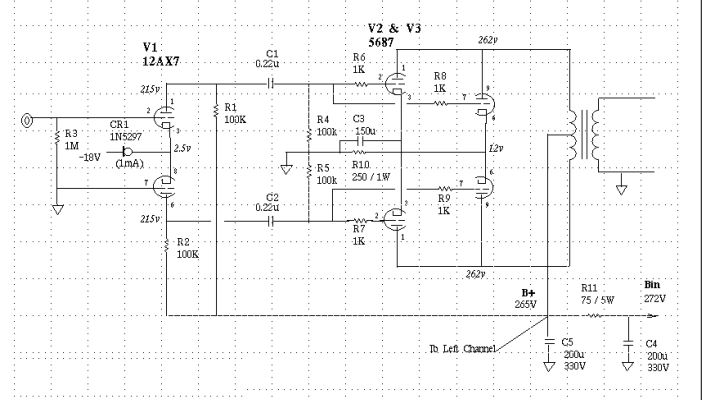
## A Real CC Amplifier



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## Push-Pull Tube Amplifier



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## Analog Design

- Amplifiers
  - I/O Z (source/driver impedance)
    - Desired: high in Z, low out Z
  - Freq/Phase responses
- Buffers
- Filters
- Power supplies

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## Practical Design Considerations

- Single-stage amplifier
- Differential designs
- Multi-stage designs
- Balanced (differential) vs. Unbalanced (single-ended) systems



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## Balanced vs. Single-ended

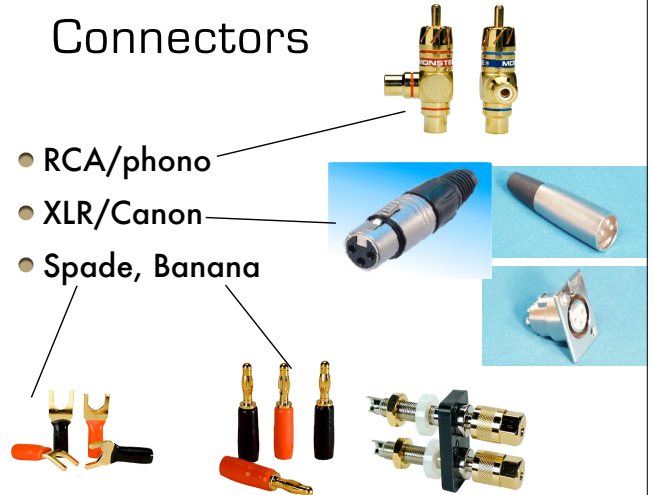
- SE = single signal relative to ground
- Balanced = +, -, and shield (reference)
- Cabling: SE is more susceptible to RFI; Bal has excellent common-mode rejection
- Cost: Balanced is twice the electronics and wiring
- Alternatives: current mode, proprietary connectors, DIN, etc.

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## Connectors

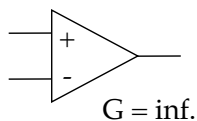
- RCA/phono
- XLR/Canon
- Spade, Banana



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## Operational Amplifiers

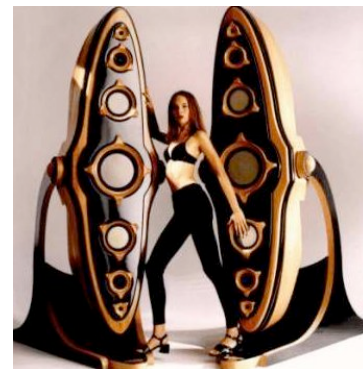


- Input and output impedance (use as buffers between stages)
- Gain and feedback
- Design issues

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## Characteristics of Components

- See above
- Sources/convertors
- Amplification/processing
- Microphones & Loudspeakers
- Interconnects
- Stands & accessories
- Room treatments

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## Sources/Convertors

- Analog sources
  - Test source content
  - Noise, distortions
- Digital sources
  - Frequency, phase, jitter
  - Inter-channel effects
  - Jitter reduction devices



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## Amplification/processing



- Distortion (vs. frequency, vs. power)
- Frequency/phase response
- THD/SNR (vs. frequency, vs. power)
- I/O considerations

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## Microphones & Loudspeakers

- Amplitude sensitivity and linearity
- Time-domain response (step, pulse)
- Frequency response
- Phase response
- Impedance response
- Directionality (off-axis response)
- Physical considerations



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## Interconnects

- How to measure
- Capacitance/inductance
- Crosstalk, RFI immunity
- Phase response
- A/B/A testing
- Connector effects



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## Stands & Accessories



- Vibration effects and damping
- Cable accessories
- Other accessories and voodoo

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## Room treatments

- Absorption
- Reflection
- Dispersion
- Band-pass effects (bass traps)



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## What's Next?

- Source components
- Listening session 1

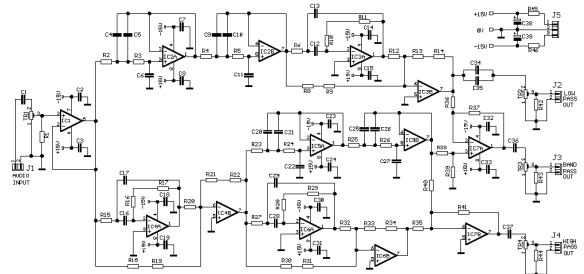


Fig. 11 3-WAY ACTIVE CROSSOVER WITH LINEAR PHASE

Rev. 11/98

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## Assignments

- Critical listening assignment & paper preparation
- Read measurement articles
- Read 1 review from each component category
- Read source component reviews

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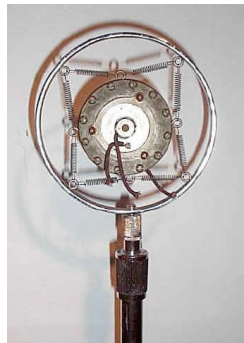
## MAT 242: Special Topics in Digital Multimedia: Audiophile Engineering Topic 3: Sources

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## Topic 3: Source Components

- System architecture
- The source chain
- LP playback
- CD/DVD/SACD playback
- Other sources



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## Topic 3 Readings

- Formats, CODECS & Networking
  - New Media for Music
  - SACD One Year Later
  - Understanding S/P-DIF and AES/EBU
  - A Suggested Explanation for (Some of) the Audible...
  - A/D Conversion Techniques
  - Dithering Around
  - AAC: Life Beyond MP3
  - Lossless Compression for DVD Audio

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## Topic 3 Reviews

- Source: LP
  - Wilson Benesch Full Circle Turntable (\$3900)
  - Koetsu Signature Platinum Phono Cartridge (\$5500)
- Source: CD/SACD/DVD-A
  - Technics DVD-A10 DVD/Audio (\$1200)
  - Sony SCD-XA777ES Multichannel SACD/CD (\$3000)
  - Esoteric DV-50 Universal Player (\$5500)
  - MBL 1611/1621 (\$31,000)
  - Burmeister Reference 970/969 (\$33,000)
- Source: DACs
  - MSB Link DAC III (\$700)
  - Digital Audio Labs CardDeluxe PC Soundcard (\$600)
  - Mark Levinson 360 DAC (\$4500)
  - dCS Purcell D/D convertor (\$5000)
  - Slim Devices Transporter WiFi D/A Processor

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## System Architecture

- Source, Processing, Transducers
- Components
  - Sources
  - Pre-pre amplifiers
  - Switchers, volume controls, equalizers
  - Preamplifiers
  - Crossovers
  - Power stages
  - Speakers, headphones

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## Configuration Examples



- Hybrid/Composite components
  - All-in-one systems
  - Receivers
  - Integrated amplifiers
  - Digital processors
  - Active speakers

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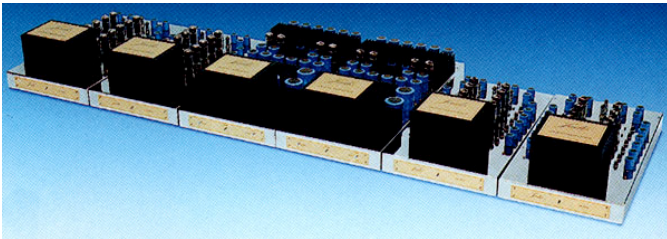
## Component Packaging

- Component/system packaging
  - Standard-size components
  - 19" rack mounting
  - Half-width
  - Show-box
  - Hand-held
- Front panel controls
- Remote controls
- Multi-unit power, etc.

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## The Source Chain

- Analog sources
  - LP (vinyl)
  - Cassette
  - Reel-to-reel tape
  - Radio tuner
- Digital sources
  - CD/DVD/SACD
  - MP3/AAC player
  - Digital broadcast
  - Internet streaming

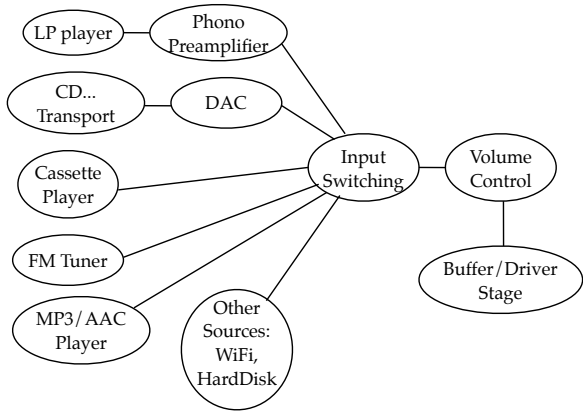
### Levels:

MC cartridge: ~1 mV  
 "Line level": ~100 mV  
 "Standard": 2 V p-p  
 Driver: ~80 V p-p

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## Source Chain Components



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## LP Playback

- LP speeds: 16 2/3, 33 1/3, 45, 78
- LP player components
  - Plinth
  - Motor/drive
  - Bearing/platter/pad
  - Tone arm
  - Cartridge
  - Interconnects
  - Cover



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## Basic Record Player (Rega Planar 3)

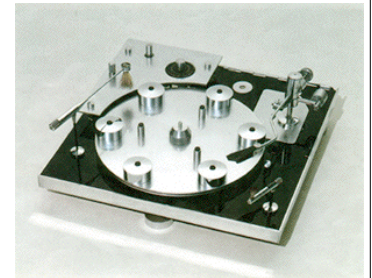


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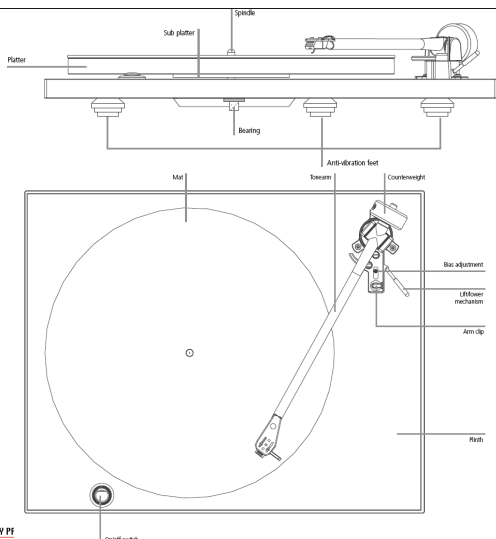
## LP Player Components

- Case, box, plinth
- Platter, suspension
- Motor, drive coupling
- Tonearm(s)
  - Pivot, bearing
  - Shaft
  - Counterweights
    - weight, anti-skate
  - Cartridge mount
- Adjustments (force, VTA, etc.)
- Wiring



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## LP Tone-arms



- Bearings
- Handling tracking errors
- Horizontal forces (skating)
- Pluggable heads
- Multiple mounts
- Manual lift
- Automatic operation

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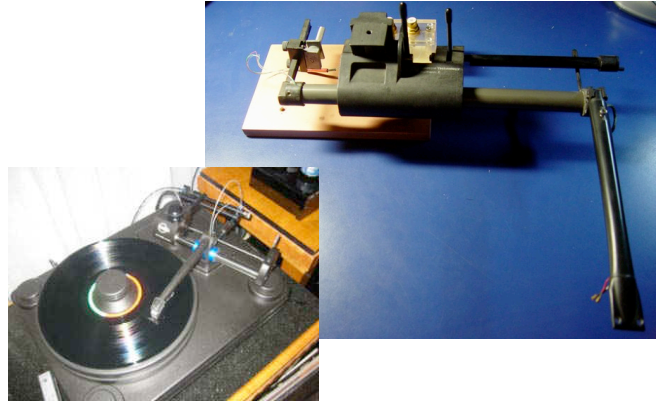
## Multi-arm LP System



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## Linear Tracking Tone-arms



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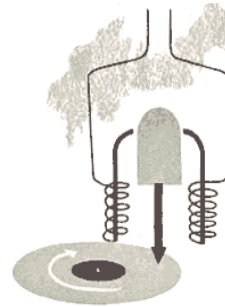
146

## Linear vs. Radial



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## Moving-magnet Cartridge

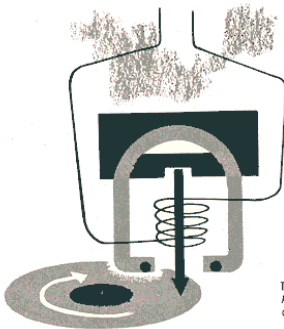


Here's simple schematic of a magnetic pickup. The wires from the coils in which current is induced lead directly to preamplifier

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## Moving-coil Cartridge

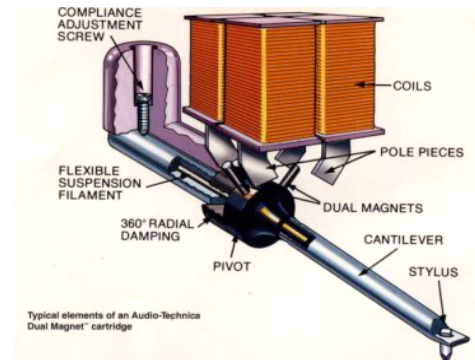


This is schematic of dynamic pickup. As stylus swings between magnetic poles, coil feeds alternating current

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## Moving-magnet Cartridge



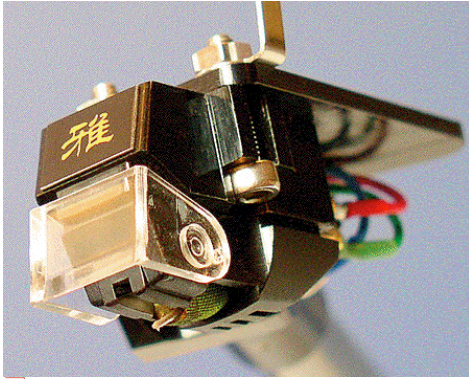
Typical elements of an Audio-Technica Dual Magnet® cartridge

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## In Real Life

- Headshell, lift, wiring, pick-up, guard, tip



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## Vinyl Playback Challenges

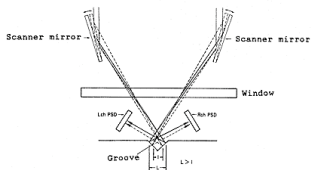
- Motor noise, vibration
- Platter rotation speed
- Accuracy of cartridge tracking angles
- Horizontal forces on the cartridge, skating
- Slippage of the disk on the platter
- Warping of the disk
- Low level of the cartridge output
- and many more...

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## Non-contact LP Playback

- ELP laser player
- UCB/Swiss microscope scanners



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## Reference Turntable



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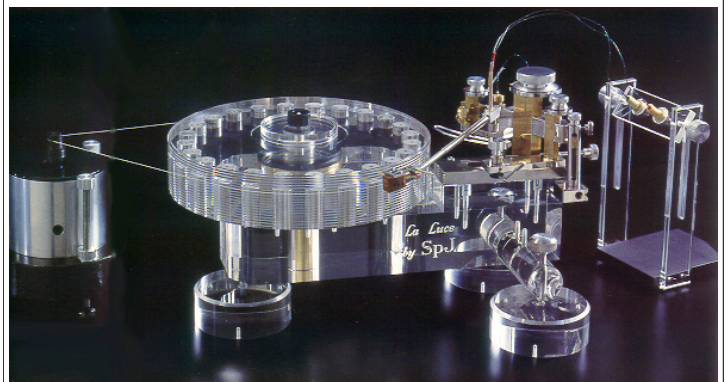
## S. Yorke Turntable



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## La Luce Turntable



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## Turntable Specs

- Noise floor
- Wow and flutter
- Frequency response
- Transient behavior
- Sensitivity to noise
- Tone arm resonance

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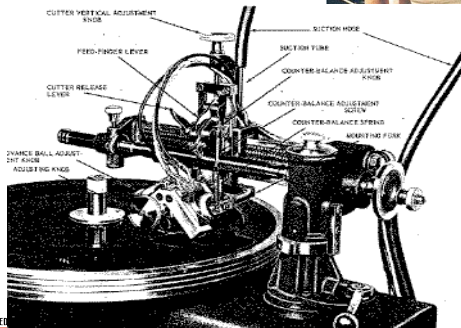
## LP Player Adjustments

- Stylus force
- Vertical tracking angle
- Anti-skating
- Platter speed
- MC/MM cartridge
- Leveling
- Vibration control

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## Cutting Records: Lathes



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## The Future of Vinyl

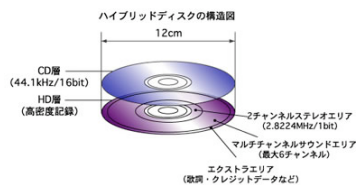
- Content exists and is still being mastered
- Direct-to-disk recordings
- Vinyl as an archival medium
- "Not dead yet..."

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## CD/DVD/SACD Sources

- Digital audio transfer formats
  - 16-bit/44.1 kHz (sample resolution/rate)
- Storage media
  - CD-format, size
- Playback devices
  - Players, transports
- D-to-A convertors (digital processors)



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## Next-generation Discs

A Table Comparing The High Definition Optical Media Formats  
DVD included for comparison

Disc	Blu-ray Disc-ROM	HD DVD-ROM	DVD-ROM
Laser wavelength	405 Nanometers		650 Nanometers
Numerical aperture	0.85	0.65	0.6
Storage capacity single layer	25 GB	15 GB	4.7 GB
Storage capacity dual layer	50 GB	30 GB	8.5 GB
Playback time in SD with MPEG-2 at 5Mbps	22.2 hours	13.3 hours	3.8 hours
Playback time in HD with AVC or VC-1 at 13Mbps	8.5 hours	5.1 hours	-
Playback time in HD with MPEG-2 at 20Mbps	5.6 hours	3.3 hours	-
Video codecs	MPEG-4 AVC (H.264) / VC-1 / MPEG-2		MPEG-2
Audio codecs lossless (mandatory)	Linear PCM	Linear PCM / Dolby TrueHD (See note)	Linear PCM (2ch)
Audio codecs lossless (optional)	Dolby TrueHD / DTS-HD Master Audio	DTS-HD Master Audio	-
Audio codecs lossy (mandatory)	Dolby Digital / DTS / MPEG Audio	Dolby Digital Plus / Dolby Digital / DTS / MPEG Audio	Dolby Digital / MPEG Audio (Europe)
Audio codecs lossy (optional)	Dolby Digital Plus / DTS-HD High Resolution	DTS-HD High Resolution	DTS / MPEG Audio (North America)
Maximum data transfer rate	54.0 Mbps	36.55 Mbps	10.08 Mbps
Maximum video rate	40.0 Mbps	29.4 Mbps	9.8 Mbps
Secondary video decoder (PIP)	Optional	Required	-
Video resolution (maximum)	1920x1080 24p or 50/60i HDTV		720x480 and 720x576 50/60i SDTV
Content protection system	(AACS-128bit) / BD+	(AACS-128bit)	CSS 40-bit
Protective Hardcoating	Required		Optional

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## CD Playback

- Drive
- Optics
- Receiver
- ECC logic and tracking
- Data formatting
- Output clocking
- Output driver stage
- Loads of patents on this

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## D/A Convertors (DACs)

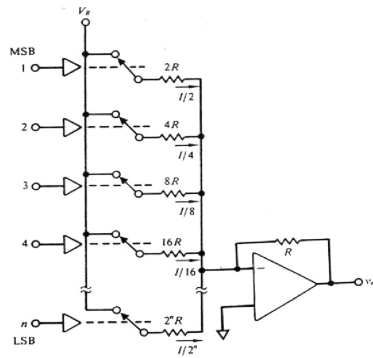
- Take a stream of digits and produce an analogous voltage (or current)
- How most of our day-to-day music/audio is produced
- Many different technologies with different advantages and costs
- Like so many things: it's easy to do really poorly; to do it well means lots of trade-offs

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## DAC Resistor Ladder 1

- Simple circuit
- Requires precision R over a wide range
- Requires low-Z power supply

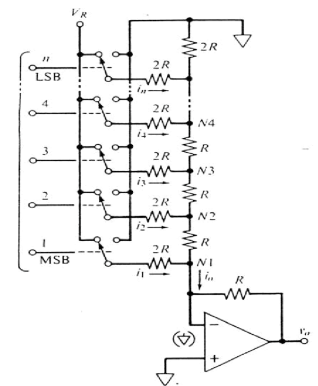


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## DAC Resistor Ladder

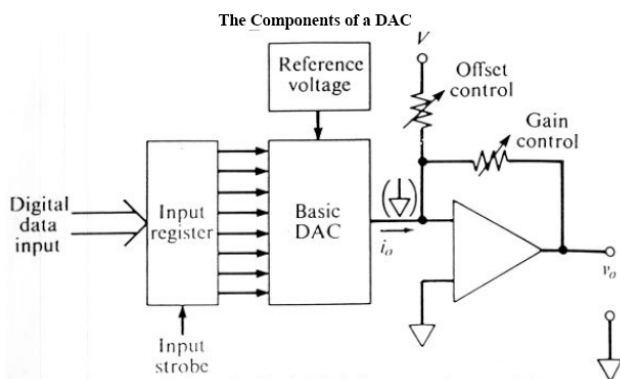
- Easier to build: only  $R/2R$  needed



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## DAC Components



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## DAC Linearity Error

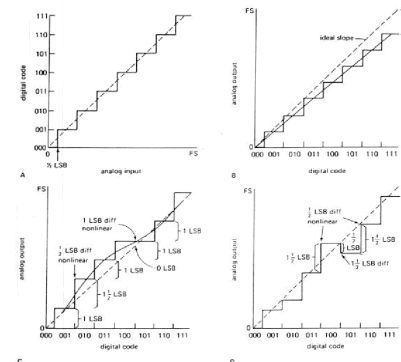


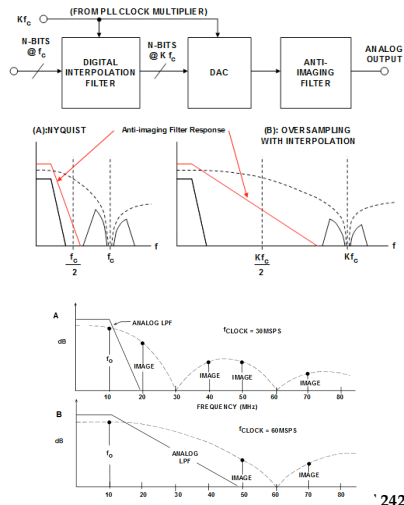
Figure 5. Graphs illustrating the definitions of four common digital conversion errors: (A) Transfer curve, 1/2 LSB offset at zero. (B) Linear transfer curve, but with 1 LSB error. (C)  $\pm 1/2$  LSB nonlinearity (implies 1 LSB possible error). 1 LSB differential nonlinearity (implies monotonicity). (D) Nonmonotonic (must be  $> 1/2$  1/2 LSB nonlinear).

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## Up-sampling DACs

- AKA over-sampling or interpolating
- Anti-aliasing filter much simpler



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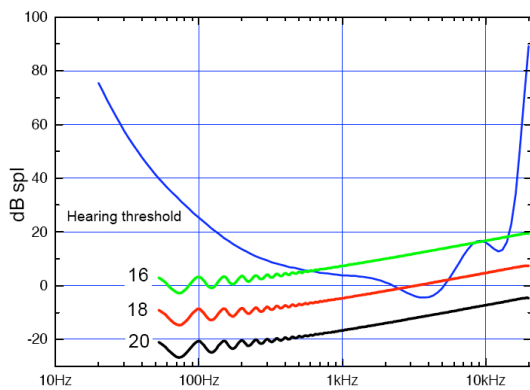
## Quantization Noise, Dither

- Standard quantization noise is white (flat)
- Dithering means adding noise before quantization (in the ADC) to compensate for quantization error
- Higher-order and multi-bit (various architectures) SDM systems each add a specific spectrum of noise (akin to quantization noise) to the signal

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## DAC Noise



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## Noise-Shaping

- Shift the noise out of the audio spectrum
- Putting the Q error in a feedback loop, making a filter, we shift the noise
- Using insights into our perception, we can get very high SNR with few bits (24 for the price of 16)

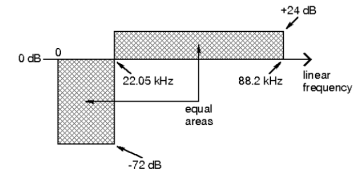


Figure 15. Illustrating the Gerzon/Craven "noise-shaping theorem" for the case of Example (c).

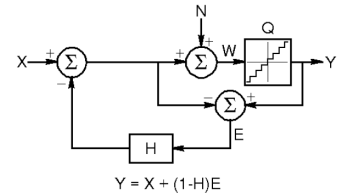
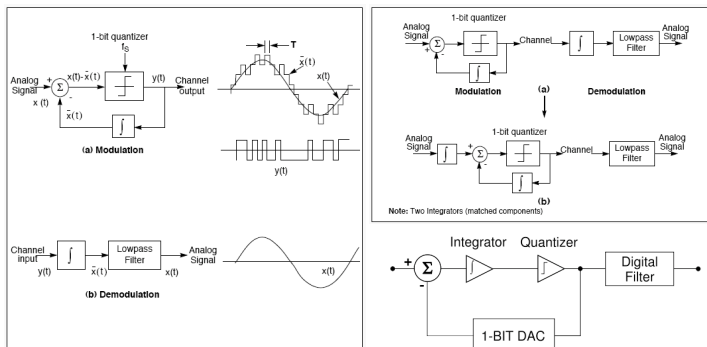


Figure 1. Simple dithered noise-shaping quantizer.

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## Delta-modulation and Sigma-Delta DACs



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## Sigma-Delta DACs

- Process Q noise with 1 or more 1- or multi-bit filters
- Delta-sigma or sigma-delta

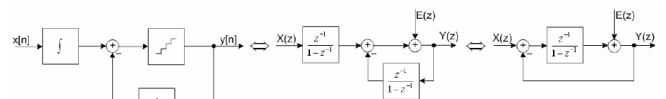
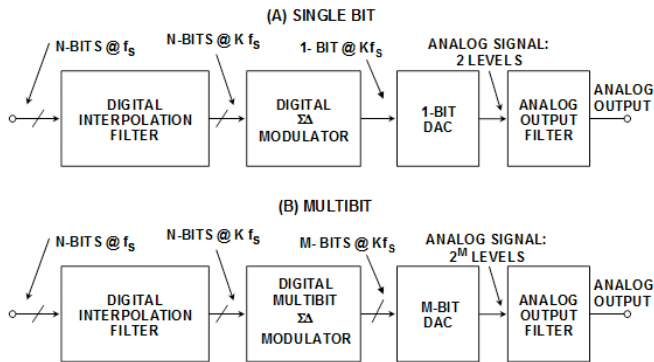


Figure 7: Filtering the noise; the delta-sigma-modulator

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## Multi-bit SDM DACs

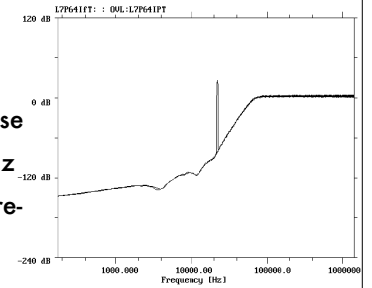


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## Noise-shaping with SDM

- There's a standard (POWR) noise shaping filter that moves the noise to  $< 60$  Hz and  $> 12$  kHz
- DSD uses sigma-delta pre-correction (SDPC) with custom noise-shaping
- Many fancy multi-bit schemes...



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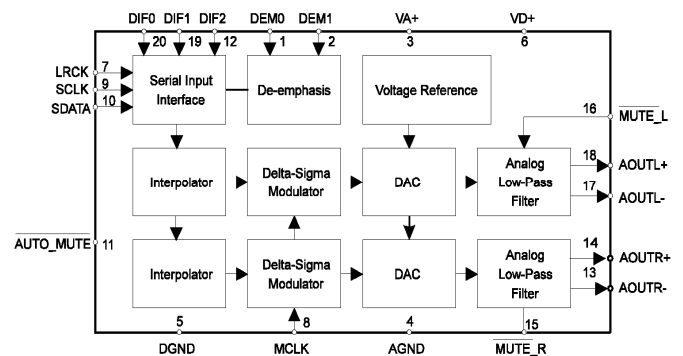
## PCM vs. DSD

- (c) Finally, consider 8-bit, four-times-oversampled PCM with noise shaping. This is also a data rate *one-half* that of DSD and double that of CD, with a sampling rate of  $4 \times 44,100 = 176,400$  Hz. It can achieve a noise floor 120 dB below full scale up to 20 kHz, using 96 dB of noise shaping, and a total noise power of  $-19$  dBFS. Its frequency response would be flat to 80 kHz. This example is perhaps the most instructive of the lot. For a data rate one-half that of DSD, it achieves a comparable signal bandwidth, with a similar noise power density up to 20 kHz, but much lower power above this frequency, and 28 dB lower total noise power. It is fully TPDF-dithered, and so is completely artefact free. At one-half the data rate it outperforms DSD on *every* count! DSD is a profligate wastrel of capacity.

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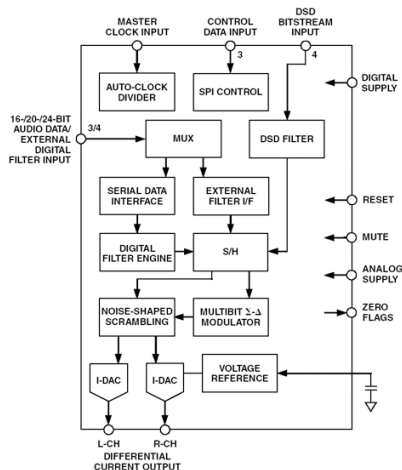
## Modern DAC Chip



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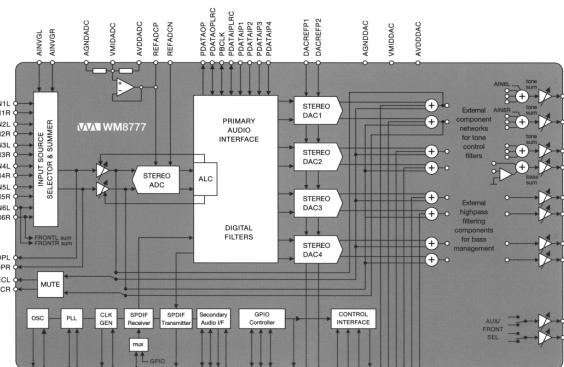
## A More Detailed View



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## Integrated System



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## DAC Design Options

- Single-ended vs. differential
- Input (clock) conditioning
- Up-sampling (1-bit convertors and reconstruction filters)
- Noise shaping (& HDCD)
- Analog anti-aliasing filter
- Driver/buffer stage

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## DAC Challenges

- Variety of digital sources
  - Sample format
  - Sample rate
  - # of channels
  - Medium
- Input accuracy
  - Clock jitter
  - Clock drift
- Power supply noise

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### Example: Benchmark DAC



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## DAC Specifications/ Variables

- Frequency/phase response
- SNR, Dynamic range
- Filter characteristics
- Clock recovery mode
- Jitter spectrum



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## Digital Audio Processors

- Jitter filters
- format converters
- Sample-rate convertors
- Surround format decoders
- Electrical/optical isolation



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## DCS D/D Convertor



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## Digital Signal Sources

- Plastic disc transports
- Digital audio tape formats
- Disk-based sources
  - Computer interfaces (still necessary)
  - "Personal" players
- LAN/WAN sources
  - Wireless
  - LAN audio tools
- A/D convertors

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## Theta CD Transport



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## Transport Decisions

- Medium/format
- "Universal" players
- Single-disc vs. carousel
- Output formats
  - SE analog
  - Balanced. Analog
  - Digital
    - Optical/electrical
    - SE vs. Balanced



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## CD vs. SACD vs. DVD/A

- CD: 16/44, possible up-sampling/noise-shaping
- SACD: 1-bit DSD, various digital out, 5.1-ch
- DVD/A: up to 24/192, digital xfer of 24/96
- Limitation of DVD players to 10 Mbps means no 5.1-ch 24/96 possible!
- DVD/A format hell
- BlueRay, AAC, etc.
- Content availability?

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## MP3, AAC, et al.

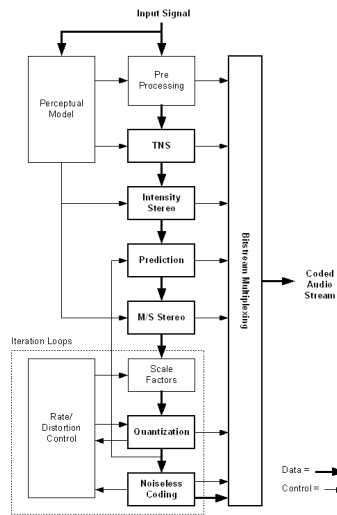
- MPEG & FHG/IIS – MP3
- Standard describes the storage format, not an encoder or decoder
- Based on time/frequency masking
- Not all coders are the same!
- Decoders are more similar...

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## AAC Encoder Structure

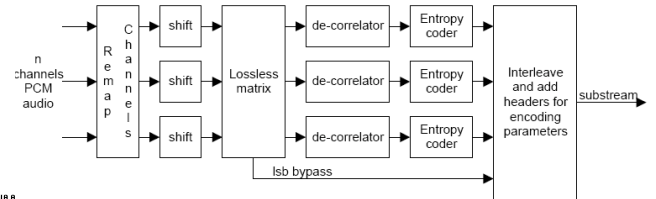
- AAC = MP3++



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## Lossless Encoding

- LPC-based representation
- Statistical methods
- Multichannel considerations
- FLAC, APE, Apple Lossless
- MLP



A

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## WiFi Audio and New Sources

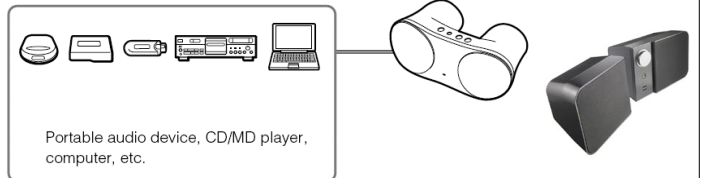


- WiFi streaming standards and 802/11g
- Bluetooth Advanced Audio Distribution Profile (A2DP, included in Vista and Jaguar)
- Apple AirPort Express WiFi/TOSlink interface

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## Bluetooth Audio Devices



Portable audio device, CD/MD player, computer, etc.

- Wireless speakers, headphones
- Cell phone as audio source
- A2DP uses MP3 for now...



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## Internet Radios

- Stand-alone vs. server-bound
- High-end: Slim Devices



SLIM DEVICES



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## Other sources

- A/D convertors
- Magnetic tape
- Still prevalent as an archival medium
- FM broadcast
- For another year or 2
- Digital/satellite broadcast
- Computer sound cards
- Future sources & media?



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## Reviews

- LP Components
- Budget DAC and CD player
- High-end DAC comparison

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## LP Playback

- Features/Variables
  - Speeds
  - Automatic features
  - Adjustments
  - Integral/replacable tone arm
  - Cartridge type

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## CD Playback

- Transports
- Players
  - What formats supported?
- DACs
  - What I and O formats supported
- Jitter-reduction HW

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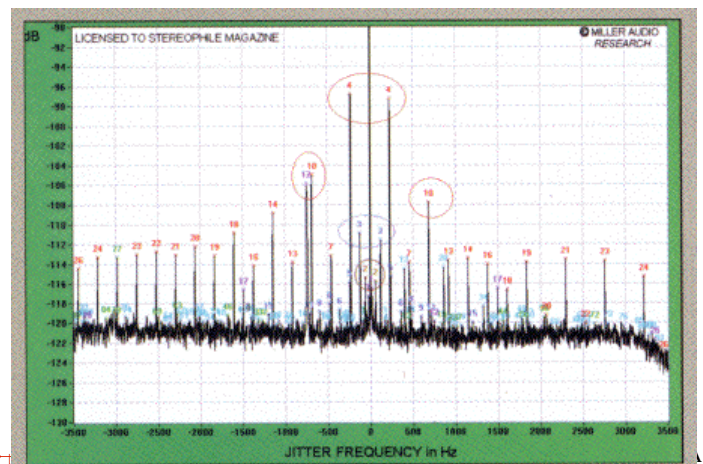
## Reading a DAC Review

- See MSB Link Review: Stereophile 09/00 pp. 87 ff.
- Frequency response
- Noise spectrum
- Linearity
- Small-signal reconstruction
- Harmonic/intermodulation distortion
- Jitter spectrum
- Pay attention to the associated equipment!

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## DAC Specs: Jitter Spectrum



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## MSB Link DAC III

- \$500
- Excellent measurements!
- Jitter measurement technique
  - 11025 Hz full-scale sine wave with LSB toggle at 229 Hz
  - Jitter produces side-bands of signal tone
- Compare to Adcom GCD-750 CD player

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## High-end DAC Comparison

- Bel Canto DAC 1 – \$1300
- Mark Levinson #360 – \$4500
- Mbl 1611 HR – \$15500 (also as pre-amp)
- Burmeister Reference 970 – \$33000
- What the specs say
  - Major differences
- What the listening tests say
  - Minor differences

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## Burmeister DAC



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## Sound Cards and Computer Interfaces

- NeXT experience (context is everything)
- DAL CardDeluxe sound card
  - Good specs, bad jitter
- Computer digital interfaces
- CREATE listening (2001) tests on "pro audio" interfaces from MOTU, Digidesign, Opcode, Echo, et al.

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## Disk-based Systems



- Combine hard-disk-based music storage and browser/player, possibly networked
- Support playlists, custom EQ, multi-zones, etc.
- Also for audiophiles: Meridian, Sonus, Linn

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## Sony SCD-XA777ES SACD Player

- \$3000 (mid-range SACD)
- SCD-777 as a CD player
- "Cable hell" comments
- Different multi-channel system
- Bass-management and 5.1 playback
- "Accurate" vs. "euphonic"
- Review system (-)



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## Technics DVD-A10

- \$1200
- DVD/A/V + CD player (new all-format player)
- "Smart content" issue
- Content selection
- Listening to 24/192



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## D/D Convertors

- dCS Purcell up-sampler/noise-shaper – \$5000
- Jitter reduction (FIFO reclocking)
- Sample-rate conversion
- Noise-shaping (variable, smart)
- Digital format conversion
- Electrical isolation

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## The "Next Big Thing" in Sources

- Internet/WiFi/satellite streaming of 5.1 AAC
- Many channels of cable radio
- Digital broadcast (e.g., XM)
- "Smart" content selection (recommender systems, pandora.com, FASTLab)
- Smaller/better MP3/AAC players
- New physical formats (x-ray)?
- Where's the hi-end content?

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## Conclusions

- Lots of source components
- Many enhancers/tweaks
- No next-generation standard yet (20 years is up!)
- Vinyl ain't dead yet! (?)
- Broadcast?
- Webcast?

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## What's Next?

- Digital distribution formats
  - Formats
  - Media
  - Networking
- Amplification Components
  - Pre/power amps
  - Integrated amps
- Listening session chez STP

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# MEDIA ARTS & TECHNOLOGY PROGRAM

## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 4: Amplification

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## Topic 4: Amplification Components

- Preamplifier, switching, and control stages
- Splitters, drivers, and power stages
- Crossovers and processors
- Passive pre-amps and attenuators
- Configurations: multi-stage vs. integrated, receivers and surround processors

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## Topic 4 Reviews

- **Preamplifiers**
  - Conrad-Johnson Premier 17LS pre (\$4500)
  - Mark Levinson 32 Reference Pre (\$15,000)
  - Boulder 2002/2010 Phono/preamplifier (\$65,000)
  - Krell Evolution 202 & 600
- **Amplification: Tube**
  - Antique Sound Labs Explorer 805 DT SET (\$3000)
  - Music Reference (RAM Labs) RM-200 (\$3450)
  - Audio Research Reference 1 Pre and VT200 Power (\$8500 + \$9000)
- **Amplification: Solid State**
  - Headroom "Max" amplifier (\$1333) and Sennheiser HD600 'phones
  - Rotel RB-1090 2-channel power stage (\$2000)
  - Halcro DM88 Reference (\$40,000)
- **Amplification: Integrated**
  - NAD C370 (\$700)
  - Krell KAV-300i (\$2350)

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## The Amplification Chain

- Pre-pre-amps
- Input switching
- Surround-sound decoding
- Attenuator/volume control
- Driver/buffer
- Power stage
- Output conditioning
- Fads: 1970s, 1980s, 1990s, now

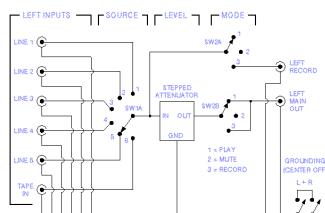


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## Kinds of Preamplifiers

- Phono stage (+ EQ), step-up pre-amp
- Line stage pre-amp
- Passive switcher/attenuator
- Digital volume control
- Digital pre-amp
- As simple as this:



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## Preamplifier Input Switching

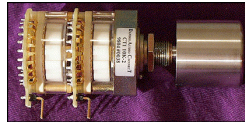
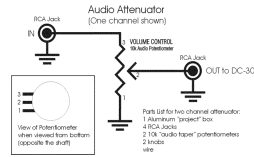
- How to handle unused inputs
- How to handle switching noise
- How to handle a mix of Bal/SE inputs (and how to switch balanced inputs cleanly)
- How to present a high input Z and low output Z at the same time
- How to handle differing input levels
- ...not an easy issue!

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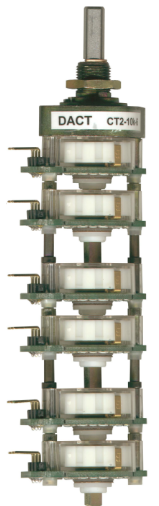
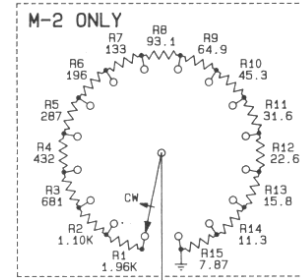
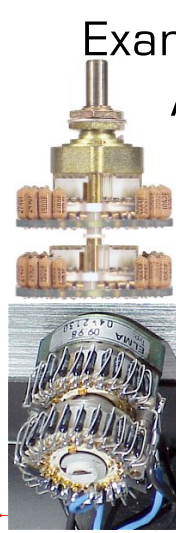
## Volume Controls

- Passive (rheostat, variable transformer)
- Active (op-amp)
- Resistor network
- Digital attenuation
- How to remote control it?
- How to add balance control?



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## Examples: Precision Attenuators



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## Low-noise Power Supplies

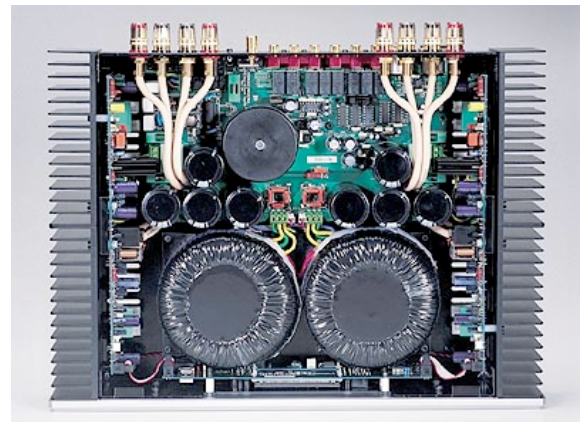
- Large buffers
- Multi-stage regulators
- Filter cap. proximity
- Multiple power supplies
- Battery operation (yes indeed)



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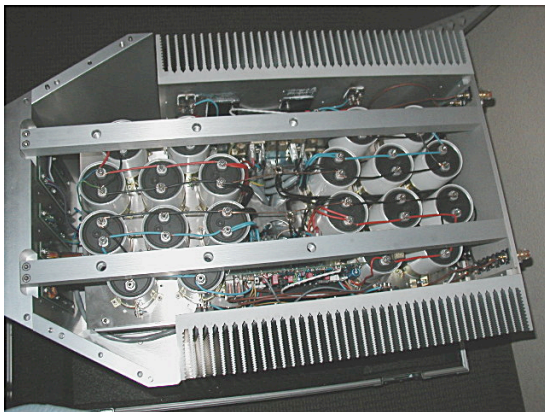
## Example: Perreaux Radiance



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## Example: Gamut 3 Amp



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## Preamplifier Specifications

- Freq/phase responses
- SNR/Dynamic range
- THD, IM
- Channel separation
- I/O connections
- Power supply purity
- Examples from Stereophile

### SPECIFICATIONS

RIAA Equalization	+/- 0.5dB
Integrated Rumble Filter	10 Hz (-1dB at 20 Hz)
Gain at 1k-Hz	1280 (62dB)
Crosstalk	below measuring range
Signal/Noise Ratio (0.5mV 0 ohm)	82dB (1HF "A")
Maximum Input Voltage	5mV (1 kHz)
Input Impedance	22k Ohms

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## Example: Krell Evolution 202 Pre-amp

### Specifications

**Inputs**  
2 pr. CAST via 4-pin bayonet connectors  
2 pr. balanced via XLR connectors  
3 pr. single-ended via RCA connectors

**Type input**  
1 pr. single-ended via RCA connector

**Main outputs**  
2 pr. CAST via 4-pin bayonet connectors  
1 pr. balanced via XLR connector  
1 pr. single-ended via RCA connector

**Type outputs**  
1 pr. single-ended via RCA connector, buffered

**Control inputs**  
1 RS-232 input via a 9-pin D-subminiature connector  
1 remote IR detector input via a 3-conductor 3.5 mm connector  
1 12 VDC trigger input via 3.5 mm connector  
1 preamplifier link via an RJ-45 connector

**Control outputs**  
2 individually programmable 12 VDC trigger outputs via 3.5 mm connectors  
1 preamplifier link via an RJ-45 connector

**Power output**  
1 phono power output ( $\pm 20$  VDC) for KPE via a 9-pin D-subminiature connector

**Input impedance**  
CAST: 45 Ohms  
Balanced: 95 k Ohms  
Single-ended: 47.5 k Ohms

**Output impedance**  
CAST:  $>1$  M Ohms  
Balanced: 50 Ohms  
Single-ended: 25 Ohms

**Gain**  
12 dB (CAST or balanced output)  
6 dB (single-ended output)

**Volume control**  
Balanced, current-mode, 16-bit, discrete R-2R ladder

**Input overload**  
CAST: 14 mA RMS  
Balanced: 14 V RMS  
Single-ended: 7 V RMS

**Output overload**  
CAST: 16 mA RMS  
Balanced: 16 V RMS  
Single-ended: 8 V RMS

**Frequency response**  
20 Hz to 20 kHz  $\pm 0.02$  dB  
0.1 Hz to 1.5 MHz  $\pm 0.1$  dB

**Total harmonic distortion plus noise**  
Balanced Output:  
 $<0.004\%$ , 20 Hz to 20 kHz, 4 V RMS or 4 mA RMS

**Signal-to-noise ratio**  
4 V RMS balanced or 4 mA RMS CAST output  
Wideband, unweighted:  $>100$  dB  
"A" weighted:  $>109$  dB

**Power consumption**  
Standby: 45 W  
Power on, with KPE: 80 W

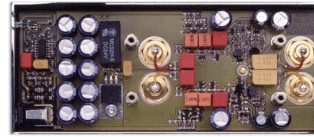
**Dimensions**  
Preamplifier only:  
17.3 in. W x 3.8 in. H x 18.3 in. D  
49.8 cm W x 9.7 cm H x 46.4 cm D  
Power supply only:  
17.3 in. W x 5.8 in. H x 17.7 in. D  
43.8 cm W x 9.7 cm H x 44.8 cm D  
Preamplifier and power supply:  
17.3 in. W x 7.6 in. H x 18.3 in. D  
43.8 cm W x 19.2 cm H x 46.4 cm D

**Weight**  
Shipped: 61 lbs., 27.6 kg  
Preamplifier only: 18 lbs., 8.1 kg  
Power supply only: 28 lbs., 12.7 kg

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## Phono Stage & Passive Pre-amps

- E.g., from Benz and Monolithic



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## Manley Steelhead Phono Stage

- Controls for gain, load, MC/MM selection, etc.



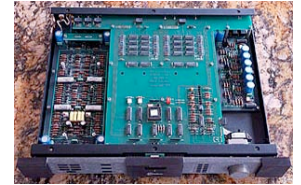
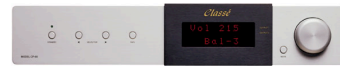
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## Line-stage Preamplifiers



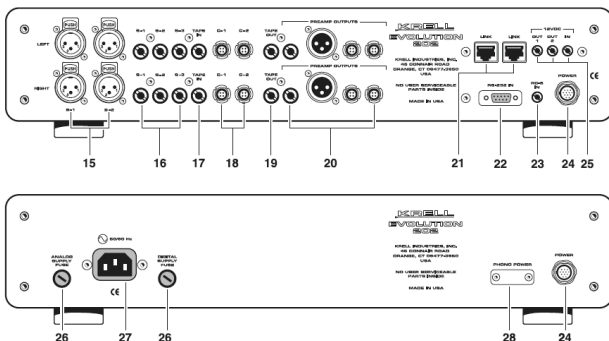
- E.g., from Krell and Classé



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## Example: Krell Evolution 202



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## Amps and Interconnects

- How many boxes?
  - Separate pre/power amplifiers
  - Separate power supplies
  - Separate control/switching/IR
- Source-to-line stage
- Line-stage-to-power-stage
- Power cables
- Speaker cables
- Separate (dual-mono) preamplifiers
- Monoblock drivers

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## Power Stage Issues

- Input Z (high is better)
- Buffer stage (independence of stages)
- Number of stages
- Driver components (few or many)
- Output conditioning (xfmr)
- Power supply (1 or many)

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## Power Stage Specifications

- Output power
  - Measured for 1% THD 20Hz-20kHz
  - Given in Watts (changes with load Z) and dB (doesn't)
- Freq/phase responses @ 1W (= 2.83V)
- Noise floor (as a fcn. of freq. and power)
- Channel separation/crosstalk (as a fcn. of freq.)
- THD/IMD @ 1W (as a fcn. of freq., using different impedances) + THD spectrum + time-domain plot
- Small-signal response (1, 10 kHz square waves)
- Slew rate (ability to handle loads with group delay)
- Other specs.
- Compare 1996 to 2006 measurements

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## Multi-channel vs. Monoblocks

- Line-level vs. speaker-level cabling
  - For long-ish runs, balanced line-level is better
  - Monoblocks tend to be more expensive
- Size/cost issues
- 2-channel vs. 5.1-channel systems
- Bi-/tri-amping and crossovers
- Powered speakers
- Digital speakers
- "Dual-mono" systems

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## Power Amplifiers

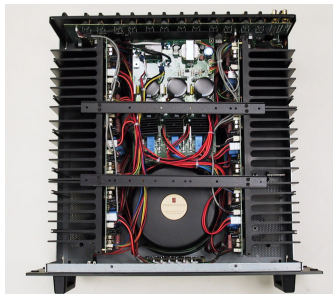
- Low-power SET & OTL systems
- Multi-stage tube designs
- Solid-state designs
- Hybrid designs
- Headphone amplifiers



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## What's Inside? (mostly power supply and heat sinks)



- Classé and Parasound

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## Multi-channel Amplifiers

- Built as (2, 3, 5, 7) separate monoblocks that share only the chassis & power
- E.g., Bryston, Krell, Onkyo

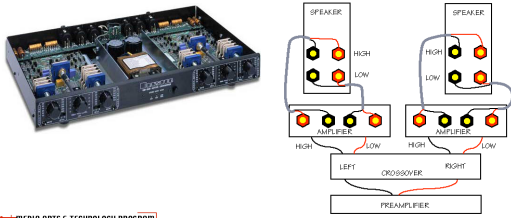


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## Bi-amplification

- Put the crossover between the pre-amp and the power stages
- Can be extended to tri- and even quad-amplification (e.g., 4-way B&W Nautilus)

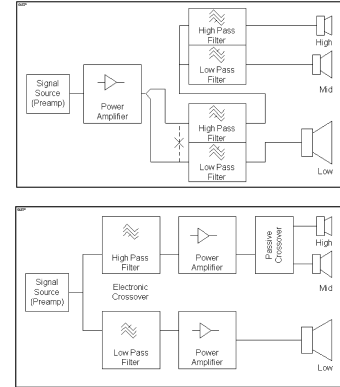


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## Bi-wired vs. Bi-amped

- Bi-wired
- Bi-amped



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## Integrated Amplifiers

- Preamplifier and power stage in one (once passé, now common)
- How separate are they?
- E.g., Classé and Jeff Rowland



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## Player/Pre-amps



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## Receivers



- Integrated amplifier, tuner, and possibly surround decoder

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## Decoder/preamplifiers

- Surround-sound format Hell
- Surround-sound source Hell
- Cable Hell
- Video and audio in the same box
- System complexity vs. quality



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## Surround Processors

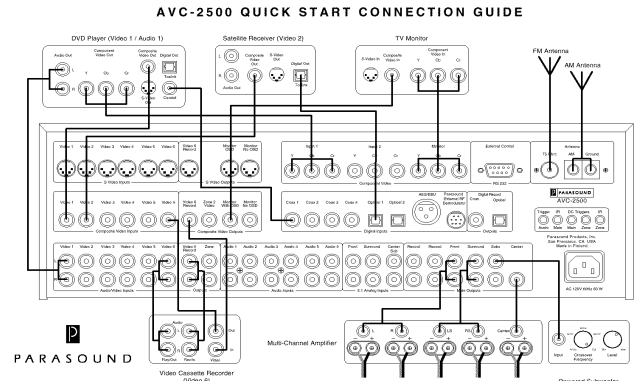
- Pre-amp vs. integrated, vs. receiver
- Surround audio vs. home-theater receivers



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## Typical Surround Wiring



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## Other Configurations

- Integrated CD-transport, DAC, ADC, and volume control (see Krell KPS-25sc above)
- Digital pre-amp (with optional ADC for analog source components)
- Pre-amp + cross-over components (now rare)
- Powered speakers and digital speakers
- Others possible (ideas?)

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## Reviews

- Conrad-Johnson 17LS pre-amp
- Audio Research Reference pre/power
- Headroom "The Max" headphone amp
- Rotel RB-1090 /home theater
- Krell Evolution pre-amp and monoblock
- NAD C370 s-s integrated
- Krell KAV-300i s-s integrated

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## What's Next?

- Transducers and interconnects
  - Loudspeakers, enclosures, and crossovers
  - Cables and interconnects
- To read
  - Harley ch. 7 & 11
  - Speaker and cable reviews
- Listening
  - Store visit
- Paper two
  - Component comparison

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## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 5: Interconnects

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## Topic 5: Cables & Interconnects

- Definitions
- Parameters
- Interconnect technologies
- Speaker cables
- Power cables
- Reviews



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## Topic 5 Readings

- Speaker Cables under \$8/m
- Our Favorite Audio Cables
- Alpha-Core interconnects (\$78/m) and speaker cables
- Nirvana S-X Ltd. (\$2200/m)
- Nordost Valhalla interconnects and speaker cables (\$4200/m)

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## Cables

- Speaker cables
- Analog interconnects
- Digital interconnects
- Network cables
- Video cables
- Power cables
- Grounds, etc.

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## Cable Properties

- Straight wire as the goal
- ...with capacitance and inductance
- Non-trivial frequency/phase responses
- Transient behavior
- RFI sensitivity
- Voodoo

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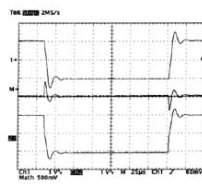
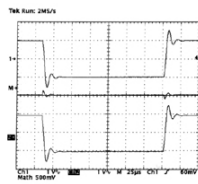
## Measuring Cables

- R, L, & C
- DC/AC response
- Freq/phase resp.
- Filter Q
- E.g., Cardas vs. Zip

Resistance and Inductance				
	Cable AC loop resistance in ohms		Cable AC loop inductance in u henrys	
	100-	1k	10k	
Golden Cross	.018	.018	.019	.36
Crosslink	.046	.046	.048	1.1
Pip Boys 8g	.014	.0153	.0206	2.5
RS 28ga	.458	.500	.500	2.4
RS Mega	.084	.084	.087	2.6

All samples are 10ft in length.

"Q" factor		
	10K AC resistance ohms	Q 10k
Freebie	.52	.45
Golden Cross	.022	3.9
Cross	.03	4.3



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## Cable Parameters

- Physical (size, stiffness)
- Conductor material
- Dielectric
- Geometry
- Termination
- Adaptor/correction filters



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## Conductor Materials

- **Copper**
  - x-9s, LGC, OFC, etc.
- **Silver**
  - Like Cu, but more desirable surface properties
- **Gold**
  - Excellent electrical properties, but very soft
  - Does not corrode; good for terminations
- **Alloys**
  - Cu-based
  - Ag-based
  - Other

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## Conductor Fabrication

- **Single-core**
- **Multi-core**
- **Extruded**
- **"Single-crystal"**
- **Other processes**
  - Cryogenic
  - Ion implantation

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## Cable Geometry

- **Zip chords**
- **Twisted pairs**
- **Braids**
- **Litz designs**
- **Flat cables**
- **Novel designs**

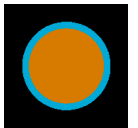


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## Solid Round

- **Advantages:**
  - 1. Simple construction.
  - 2. Low DC resistance per unit area.
  - 3. Good resistance to capacitance ratios achievable in most embodiments.
- **Disadvantages:**
  - 1. High relative inductance.
  - 2. Stiff and likely to harden with use.
  - 3. Solid conductors tend to ring, due to low "Q".
  - 4. High DC to AC resistance ratio.



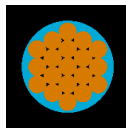
Courtesy of  
Cardas

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## Stranded Geometry

- **Advantages:**
  - 1. Flexibility.
- **Disadvantages:**
  - 1. High relative inductivity.
  - 2. Very prone to corrosion.
  - 3. Low ring point.
  - 4. Resonant and gritty sounding.
  - Not generally used or sold in high-end, it usually comes free with mass market speakers etc.



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## Multi-gauge Standed

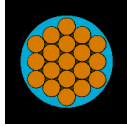
- **Advantages:**
  - 1. Slightly lower inductivity.
  - 2. Much lower electro-mechanical resonance due to the elimination of strand multiplicity if done right.
  - 3. Low DC resistance for given cross-section.
  - 4. Flexibility.
  - 5. Works well in braided cable construction.
- **Disadvantages:**
  - 1. Relative inductivity still high.
  - 2. Possible corrosion in non-Litz configurations.



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## Litz Geometry

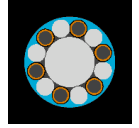
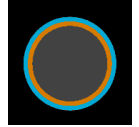


- **Advantages:**
  - 1. Low inductivity.
  - 2. Coated strands don't corrode.
  - 3. Embodiments tend to Have good conductor resistance and inductance to cable capacitance ratios.
- **Disadvantages:**
  - 1. Resonant or wooly sound in traditional configurations due to strand multiplicity and harmonic interaction.

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## Tubes: Straight and Stranded

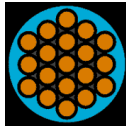
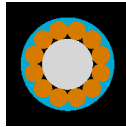


- **Advantages:**
  - 1. Low inductivity.
  - 2. Semi-flexible in stranded versions.
- **Disadvantages:**
  - 1. High resistance for a given size.
  - 2. Tubes work by virtue of their thinness

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## Parallel Solid Multi-core

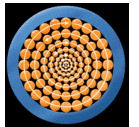


- **Advantages:**
  - 1. Lower inductivity.
- **Disadvantages:**
  - 1. Design is limited by high dielectric involvement, bulk, difficulty holding symmetry as the number of strands increases.
  - 2. Higher resistance for given size construction.

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## Golden Section Stranding

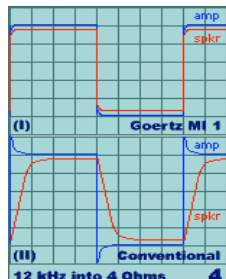


- **Advantages:**
  - 1. Lowest inductively for given size.
  - 2. Low resistance for given size.
  - 3. Very high Q (L/R).
  - 4. Low electromechanical resonance.
  - 5. Very low polar moment - low conductor field interaction.
  - 6. Low stored energy.
  - 7. Coated strands eliminate corrosion.
- **Disadvantages:**
  - 1. Labor and time intensive construction.
  - 2. Rather costly.

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## Flat: Parallel/Layered



- **Advantages:**
  - Very low inductance
- **Disadvantages:**
  - Wide
  - Susceptible to RFI (?)

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## Dielectrics

- Insulation vs. spacers
- Mechanical properties
- Electromagnetic properties
- Air
- Petrochemicals
- Metals

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## Termination Networks

- RLC network to compensate for cable properties
- E.g., Transparent, MIT



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## Terminations

- **Line-level**
  - RCS/Phono (standard SE, poor)
  - XLR/Canon (balanced, locking, ground-first)
  - 1/4" TS/TRS (hot-first)
- **Speaker-level**
  - Raw wire (smushed at binding post)
  - Spades (soft, pressed to binding post)
  - Banana plugs (multiple points of contact)
  - Speak-on (locking, big)
- **Connection: soldering, welding**

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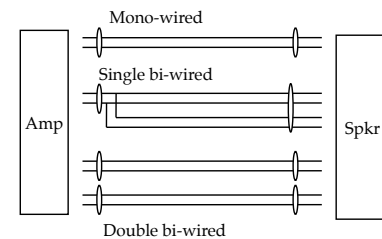
## Cable Voodoo?

- **Digital Cables**
  - Jitter factor
- **Power cable enhancers**
  - Separate grounds
  - Spike filters
- **Magnetic Shields**
  - RFI magnets
- Cable burn-in
- Cable stands

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## Speaker Cabling



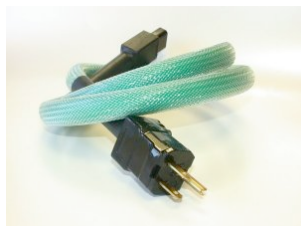
- **Mono-wired**
- **Single/double Bi-/tri-wired**
- **Single-conductor cables**

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## Power Cables

- Transfer characteristics
- Freq. Response (?)
- Isolation
- Grounding
- Voodoo?



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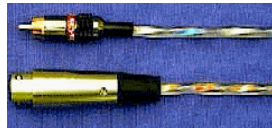


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## Examples: Nordost/ AlphaCore

- Flat layered or side-by-side Silver or OCF

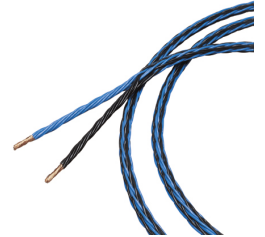


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## Examples: Kimber

- Braided multi-gauge Ag or OFC

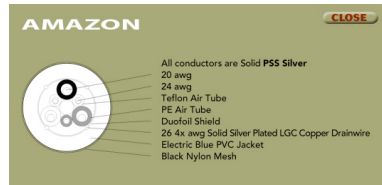
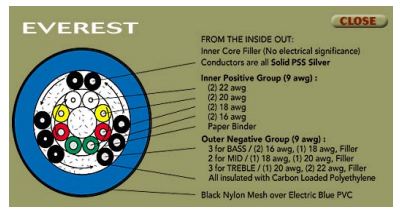


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## Examples: AudioQuest

- Multi-gauge Silver or OCF Hyperlitz
- Complex geometries

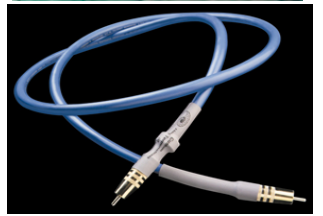


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## Examples: Cardas

- Constant Q (Golden Mean) Ag or Au

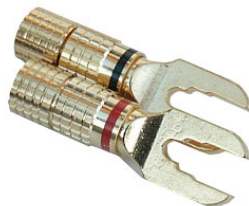


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## Termination Adaptors

- Interconnect
  - Balanced/SE
  - Floating ground
  - Isolation transformers
  - Direct boxes
- Speaker cable
  - Spade/banana

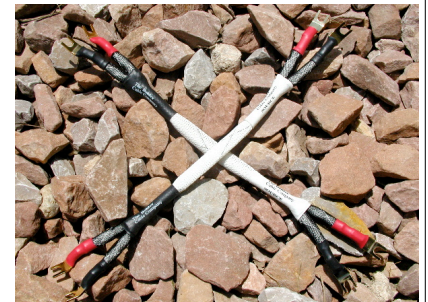


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## What to Listen For

- HF aspects
  - Grain
  - Air/space
  - Speed, transients
- LF aspects
  - Focus
  - Slam
  - Dynamics



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## System Considerations

- Source-preamp (low-level) interconnects
- Multi-stage source chains
- Amp-speaker cables
- Power conditioning and cabling
- Stereotypes
  - Low-power and high-grade
  - SS and terminated
  - Balanced systems
- Importance of auditioning the system

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## Reviews

- Comparison article: affordable speaker cables (all tested on the same system!)
- Reviewer's choices: diversity of criteria and choices
- AlphaCore medium-range
- Nirvana S-X high-end
- Nordost Vahhalla high-end

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## What's Next?

- Speaker placement and room treatments
- Readings: Harley ch. 4
- Paper 2
- Schedule
- Listening sessions in May

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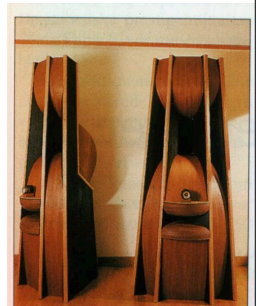
## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 6: Speakers

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## Topic 6: Loudspeakers

- Loudspeakers and headphones as transducers
- Types of loudspeaker mechanisms
- Design patterns and systems
- Headphones and ear-speakers
- Reviews



Hos A II Ingeniere SA vistes hornhøjtalere af meget høj klasse. Selve kabinettet er fremstillet i formspændt træ. Her er modellen Eurythmie 33.

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## Topic 6 Readings

- Speaker measurement from above
- Polk Audio RT25i (\$320)
- PSB Image 4T (\$650)
- Magnepan MG3.6/R (\$3750)
- Quad ESL-989 Electrostatic (\$8000)
- Avantgarde Series Two (\$11,000)
- B&W Nautilus 801 (\$11,000)
- Rockport Antares (\$41,500)
- Wilson X-1 Grand Slamm Series II (\$77,000)

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## Transducers

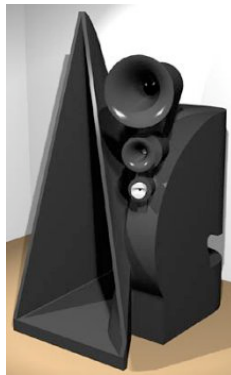
- Turn an electrical current into air pressure variations
  - Move a lot of air, fast
- Efficiency and coupling
- Full-range and multi-way systems
- Characteristics

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## Sound Pressure Transducers

- Electro-magnetic systems
  - Dynamic
  - Electrostatic
  - Electromagnetic
- Electro-mechanical systems
  - Piezo-electric
- Controlled sparks (Tesla coil)
- Controlled fire/plasma
- Others/Future?



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## Transducer Characteristics

- Sensitivity – dB / w @ 1 m. (?)
- Directional radiation pattern (4D)
- On/off-axis frequency response
  - Why off-axis?
- Impulse response
  - Step vs. impulse
- Frequency/phase responses and Z
- Coupling (piston in a tube)
- Others...

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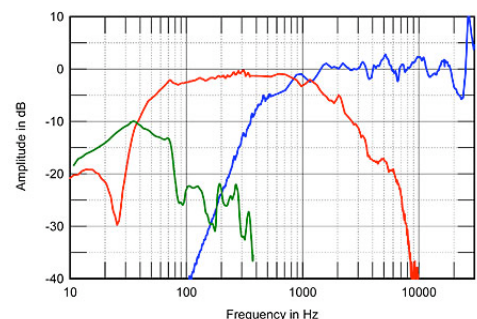
## Measuring Loudspeakers

- Frequency response (in what environment)
- Impedance/phase response
- Directional response

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## Per-driver and Summed Frequency Responses



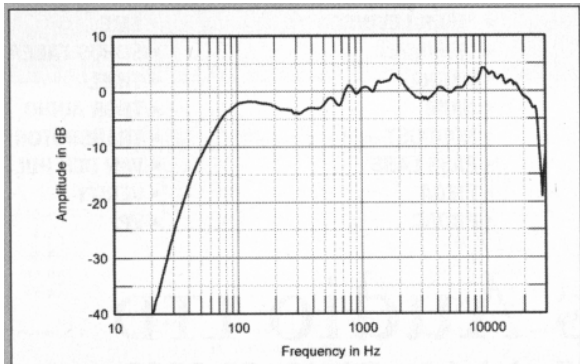
- Look at cross-over regions, port resonances

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## Frequency Response

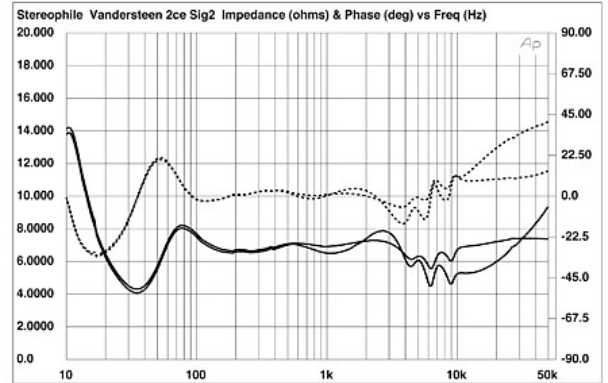
- Problem cases



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## Impedance R and Phase

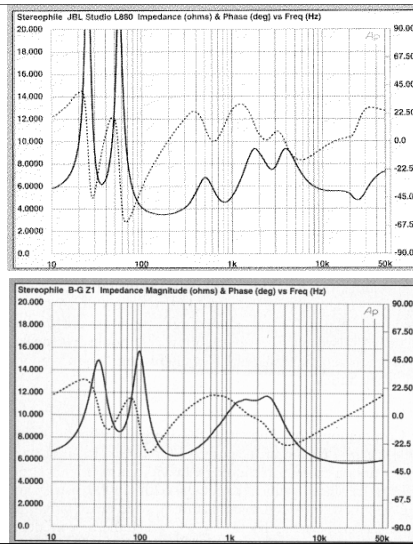


- Minimum R, areas of high rroup delay

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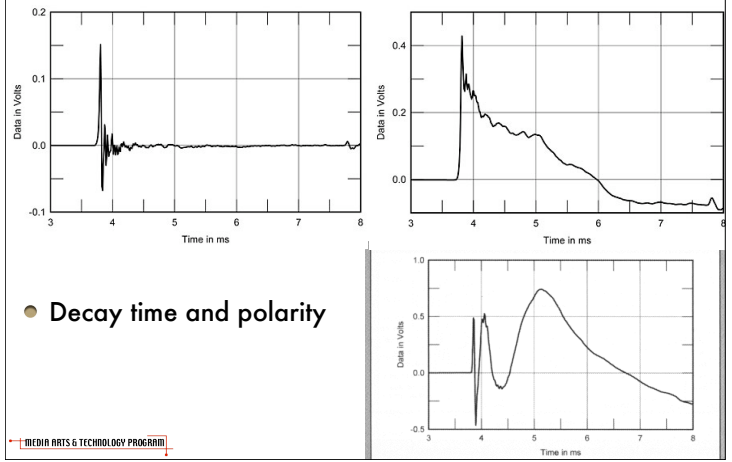
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## Problem Impedance Responses



303

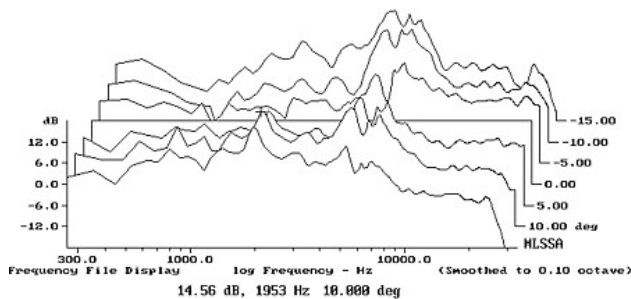
## Impulse and Step Responses



- Decay time and polarity

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## Off-axis Response

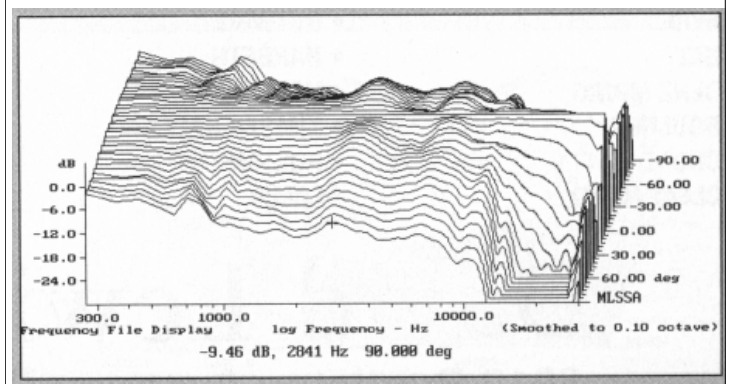


- Always relative to on-axis, look for suck-out or peaks

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## Directionality Problems



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A schematic diagram of a magnetic core. It consists of a central rectangular core with two vertical legs. Each leg has a coil wound around it, labeled 'Coils'. The core is flanked by two vertical bars labeled 'Mag'. The entire assembly is supported by a trapezoidal base.

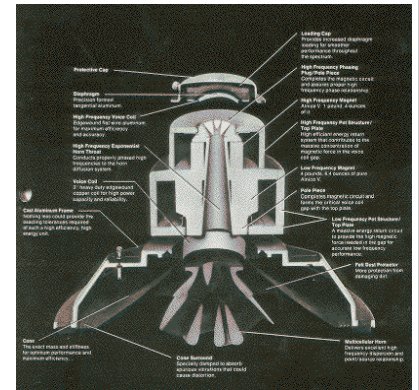


figure 4.

The figure consists of two parts. The left part is a schematic diagram of an ESL system. It shows an 'ESL' (Electrostatic Loudspeaker) unit connected to a 'Bios Supply' (represented by a battery symbol) and a 'Diaphragm connection'. The supply is connected to a 'Transformer' with a primary winding of 'Hi-Z 8K-20K' and a secondary winding of 'Lo-Z 4-80'. The secondary is connected to an 'Amp.' (amplifier). The right part is a cross-sectional diagram of the ESL assembly, showing layers from top to bottom: 'Perforated Metal', 'Insulator Frame', 'Diaphragm', 'Insulator Frame', and 'Perforated Metal'.

ESL

Hi-Z 8K-20K

Bios Supply

Diaphragm connection

Lo-Z 4-80

Amp.

Transformer

Perforated Metal

Insulator Frame

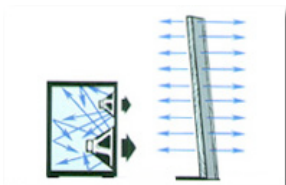
Diaphragm

Insulator Frame

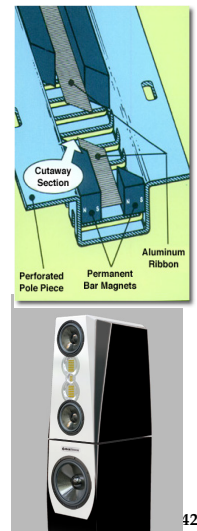
Perforated Metal

30 • MAY 1988

- Stator and plate
- Power requirements
- 1- and 2-way systems
- Hybrid systems
- Mounting and enclosures

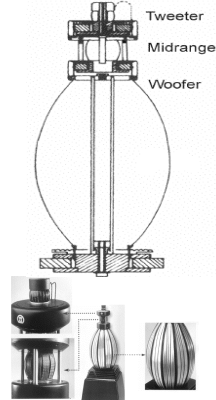
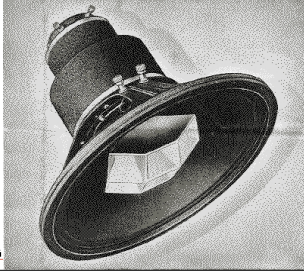


- Current-carrying membrane in a strong magnetic field
- Strip size
- Frequency range
- Designs (Magnepan, ADAM, Legacy, etc.)



## Extended Dynamic Designs

- Coaxial systems (Thiel, Altec/Lansing)
- MBL *Radialstrahler*



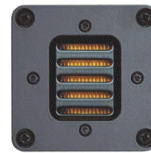
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## Novel Tweeters

- Ribbon
- Piezo
- "Solid"
- Back-handled
- "Pure piston"
- "Direct"
- Plane-wave

The A.R.T. Tweeter



Many functional distinctions in construction and kinematics can be drawn between the A.R.T. tweeter and voice coil-driven dome tweeters. It starts with the construction:



Construction of the unit with neodymium magnets and a yoke (the ring), result in perfect magnetic shielding

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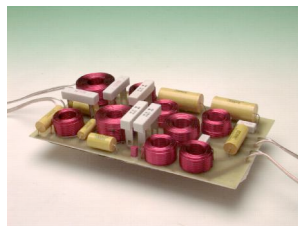
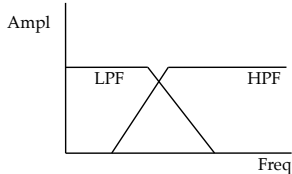
## Speaker Design

- Number & type of drivers
- Enclosure & suspension
- Surfaces & driver mounting
- Crossover & multi-wiring
- Connection posts and internal wiring
- Integration with amplifier

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## Cross-overs

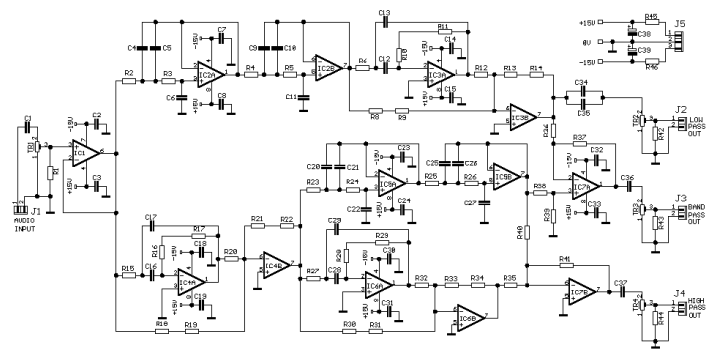


- 2-, 3-, n-way, powered woofers
- Coupling with drivers, amplification
- Configurations and cabling
- Digital cross-overs

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## Active 3-way Crossover



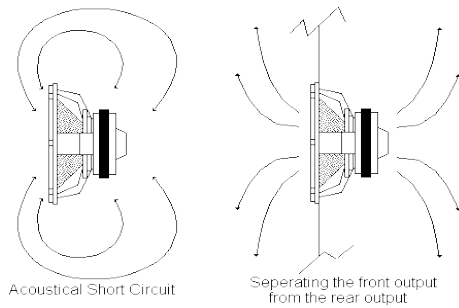
[Fig. 11] 3-WAY ACTIVE CROSSOVER WITH LINEAR PHASE

SAB 11/92

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## Bipolar Radiation (back-wave)

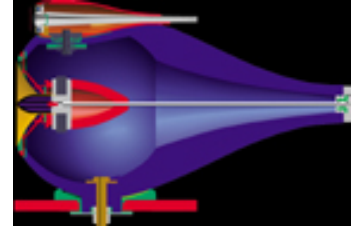


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## Back-wave Handling

- B&W Nautilus Tweeter
- Piston-in-a-tube



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## Multi-way Systems

- Woofer
- Squalker
- Tweeter
- Extensions
- Cross-over points
- Bi-wiring, Bi-amping

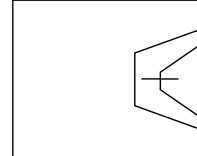


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## Sealed box

- Absorb back-wave in (foam filled) box

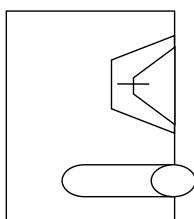


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## Ported box

- Route back-wave front "in phase"
- Standard, has problems

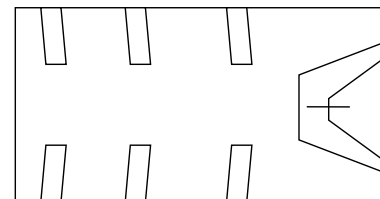


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## Baffles

- Dissipate back-wave within the enclosure



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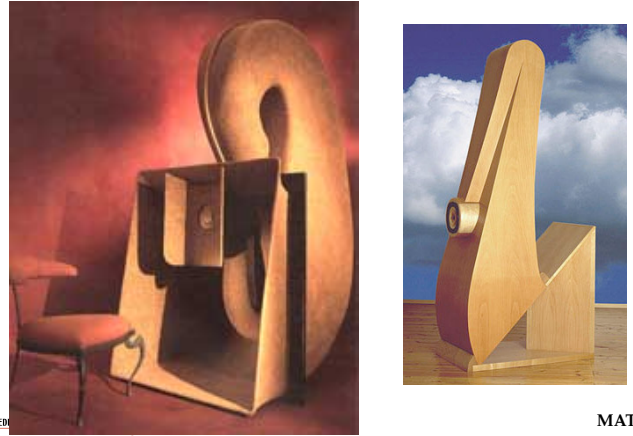
## Horn-mounted Drivers

- Acoustical impedance matching of driver
- Encourage piston-like range
- Increase efficiency, strange looking



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## Example: Cabasse Horns



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## More Horns

Klipsch



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## Enclosure Reinforcement

- Box-as-resonator
- Baffles
- Strutting
- Mixed materials
- New materials



B&W

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## Novel Alternative Designs

- Lowther 1-way designs (no crossover)
- Others?

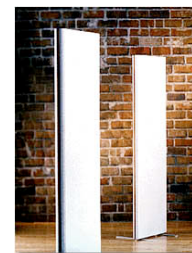


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## Electrostatic and Ribbon Systems

- Bipolar designs
- E.g., Martin Logan and Magnepan



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## Hybrid Designs

- Electrostatic + dynamic
- Ribbon + electrostatic



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## Extreme [Complex] Designs

- Genesis, Montana, Krell, etc.



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## Woofers and Subwoofers

- Freq. Extension
- Power
- Compatibility
- Radiation
- 0.1 LFE channel



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## Speakers with Knobs

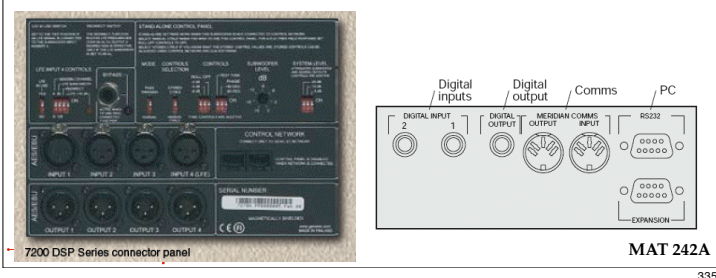
- Crossover balance
- Multi-input mixing/routing
- Common on recording studio monitors



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## Active, Digital Speakers

- Active speaker = crossover + amp + speaker in 1
- Add a DAC to this = digital speaker
- Input may be S/P-DIF, FireWire, USB, or Bluetooth
- What about channel routing?



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## System Considerations

- Speaker-as-load
- Speaker and cabling
- Stereotypes
  - Drivers (dyn, e-stat, ribbon, etc.)
  - Amplification (tube/ss, OTL, etc.)
  - Cabling (mono/bi, cable issues)
  - Room dependencies
  - Combinations
- Mounting, placement, and room treatment



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## Headphones

- “Ear speakers”
- On/in/over-ear
- Criteria
  - Weight
  - Mounting
  - Driver(s)
- ‘phone amps
- Surround processors

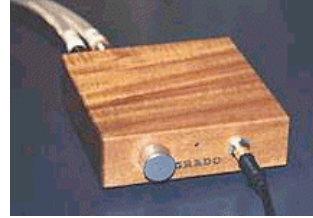


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## Headphone Amplifiers

- Headroom
- Grado
- Cary
- See also DAC + HP-amp



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## Types of Headphones

- In-ear
  - No ear-canal resonance
- On-ear
  - Includes ear-canal resonance
- Before-ear
- Multi-element and multi-channel
- DSPs and ‘phones
  - Dolby/Lake
- Binaural recording and mixing
  - Dummy-head recording

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## Other Configurations

- Car stereo
  - Coaxial or 1-way
  - Dedicated woofer
- “Multimedia” speakers
  - Packaging considerations
  - Configurations
- Home Theater 5.1 systems
  - How many types of elements?
  - 7.1? 10.1? 10.2?
- In-wall systems

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## Reviews

- Polk RT25i (\$320)
- PSB Image 4T (\$650)
- Maggies (\$3750)
- Avantgarde Uno2 (\$11k)
- M-L Prodigy (\$11k)
- B&W Nautilus 801 (\$11k)
- Dynaudio EvTempt (\$30k)
- Wilson X-1 Grand Slamm (\$77k)
- Sennheiser HD600 ‘phones (\$450)
- Stax SR-007 amp/‘phones (\$11k)

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## What’s Next?

- Interconnects, Room treatments
- Readings: Harley and Reader
- Paper 2
- Schedule
- Listening sessions

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## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 7: Content & Tweaks

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### Topic 7: Audiophile Recordings, Tweaks, etc.

- Audiophile recording and mastering
- Audiophile media
- Tweaks and system tuning
- Review/Summary

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### Topic 7 Readings

- Audiophile Content
  - Bob Ludwig Interview
  - I Want More (Tom Jung interview)
  - Hard Disk Classical Music Recording
  - Recording Deep River (excerpt)
- Tweaking
  - Optimizing your Audio System
  - Tweaks!
  - Digital Room and Speaker Correction: The Big Picture
  - Digital Correction for Audio, Part 1
  - Loudspeaker Placement
  - Cinemusic Room Treatments

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### Audiophile Content

- Would you buy a CD just because of the way it's recorded or mastered?
- Are there real differences between recording and mastering techniques and "high-end" media?

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### Recording Techniques

- Microphones, mike placement, capturing a multi-channel spatial image
- Minimalist processing
- Recording spaces

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## Recording Engineering

- Early days: Musicians gather around the gramophone horn
- 1940s: Multi-mike techniques with live mix-down to mono
- 1960s: Multi-track close-miked techniques and separate mix-down and reverb/spatialization
- 1990s: 5- or more-channel surround sound brings mixing headaches

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## Audiophile Recording

- Vintage microphones
- Vintage mixers
- Vintage techniques
- "Recorded by and for audiophiles"

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## Alternative Mike Techniques

- Stereo-pair microphones (X/Y, ORTF, RAI, DIN, etc.)
- Multi-omni techniques: Decca tree, Wide pair
- Dummy head recording
- Soundfield recording
- Coupled with mix-down technique

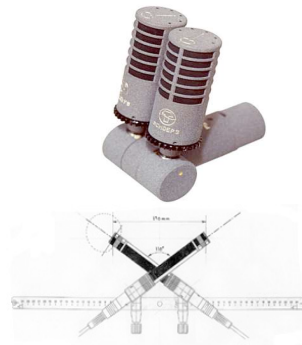
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## Stereo Microphone Pairs

- Differ in distance, angle, and mike pattern

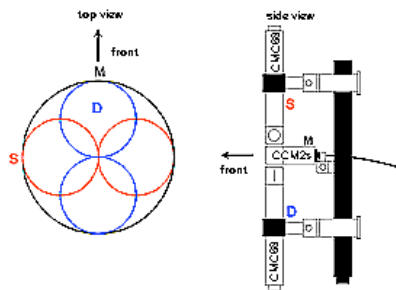


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## M/S and Other Stereo Systems

- Middle/side recording and processing
- Decca tree and wide-omni systems



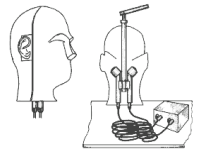
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## Dummy Heads

- Useful only for headphone listening?



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## Soundfield Microphones

- Ambisonics
- Holophonics



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## Processing and Mixing

- AAD vs. DDD
- Minimal path mixing
- Direct-to-disk (vinyl) recording
- Reverb, spatialization, creation of stereo image
- Assumptions about the playback space

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## Record Mastering

- The role of the mastering engineer
- Mastering transfers
- Mastering to multiple formats
- Levels, EQ, etc.

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## Audiophile Media

- Vinyl formats
- Advanced CD formats
- DVD/A and SACD
- New digital broadcast formats

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## Advanced Vinyl

- Heavy records
  - 180 gram recordings
- Hi-speed records
  - 45 RPM LPs
- Low-speed mastering (16 2/3 RPM)
- Direct-to-disk recordings
- 5.1-channel vinyl (a la 1970s)?

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## Fancy CDs

- Gold and other materials
- Special production processes
- Voodoo?

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## Extended CD-Compatible Formats

- HDCD: Use 1/32 bit per sample for encoding dithering mode
- XRCD: Controlled mastering process
- 88k CD: Onkyo experimental format
- Dual-layer CD/SACD
- MP3 on CD/R

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## Other Audiophile Formats

- Digital cable radio
- XM/Sirius
- AAC
- FLAC, APE, MLP
- Others coming?

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## Audiophile labels

- Some linked to studios
- New recordings: jazz, classical, blues
- Reissue houses
- Big 5 re-releases

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## Tweaks and System Tuning

- Basic tweaking
- Source components and media
- Amplification and electronics
- Interconnects and cables
- Room treatment
- Stands and physical tweaks
- Accessories vs. Excessories: tweak voodoo

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## Simple Tweaks

- Only relevant for mid-fi systems
- Power quality = most important (according to several sources)
- Stands and isolation, also important
- Room treatment too often overlooked
- Regular care and maintenance
- Use your ears!

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## Tune Villa Advice

1. Mount Fuse box on "tuning board."
2. Use dedicated circuits for audio system.
3. When choosing power wire use 10 gauge for full, 12 gauge for medium, 14 gauge for light. (Use audio grade where possible)
4. Use audiograde outlets, boxes and plates.
5. Use cable grounds or raise all cables and wire off ground or floor.
6. Mechanically ground and tune all components; amps, CD player, computers, etc... on tuning racks and boards.
7. Use MTD's or Harmonic Feet under every component. (When clamping, use MTD on top as well... call us for assistance)
8. Use Tuning Boards or MTD's on carpet, and MTD's or Harmonic Feet on hardwood floors for speakers.
9. When painting: Flat=Dry; Eggshell=Medium-Dry; Satin=Medium; Semi Gloss=Fast; Gloss=Bright.
10. Acoustically treat the pressure zones.

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## Media Tweaks

- Vinyl
  - Record cleaning
  - Record surface treatment
  - LP player clamps, weights, adjustments
- CD treatment
  - Cleaning
  - Colored pens
  - Degaussing



▶ HW-16.5

Features  
 ▶ 30 second cleaning cycle  
 ▶ High-torque turntable motor  
 ▶ Stainless steel fluid collection system  
 ▶ Safety coated record contacts  
 ▶ No-mess cleaning enclosure



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## Speaker Tweaks

- Stands
- Mounting points
- In-wall
- Weighting
- Sub-sub
- Super-tweeter



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## Amplification Components

- Tube gloves, heat sinks
- Socket covers
- Contact treatments
- Isolation



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## Interconnection

- Cable routing
- Special ground handling
- EMI/RFI handling
- Digital cables
- Speaker cable stands

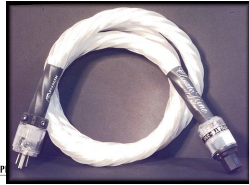
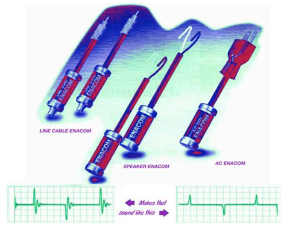


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## Power Treatment

- Spike filters
- High-grade sockets
- Dedicated grounds
- Special power cables

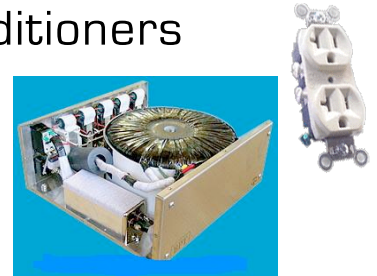


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## Power Conditioners

- Specialty plugs
- RFI Filters
- AC synthesizers



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## Stands and Physical Tweaks



- Mounting and stands
  - Isolation and microphonics
- Feet and coupling
  - Bouncy, squishy, roly, and single-point



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## What's Next?

- Listening sessions
- Rooms and processors
- final presentations

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## MAT 242: Special Topics in Digital Multimedia: **Audiophile Engineering** Topic 8: Placement & Treatments

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## Topic 8: Speaker Placement and Room Treatments

- Basic room acoustics
- Kinds of rooms
- Speaker placement
- Room treatments
- Special cases



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## Topic 8 Readings

- Power and Accessories
  - Nine Power Conditioners Surveyed
  - AC Outlet Replacement
  - Acoustic Sciences Studio Traps (\$315)
- Processors
  - TacTRCS2.0 digital EQ/preamp and software (\$4300)
- Integrated/Disk-based Systems
  - Sonos ZP80 & ZP100 WiFi Music System
  - Linn Knekt Kivor Hard Disk System (\$20,000)
  - Meridian Digital Theater System (\$73,000)

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## Room Acoustics

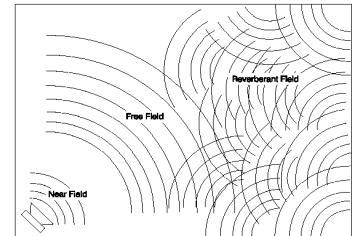
- Waves in enclosed spaces
- Standing waves and room modes
- Dissipation of energy
- Source placement
- Surface treatment
- Creation of a stereo or multi-channel spatial image

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## Listening Spaces

- Recording studios
- Performance spaces
- Listening rooms
- Home theater
- Cars
- Headphones



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## What are we listening to?

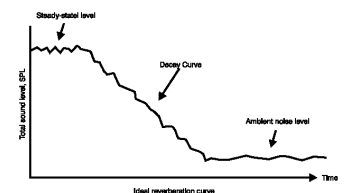
- Not all recordings are mixed for the same room!
- Most recording studio control rooms are very dead
- The only real answer is an adjustable room or DSP-based reverberator and correction filter

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## Reverberation

- Early vs. late reflections
- Smoothness of decay
- Flutter, echoes, and comb filter effects



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## Auditorium Acoustics (CCRMA)

- Optimum reverberation time is a compromise between clarity (short reverberation time), sound intensity (high reverberant level), and liveness (long reverberation time).
- The optimum reverberation time of an auditorium is dependent on the use for which it is designed.
- Reflected sound arriving from the sides seems to be important to the overall “reverberance” of the room.
- Important subjective attributes of concert hall acoustics include intimacy, liveness, warmth, loudness of direct sound, reverberant sound level, definition or clarity, diffusion or uniformity, balance and blend, ensemble, and freedom from noise.

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## Auditorium Acoustics 2

- Spatial impression and early decay time are important. The spatial impression is dependent on contributions to the early reflections from the sides and above. The initial rate of decay of reverberation is more perceptually important than the total reverberation time.
- Echoes, flutter echoes, sound focusing, sound shadows, and background noise should be avoided in an auditorium design.
- The greater the early decay time (<2 sec), the greater the preference for the concert hall. Above 2 sec, the trend it reversed.
- Narrow halls are generally preferred to wide ones.
- Preference is shown for halls having high “binaural dissimilarity”
- Less “definition” is preferred. Definition represents the ratio of energy in the first 50 milliseconds to the total energy.

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## Room Mode Analysis

- Using distances between walls, calculate 3D standing waves

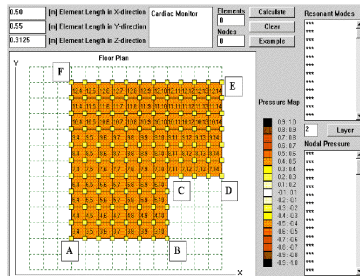


Figure 5. Listening room having shape.

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## Room Resonance Modes (example)

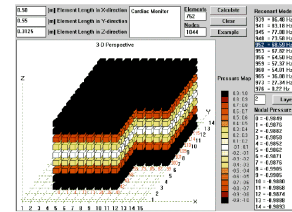


Figure 9. Pressure distribution of the 68Hz mode.

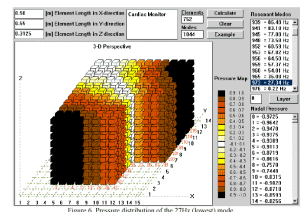


Figure 6. Pressure distribution of the 271Hz (lowest) mode.

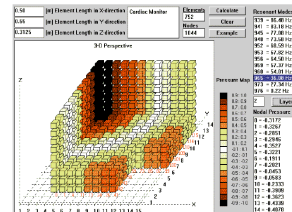


Figure 7. Pressure distribution of the 361Hz mode.

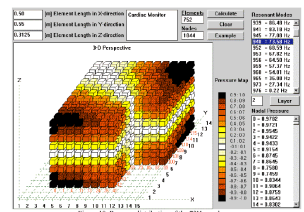


Figure 10. Pressure distribution of the 731Hz mode.

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## Speakers as Sources

- Ideal speakers
  - Narrow cone
  - Omnidirectional
- Real-world
  - Irregular and asymmetrical off-axis responses
  - Side/rear radiation
  - Enclosure radiation

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## Basic Speaker Placement

- Corner placement
  - $\pi/8$  Corner horns (still popular, see subwoofer placement advice)
  - Placement of dipole speakers
- Placement to defeat room modes (far from walls, different distances from rear/side walls)
- Placement to enhance spatial imaging (magic triangles)

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## Basic Placement Rules (Harley)

- Speaker-listener relationship (magic triangles)
- Wall proximity and bass (emphasis with in-phase reflections)
- Room resonant modes (defeat them)
- Distance to walls (precedence effects)
- Listening height (phase and response)
- Toe-in (on-axis response)

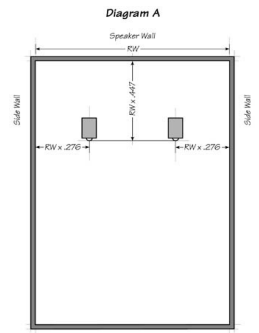
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## Speaker Placement

### Criteria

- Delay first reflection
- Width of stereo image
- Toe-in for on-axis listening
- Sweet spot at listening position
- Ignore practical concerns!



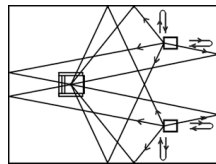
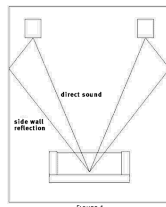
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## Speaker Placement

### Early reflections

- Multiple comb filter calculation
- Reflections back to speaker
- Space from rear and side walls
- Ceiling reflections (do not ignore!)
- Many trade-offs



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## Calculating Speaker Placement (example)

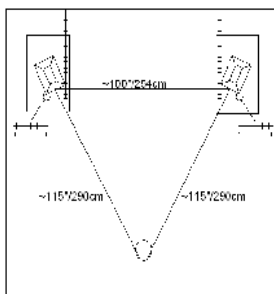
- Multiply room width (RW) by .276 and you will come up with the distance from the side wall to the center of the woofer. Multiply room width (RW) by .447 to obtain the distance from the front wall to the center of the woofer's face. This number should also be the distance between the two speakers (center-of-woofer to center-of-woofer). This gives us the following values:
  - Speaker to side wall:  $RW \times .276 = 4 \text{ feet } 4.9 \text{ inches}$
  - Speaker to rear wall:  $RW \times .447 = 7 \text{ feet } 1.8 \text{ inches}$
  - Speaker to opposite side wall:  $RW \times .724 = 11 \text{ feet } 7.0 \text{ inches}$
  - Speaker to speaker:  $RW \times .447 = 7 \text{ feet } 1.8 \text{ inches}$
- Now you can use the isosceles-triangle proportion to determine your listening position and you have a fairly good idea of what the final positions will be.

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## WASP Triangle

- Stereo image breadth and speaker placement



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## Irregular Rooms

- Treat as rectangular room with an opening to another space
- Ignore energy lost to added space
- Handling non-rectangular reflection surfaces
  - Old rules about early reflections and energy dissipation
- Even weirder situations (move)

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## Problem Rooms

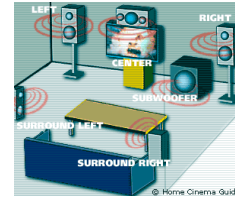
- Parallel untreated walls (resonant modes)
- Problem floor and side wall reflections (treat)
- Bass overkill (change speakers, bass traps)
- Reflective objects near speakers
- Cars as listening rooms (shape, size, surfaces, listener positions, background noise, power and driver limitations)

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## Home Theater Systems

- Space considerations
- ...typically ignore good placement of front speakers
- Biggest issues are placement of rear surround speakers and subwoofer!



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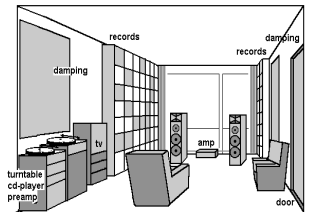
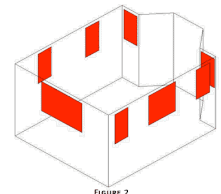


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## Room Treatments

- Acoustical Design
- Surface treatments
  - Absorption
  - Diffusion
- Resonance control
  - Corners
  - Bass modes
  - Diffusion

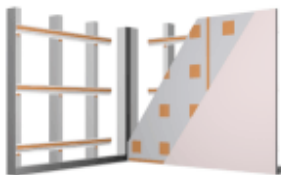


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## Architectural Acoustic Design

- Wall as membrane
- Inter-room coupling and sound-proofing
- Resonators



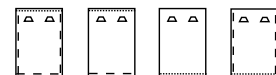
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## Surface Treatment (example)

- The Nippon-Gakki Experiments (AES 1979)

- Materials: Absorptive material ——— Drapes - - -



- |                    |      |      |      |      |
|--------------------|------|------|------|------|
| • Localization     | good | poor | poor | fair |
| • Non-coloration   | good | poor | poor | fair |
| • Loudness         | poor | good | good | good |
| • Image broadening | poor | good | good | fair |
| • Perspective      | good | good | poor | good |

- Many similar subjective tests from other sources

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## Absorption



- Mechanically absorb incident sound energy
- Characterized by absorption spectrum

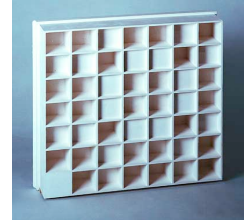
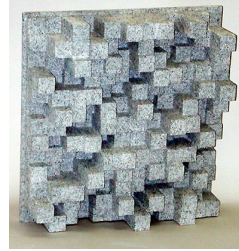


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## Diffusion

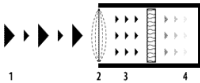
- Schroeder diffuser design
- "Abfusion"



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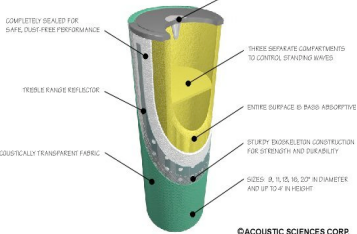
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## Bass Management

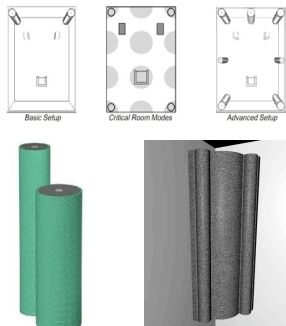


- Absorb energy at bass mode nodes and primary reflection points

US Patent #4,548,292



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## Complex Treatments

- Combination of all treatment methods
- Room design as a field of expertise

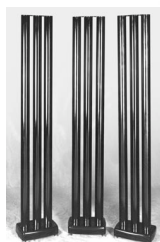
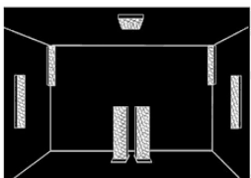


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## Special Resonators

- Absorb standing waves
- Tube and box designs



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## DSPs as Room Accommodators

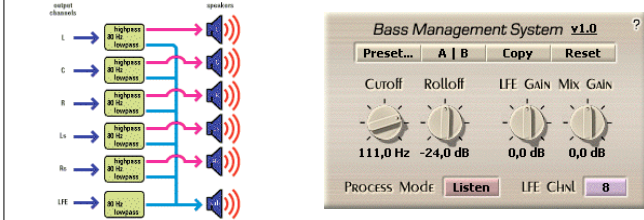
- DSP-based filters
- Active DSP systems
- DSP-based room tuning

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## Bass Management

- 5.1 mastering: separate LFE from main channels to accommodate main spkrs with limited LF extension
- Bass management: mix this back in for systems with 5 full-range speakers and no "sub-woofer"

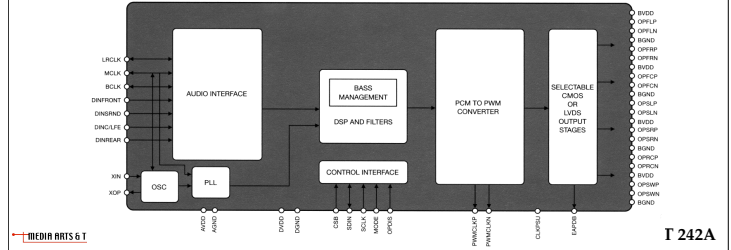
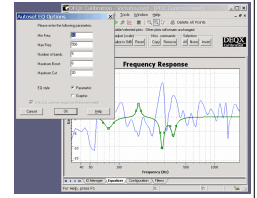


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## Room/Speaker Correction

- Measure room acoustics to find speaker dips and standing waves
- Compensate with a room/system-specific filter
- Easy to do poorly...

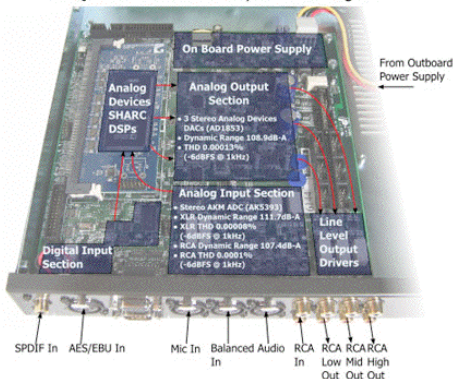


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## DSP for Room Correction

DEQX PDC 2.6P Internal Layout Block Diagram



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## Speaker Stands

- Optimal height and angle
- Stand resonance
- Floor reflection issues
- Floor coupling issues
- Subwoofer stands (?)



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## Speaker Treatments

- Weighted speaker wall mounts
  - Increase effective mass of enclosure walls (lowering radiated energy)
- Special stand issues
  - Non-resonant stands
- Off-floor mounts for full-range speakers
  - Bass reflections

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## Adjustable Rooms

- Drapery and adjustable absorption
  - To compensate for different mixes
- Mobile diffusors
- Handling of glass and doors
  - Handling practicality and listening
- Handling of room geometry

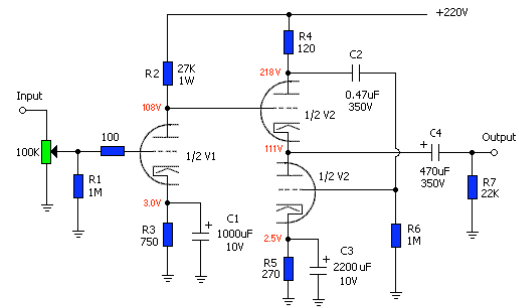


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## Speaker Selection

- Room dependencies
  - Frequency response
  - Directionality and enclosure radiation
  - Off-axis response
  - Room treatments
- Listening preferences
  - Volume, style, critical listening
  - Associated equipment



V1, V2 - E88CC/6D38 audio tube  
(one additional E88CC  
required for stereo)

All resistors are 1/2W metal film  
unless otherwise shown.

Optimized Morgan Jones Headphone Amplifier (one channel)

## Summary/Review

- Critical listening
  - Know your preferences
- System thinking
  - Don't buy components
  - Think of system issues (interconnects, room treatment, etc.)
- Audiophilia as a hobby
  - Not for everybody
  - Can be phasic

## Where do we go from here?

- Projects
- Courses
- Facilities

## MAT 242A Topics

- Principles of high fidelity
- Critical listening, system evaluation
- Audio components
  - Sources, electronics, transducers, and interconnects
- Room acoustics, design, and treatment
- Audiophile, pro-audio, and recording studio systems
- Audiophile recording techniques and equipment
- Digital audio formats and content distribution
- Multi-channel formats and surround sound
- System measurement, evaluation, and comparison

Thank you!



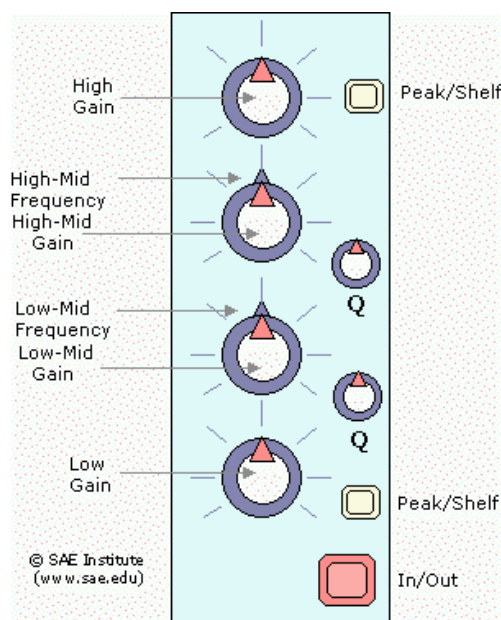
## MAT 242B Recording Studio Design and Engineering (Spring, 2009)

### Overview

MAT 242B focuses on the design and engineering of sound recording studio equipment. The topics include the components of the studio signal chain, from microphones through mixing consoles to monitor loudspeakers. We address the various processing stages, recording formats, post-production, and encoding for distribution. Students read articles from the audio research and commercial literature, learn the fundamentals of the design of recording studio equipment, and carry out experiments in the studios of the Music Department. Grading is on the basis of written papers and in-class participation.

### Topics

- Introduction
- Studios and Control Rooms
- Power and Wiring
- Microphones and Pre-amps
- Mixing Consoles and Channel Strips
- Storage Formats and Media
- Monitoring and Playback
- Processing and Signal Conditioning
- Mixing and Mastering
- Computers and Digital Audio Workstations
- New Media Systems



### Prerequisites

Basic knowledge of acoustics, willingness to read mathematics and simple circuit diagrams, and some familiarity with audio equipment. (No specific electronic or musical skills are assumed.) Upper-division undergraduates are welcome with permission of the instructor.

### Course Materials

- A reader for this course will be available at the UCSB book store.

### Instructor

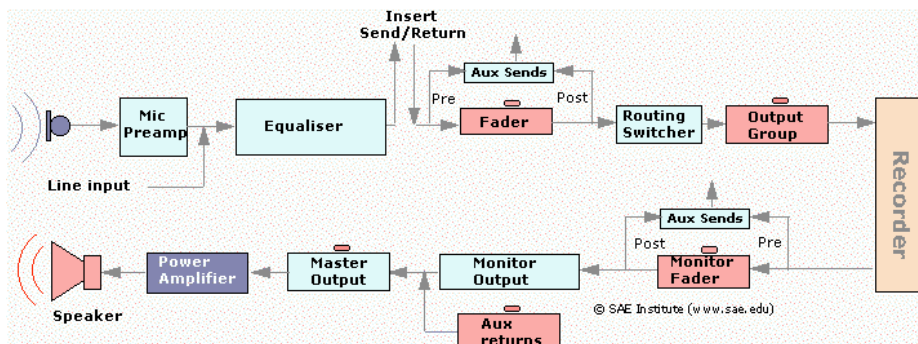
- Stephen T. Pope  
(stp@mat.ucsb.edu)

### Meeting time and place

- T/Th 12:00 - 1:50 PM,  
Music 2215

### Course Web Site, Mailing List

See <http://create.ucsb.edu/242>  
for all details



# **MAT 242B: Special Topics in Digital Multimedia: Recording Studio Engineering, Spring Quarter 2005**

## **Course Logistics**

### *Instructor*

Stephen T. Pope (stp@mat.ucsb.edu, <http://create.ucsb.edu/~stp>)

### *Meeting time/place*

TBD: first meeting: Monday, April 4, 2005, noon

MAT class room (South Hall 3431)

### *Materials*

Web site: <http://mat.ucsb.edu/242>

Mailing list 242@mat.ucsb.edu, <http://mat.ucsb.edu/mailman/listinfo/242>

## **Overview**

MAT 242B focuses on the design and engineering of sound recording studio equipment. The topics include all the components of the studio signal chain, from microphones through mixing consoles to monitor loudspeakers. We address the various processing stages, recording formats, post-production, and encoding for distribution. Students in MAT 242B read articles from the audio research and commercial literature, learn the fundamentals of the design of recording studio equipment, and carry out experiments in the studios of the Music Department (it is not a recording engineering techniques course, however). Grading will be on the basis of written papers, individual or group R&D projects, and in-class participation.

### *Prerequisites*

Basic knowledge of acoustics, willingness to read mathematics and simple circuit diagrams, and some familiarity with audio equipment. (No specific electronic or musical skills are assumed.) Upper-division undergraduates are welcome with permission of the instructor.

## **Topics**

- Introduction
- Studios and Control Rooms
- Power and Wiring
- Microphones and Pre-amps
- Mixing Consoles and Channel Strips
- Storage Formats and Media
- Monitoring and Playback
- Processing and Signal Conditioning
- Mixing and Mastering
- Computers and Digital Audio Workstations

# **MAT 242B Reader Table of Contents**

## **Syllabi**

City and Guilds of London Sound Engineering 1820/3 Syllabus  
Recording Connection Course Outline  
Introduction to Sound Recording Book TOC, [Tonmeister.ca](http://Tonmeister.ca)  
Music Technology Magazines, [audioMIDI.com](http://audioMIDI.com), 2001

## **Introduction**

Audio Chapter from WPI Technical Theater Handbook, S. Richardson, 2000  
Studio Setup, [audioMIDI.com](http://audioMIDI.com), 2001  
Leopold's Comparison Between Audio Formats, H. Herranen, 2000  
Digital Audio Representation and Interchange Formats, STP and PES, 2003  
Signal Processing Fundamentals, [RaneNote](http://RaneNote)  
Audio Specifications, [RaneNote](http://RaneNote)  
Analog Design in a Digital Environment, [RaneSlides](http://RaneSlides)

## **Studios and Control Rooms**

Studio Plans, [Saecollege.de](http://Saecollege.de)  
Representative Control Rooms, Master Handbook of Acoustics  
Modern Control Room Design and Construction, anonymous, [electroacoustics.co.uk](http://electroacoustics.co.uk)  
Speed Tuning a Room, G. Miller, Gold Line Inc., 2000

## **Power and Wiring**

Introduction to Audio Wiring, [Saecollege.de](http://Saecollege.de)  
Introduction to Power and Lights, [Saecollege.de](http://Saecollege.de)  
Ground Loop Problems and How to Get Rid of Them, T. Engdahl, 2000  
Digital Audio Formats and Cables, [AudioMIDI.com](http://AudioMIDI.com), 2002  
Common Pro Audio Plugs and Connectors, Mackie, Inc., 2003  
Interconnection of Balanced and Unbalanced Equipment, B. Whitlock, Jensen, Inc., 1995  
Sound System Interconnection, [RaneNote](http://RaneNote)  
Grounding and Shielding Audio Devices, [RaneNote](http://RaneNote)

## **Microphones and Pre-amps**

Introduction to Microphones, [Saecollege.de](http://Saecollege.de)  
Capsule Technology and Types, P. Janis, [DigitalProSound.com](http://DigitalProSound.com), 2003  
Cardioid Carrying Member, E. Ciletti, Tangible Technology, 1998  
Microphile "Undressed," E. Ciletti, Tangible Technology, 1997  
Selecting Mic Preamps, [RaneNote](http://RaneNote)  
The Boston PRE Party, E. Ciletti, Tangible Technology, 1998  
Earthworks ZDT Preamp Data Sheet, Earthworks, Inc., 2003  
Earthworks Omni Applications Guide, Earthworks, Inc., 2003  
A Direct Box Can Be Indispensable, A. Keltz, Whirlwind, Inc., 2003  
Direct Feeds, anonymous, [electroacoustics.co.uk](http://electroacoustics.co.uk)

## **Mixing Consoles and Channel Strips**

Mackie DB8 Setup Instructions, Mackie, Inc., 2002  
Mixing Consoles 1 & 2, Pro Engineer School, [Record-Producer.com](http://Record-Producer.com), undated

Introduction to Consoles, [Saecollege.de](http://Saecollege.de)  
 Introduction to Mixing, [Saecollege.de](http://Saecollege.de)  
 Console Ergonomics, [anonymous, electroacoustics.co.uk](http://anonymous.electroacoustics.co.uk)  
 Channel Strip Buyer's Guide, [JD. Mars, DigitalProSound.com](http://JD.Mars.DigitalProSound.com), 2002  
 Designing the Large-Format Digital Console, [R. Maycock, Mix Magazine](http://R.Maycock.MixMagazine.com), 2000  
 Yamaha 02R96 and DM2000 Information, [Yamaha Corp.](http://YamahaCorp.com), 2003  
 Understanding Console Automation, [B. Nathan, Keyboard](http://B.Nathan.Keyboard.com), 1985  
 Bass Management Electronics, [M&K Inc.](http://M&KInc.com), 2003

#### Recording, Storage Formats and Media

Introduction to Recorders, [Saecollege.de](http://Saecollege.de)  
 Analog Recording, Digital Recording, [Pro Engineer School, Record-Producer.com](http://ProEngineerSchool.Record-Producer.com), undated  
 Digital-Analog Conversion, [T. Kuphaldt, Lessons in Electronic Circuits](http://T.Kuphaldt.LessonsinElectronicCircuits.com), 2003  
 Digital Dharma of Audio A/D Converters, [Rane Note](http://RaneNote.com)  
 AU and RME ADC Data, [UA, Inc.](http://UA.Inc.com), [RME, Inc.](http://RME.Inc.com), 2003  
 Mixdown Tools, [R. Maycock, DigitalProSound.com](http://R.Maycock.DigitalProSound.com), 2003  
 Mackie HDR24/96 Brochure, [Mackie, Inc.](http://Mackie.Inc.com), 2002  
 Synchronization and Timecode Basics, [B. Hoover, audioMIDI.com](http://B.Hoover.audioMIDI.com), 2001  
 Dolby Noise Reduction, [HyperPhysics](http://HyperPhysics.com), 2000  
 Noise Reduction Systems, [P. Giddings, Engineering Harmonics, Inc.](http://P.Giddings.EngineeringHarmonics.com), 1990

#### Monitoring and Playback

##### No readings

#### Processing and Signal Conditioning

Introduction to Equalization, [Saecollege.de](http://Saecollege.de)  
 Exposing Equalizer Mythology, [RaneNote](http://RaneNote.com)  
 Operator Adjustable Equalizers, [RaneNote](http://RaneNote.com)  
 All About Equalizers, [RaneSlides](http://RaneSlides.com)  
 Active Filters, Equalizers, and Crossovers, [RaneSlides](http://RaneSlides.com)  
 Compressor/Expanders, Limiters, and Gates, [Saecollege.de](http://Saecollege.de)  
 Good Dynamics Processing, [RaneNote](http://RaneNote.com)  
 UA 1176LN Limiting Amplifier Brochure, [Universal Audio](http://UniversalAudio.com), 2003  
 Digital Dynamics Processing, [F. Foti, Omnia Inc.](http://F.Foti.OmniaInc.com), 2000  
 Guitar Effects FAQ, <http://www.geofex.com>  
 Eventide Eclipse Description and Preset Effects List, [Eventide, Inc.](http://Eventide.Inc.com), 2003  
 Introduction to Reverberation, [Saecollege.de](http://Saecollege.de)  
 Audio Processing & HD Radio, [F. Foti, Omnia Inc.](http://F.Foti.OmniaInc.com), 2000  
 State of the Art Speech Processing for Broadcasting, [M. Wolters, Cutting Edge](http://M.Wolters.CuttingEdge.com), 1999  
 Rane Condensed Catalog

#### Mixing and Mastering

Overview of CD Mastering, [DRT Mastering](http://DRTMastering.com), 2002  
 Home Cinema Systems, [RaneNote](http://RaneNote.com)  
 You're Surrounded, [M. Sokol, DigitalProSound.com](http://M.Sokol.DigitalProSound.com), 2000  
 Signal Processing and Methods in Surround Mixing, [B. Rudolph, Mix](http://B.Rudolph.Mix.com), 2003

*Some Guidelines for Producing Music in 5.1-Channel Surround*, Dolby Labs, 1998  
*Computers and Digital Audio Workstations*  
*Recording, Mixing, and signal Processing on a Personal Computer*, A. Freed, ICMC, 1987  
*Build It: DAW*, D. Salvator, ExtremeTech, 2003  
*Ardour brochure*, [ardour.sourceforge.net](http://ardour.sourceforge.net), 2003  
*Linux Applications using jack*, [jackit.sourceforge.net](http://jackit.sourceforge.net), 2003

## **Course Schedule**

### *Week 1*

**Introduction, Overview**  
**The studio signal chain and interconnection**

### *Week 2*

**Recording studio and control room design**  
**Infrastructure, power, Lighting, wiring, noise**

### *Week 3*

**Microphones, pick-ups, and sources**  
**Pre-amps, direct boxes, etc.**

### *Week 4*

**Mixing consoles, channel strips, auxes, etc.**  
**Kinds and applications of consoles**  
**Equalization for recording**

### *Week 5*

**Recording formats and media**  
**Analog and digital recorders**  
**A/D and D/A convertors**

### *Week 6*

**Signal conditioning and processing**  
**Reverb, dynamic range processing, etc.**  
**Processing for restoration**

### *Week 7*

**Monitoring and playback**  
**Mixing, mastering, and encoding**  
**EQ, dynamics processing, and “sweetening”**

### *Week 8*

**Distribution media and formats, broadcast and streaming**  
**Surround sound and home theater**  
**Media synchronization**

### *Week 9*

**Modern digital audio workstations**  
**Hardware and software solutions**

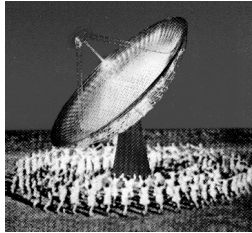
### *Week 10*

**Discussion, final presentations**

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**MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering**



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**Lecture 1 Outline**

- ◆ Goals
- ◆ Logistics
- ◆ Materials
- ◆ Course Overview
- ◆ Topic 1
  - Introduction
  - History
  - Recording studios

MAT 242 3/29/03 MEDIA ARTS & TECHNOLOGY PROGRAM 2

**Goals for MAT 242-RE**

- ◆ Relation to MAT 242-AE and MAT 240 series
- ◆ Background in recording engineering  
(NB: this is not a RE course!)
- ◆ Topics
  - Studio/control room design and infrastructure
  - The signal chain: sources, processing, mixing, recording, playback
  - Mastering for encoding and distribution
  - Computers and digital audio workstations


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**Logistics**

- ◆ Instructor
  - Stephen T. Pope (stp@mat.ucsb.edu, <http://create.ucsb.edu/~stp>, 967-2621)
- ◆ Meeting time
  - Thursdays 2:00 - 5:00 PM (OK?)
  - MAT class room (South Hall 3431)
- ◆ Grading
  - 3 projects/papers (do you want tests?)
    - Due weeks 4, 7, and 10
    - At least 1 written and 1 technical (HW or SW)
    - At least 1 "focused" and 1 "survey"

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**Materials**



- ◆ Reader
  - Comprehensive
  - Available at UCSB book store
  - TOC on-line
  - Important to course content
  - Comments or additions are welcome!
- ◆ Presentation Slides
  - Delivered as PDF files as we go...

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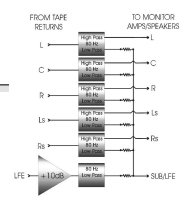
**Other Materials**

- ◆ Web site: <http://mat.ucsb.edu/242> with link list -- comments/corrections/additions are welcome!
- ◆ Mailing list: 242@mat.ucsb.edu, <http://mat.ucsb.edu/mailman/listinfo/242>
- ◆ CD-ROMs: encoders, microphones, listening examples, etc.
- ◆ Materials of the AES (Audio Engineering Society) [www.aes.org](http://www.aes.org)
- ◆ Other media (see reader)

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## MAT 242 Topics

- ◆ Introduction, overview, history
- ◆ Studios and Control Rooms
- ◆ Power and Wiring
- ◆ Microphones and Pre-amps
- ◆ Mixing Consoles and Channel Strips
- ◆ Storage Formats and Media
- ◆ Monitoring and Playback
- ◆ Processing and Signal Conditioning
- ◆ Mixing and Mastering Processes and Equipment
- ◆ Computers and Digital Audio Workstations



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## Course Schedule

- ◆ Week 1: Introduction, history, overview
  - Overview, history of recording engineering
  - Processes and equipment
  - The recording studio signal chain
- ◆ Week 2: Studios and control Rooms
  - Power and wiring, noise, lighting
  - Interconnection
- ◆ Week 3: Microphones and pre-amps
  - Source chain components
- ◆ Week 4: Mixing consoles and channel strips
  - Console design and engineering
  - Analog and digital consoles

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## Course Schedule

- ◆ Week 5: Recording, storage formats and media
  - Analog and digital recorders
- ◆ Week 6: Processing and signal conditioning
  - Effects and reverberation
- ◆ Week 7: Monitoring and playback
  - Mastering for encoding and distribution
- ◆ Week 8: Distribution formats
  - Broadcast and streaming
  - Sync. With other media
- ◆ Week 9: Computers and digital audio workstations
  - Software solutions

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## The MAT 242 Reader in Detail

- ◆ **Syllabi**
  - City and Guilds of London Sound Engineering 1820/3
  - Syllabus Recording Connection Course Outline
  - Introduction to Sound Recording Book TOC, Tonmeister.ca
  - Music Technology Magazines, audioMIDI.com, 2001
- ◆ **Introduction**
  - Audio Chapter from WPI Technical Theater Handbook
  - Studio Setup, audioMIDI.com
  - Leopold's Comparison Between Audio Formats
  - Digital Audio Representation and Interchange Formats

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## Reader in Detail

### ◆ Studios and Control Rooms

- Studio Plans, Saecollege.de
- Representative Control Rooms, *Master Handbook of Acoustics*
- Modern Control Room Design and Construction
- Speed Tuning a Room



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## Reader in Detail

### ◆ Power and Wiring

- Introduction to Audio Wiring
- Introduction to Power and Lights
- Ground Loop Problems and How to Get Rid of Them
- A Clean Audio Installation Guide
- Getting a Perspective on Noise
- Digital Audio Formats and Cables
- Common Pro Audio Plugs and Connectors,
- Interconnection of Balanced and Unbalanced Equipment

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## Reader in Detail

### ◆ **Microphones and Pre-amps**

- Introduction to Microphones, Capsule Technology and Types
- Cardioid Carrying Member (Proximity effects)
- Microphone "Undressed,"
- Microphones and Wind
- Earthworks Measures Microphones
- The Boston PRE Party
- Earthworks ZDT Preamp Data Sheet
- Earthworks Omni Applications Guide
- A Direct Box Can Be Indispensable
- Direct Feeds, Bellari ADB3b Direct Box Brochure

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## Reader in Detail

### ◆ **Mixing Consoles and Channel Strips**

- Mixing Consoles 1 & 2
- Introduction to Consoles, Mixing, & Equalization
- Console Ergonomics
- Channel Strip Buyer's Guide
- Designing the Large-Format Digital Console
- Yamaha 02R96 and DM2000 Information
- Soundcraft D328 Brochure
- Mackie DB8 Setup Instructions
- Understanding Console Automation
- Bass Management Electronics

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## Reader in Detail

### ◆ **Recording, Storage Formats and Media**

- Analog Recording, Digital Recording
- Introduction to Recorders
- Analog Tape 101
- Digital-Analog Conversion
- AU and RME ADC Data
- Mixdown Tools
- ADAT vs. DA-88, DA-88 Hook-up
- Mackie HDR24/96 Brochure
- Synchronization and Timecode Basics
- Dolby Noise Reduction, Noise Reduction Systems

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## Reader in Detail

### ◆ **Monitoring and Playback**

- No readings (see other sources)

### ◆ **Processing and Signal Conditioning**

- Guitar Effects FAQ
- Eventide Eclipse Description and Preset Effects List
- Introduction to Reverberation
- Compressor/Expanders, Limiters, and Gates
- UA 1176LN Limiting Amplifier Brochure
- Digital Dynamics Processing
- Audio Processing & HD Radio
- State of the Art Speech Processing for Broadcasting

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## Reader in Detail

### ◆ **Mixing and Mastering**

- Overview of CD Mastering
- Secrets of Doing Surround Sound on your Existing Console
- You're Surrounded
- Signal Processing and Methods in Surround Mixing
- Whatever Happened to Dynamic Range on Compact Discs?
- Surround Sound: Past, Present, and Future
- Some Guidelines for Producing Music in 5.1-Channel Surround



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## Reader in Detail

### ◆ **Computers and Digital Audio Workstations**

- Recording, Mixing, and signal Processing on a Personal Computer
- Build It: DAW
- Ardour brochure,
- Linux Applications using jack

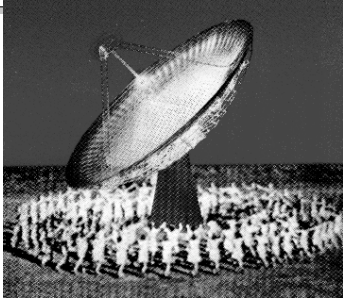
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**What is the Field, the Profession?**

- ◆ Audio Engineers work in:
  - Recording/broadcast studios
  - Live sound (sound reinforcement)
    - Concert (hall, theater)
    - Arena/stadium
    - Church
  - Theater sound
  - Sound for film and “multimedia”
  - Voice/telephony
  - SW application development
  - Other domains (medical, military, etc.)

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**Topics for Audio Engineers**

- ◆ (See collected syllabi)
- ◆ Musicianship
- ◆ Musical acoustics
- ◆ Electronics
- ◆ Computer technology
- ◆ Recording/production techniques



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**Topics: Musicianship**

- ◆ Basic musicianship
- ◆ Pitch and tuning
- ◆ Score reading
- ◆ Musical terms
- ◆ Instrumentation and orchestration
  - Instrument families
  - Electronic instruments
- ◆ Form and structure

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**Topics: Musical Acoustics**

- ◆ Properties of sound
  - Physical and perceptual features
- ◆ Envelopes and time evolution
  - Transients, steady-state phenomena
- ◆ Spectra and the frequency domain
  - Noise, formants
- ◆ Physical models of instrument families
- ◆ Room acoustics, resonance and standing waves
- ◆ Formats for spatial sound

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**Topics: Electronics**

- ◆ Basic circuits (Ohm, Kirchoff, RLC, magnetism, transformers, semiconductors)
- ◆ System-level configuration (block diagrams)
- ◆ Analog audio signal processing
  - Amplification and attenuation
  - Filters and EQ
  - Dynamic-range processing
  - Noise reduction
  - Other effects
- ◆ Recorder electronics
- ◆ Electromechanical echo and reverberation

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## Topics: Computer Technology

- ◆ Sampling and quantization of audio
- ◆ A/D and D/A conversion
- ◆ Digital audio signal processing
  - Filters
  - Dynamic-range processing
  - Compression and coding
  - Other effects
- ◆ Digital audio storage
- ◆ Computer-based DAW systems
- ◆ Software development for audio applications

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## Topics: Recording/Production Techniques

- ◆ Microphone types, characteristics
- ◆ Microphone selection and placement for amplification and recording
- ◆ Recording/mixing techniques
- ◆ Monitoring and fold-back
- ◆ Live recording, live sound
- ◆ Mastering and post-production
  - Surround sound, encoding, etc.
- ◆ Multimedia synchronization
- ◆ MIDI in the studio, on stage

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## Topics: Equipment

- ◆ Microphones
- ◆ Mixing consoles
- ◆ Recorders and noise reduction
- ◆ Processors
  - Equalizers
  - Dynamic-range
  - Delay, reverb
  - Voice processing
  - Others
- ◆ Metering
- ◆ DAWs



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## A bit (well, several bits) of history

- ◆ 1870s: Telephony, dynamic mic.
- ◆ 1880s: Sound reproduction (wax cylinders)
- ◆ 1920s: Tubes, 78 rpm shellac disks, Jazz, 12-tone music
- ◆ 1930s: Radio, TV, electrical (wire) recording, ribbon mic.
- ◆ 1940s: Multi-way speakers, *musique concrete*, *elektronische Musik*, condenser mic.
- ◆ 1950s: Stereophony (on LPs), tape recording, computer music, FM broadcast, 1-piece stereo HiFi "consoles"

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## More History

- ◆ 1960s: "HiFi" as a concept, analog synthesizers, multi-track recording, solid-state audio electronics, electret mic.
- ◆ 1970s: Stereo FM radio, Quad LPs, digital synthesizers, effects boxes (delay, phasor, flanger), 16/44 DACs, separate stereo "components," audio OpAmp ICs
- ◆ 1980s: CDs (14-bit ADC/DAC), PCM-on-VHS (helical scan), DASH/DAT, THX theater sound, pluriphony, walkman, digital effects (harmonizer), computer-based interactive/real-time systems

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## Recent History

- ◆ 1990s: True 16/44 conversion, digital consoles, HD-based recorders (DAWs), multi-effects units, 5.1-channel home theater, ISDN WAN, MP3/WWW, HDCD, CD-walkman, 20-bit DAT, ADAT/DA-88 recorders, MiniDisc
- ◆ 2000s: 24/96 format, all-SW DAW systems, AAC, WAN p2p SW, portable MP3/AAC players, DSD/SACD, DVD/A
- ◆ Next: ?

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### 1920s Recording Studio

- ◆ Single-horn direct-to-disk
- ◆ “Proximity-based mixing”



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### 1930s Recording Studio

- ◆ 1 or few microphones
- ◆ Direct-to-vinyl



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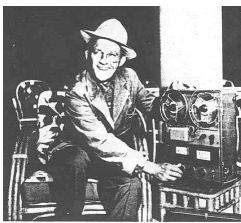
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### 1950s Recording Studio

- ◆ Multi-mic (per-section) direct-to-tape
- ◆ Mixer is just (rotary) faders



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### 1970s Recording Studio

- ◆ Multi-mic (close) to 8-24-track analog tape
- ◆ Complex mixing consoles: many inputs, flexible routing to auxes & busses
- ◆ Extended basic effects: several kinds of EQ, dynamic range processing, artificial reverb
- ◆ Analog synthesizers
- ◆ Separate mix and reverb
- ◆ Mastering to LP

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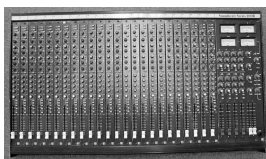
### 1970s Recording Studio



Analog mixing consoles



Master and mix-down recorders



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### 1980s Recording Studio

- ◆ More (A & D) effects processors
- ◆ Integration of MIDI and timecode
- ◆ Console (fader) automation
- ◆ Mastering to DAT
- ◆ Mastering to CD
- ◆ Project studios

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## 1990s Recording Studio

- ◆ Digital multi-track recorders (ADAT, DA-88)
- ◆ SW-based HD recorders: ProTools, Cubase, Logic, DigitalPerformer
- ◆ More console automation (mutes, etc.)
- ◆ DAW evolve from SW / HD
- ◆ All-digital consoles

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## Example Current Control Room



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## Modern (?) Recording Studio

- ◆ DAW-based
  - Analog only in "vintage" studios
- ◆ Score in sequencer
- ◆ Use of samples, drum loops
- ◆ Integrated with mastering & distribution (WAN streaming content server)

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## Example Current Project Studio

- ◆ Controllers, retro gear
- ◆ Analog & digital control and processing
- ◆ Computer / DAW

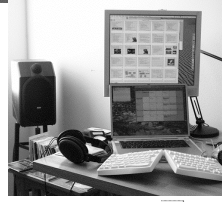


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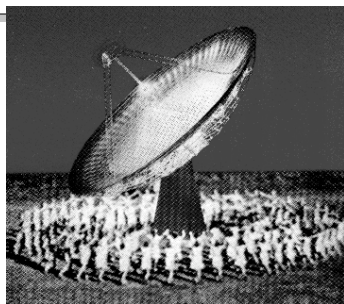
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## What's in a Recording Studio?

- ◆ The studio signal chain
  - **Sources:** microphones, direct boxes, electrical inputs, samples
  - **Interconnection:** cabling, patch bays, analog and digital signal distribution
  - **Mixing, processing:** mixing console, effects processors (EQ, dynamic range, etc.)
  - **Storage:** multi-channel recorders (analog tape, digital tape, hard disk)
  - **Monitoring:** speakers, headphones

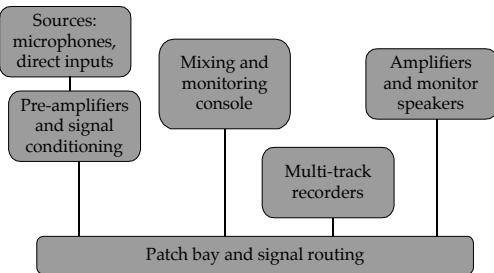
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## Basic Studio Configuration



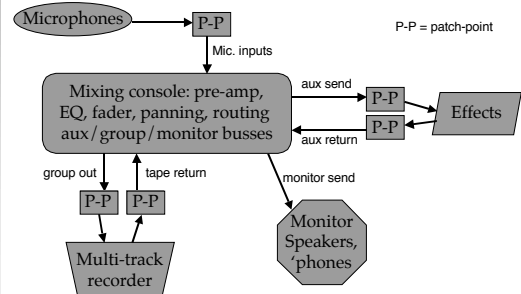
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## Signal Chain Block Diagram



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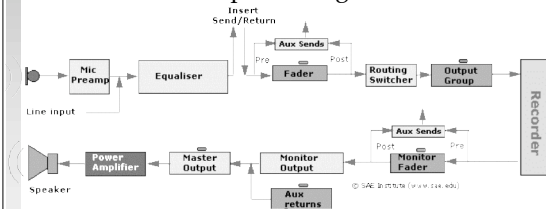
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## The Recording Signal Chain

- ◆ Input, EQ, level, routing, recorder
- ◆ Recorder, aux processing, monitor mix



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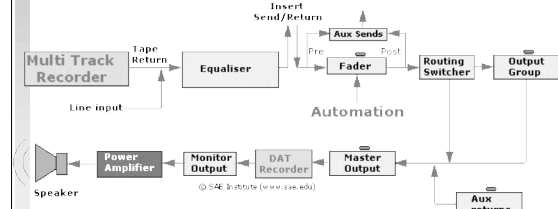
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## The Mixing Signal Chain

- ◆ Master recorder, processing, routing, groups, mix-down recorder



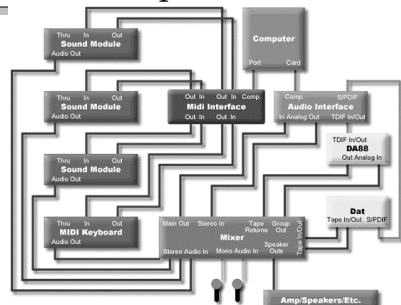
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## DAW / Computer-based Studio



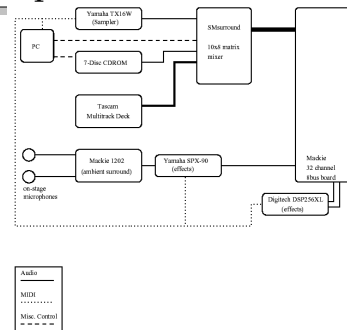
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## Example: Theater Sound Input

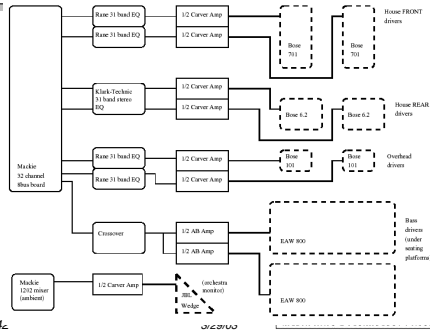


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### Example: Theater Sound Output



## What's the Process?

- ◆ The “standard” (1970s) recording/mixing/mastering process
  - Recording basic tracks
  - Over-dubs
  - Mixing
  - Mastering
- ◆ Exceptions
  - Live sound
  - Theater sound

## The Process in Detail

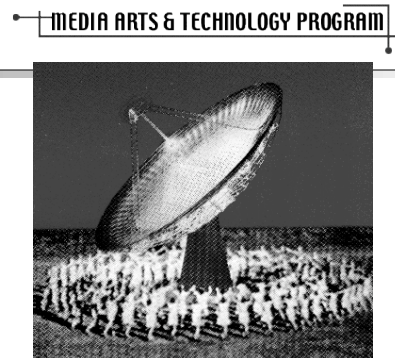
- ◆ **Basic tracks**
  - Isolation
  - Clean base tracks
  - “Scratch” vocals and soli
- ◆ **Overdubs**
  - Clean v&s (possibly for mute automation)
- ◆ **Mix-down**
  - Stereo or surround balance and spatial image
  - Possibly multi-format at first pass
- ◆ **Mastering**
  - Compression, EQ for distribution
  - “Album continuity”

## What's the Current Process?

- ◆ Single-person project studios
- ◆ Live-to-streaming sound
- ◆ Sample-based production
- ◆ Recording to MP4 models
- ◆ MIDI/sample-based distribution
- ◆ Many other variations

## What's Next?

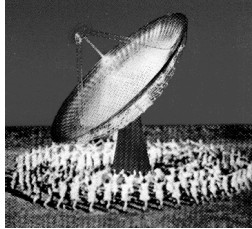
- ◆ Studio design and infrastructure
- ◆ Components in the signal chain
  - Sources
  - Mixing
  - Effects and DSP
- ◆ Mastering and encoding/distribution processes
- ◆ DAWs and SW solutions
- ◆ Readings



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**MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering**



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**Lecture 2 Outline**

- ◆ Studios and control rooms
  - Studio and theater architecture and layout
  - Architectural acoustics for music spaces
- ◆ Electronics 101
- ◆ Power and wiring, noise, lighting
  - Power, grounds, and audiophile analog equipment
  - Mixing analog, digital, and high-power equipment
- ◆ Interconnection
  - Cabling and A/D interconnection
  - Patch bays and signal routing
- ◆ Other infrastructure

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**Readings**

- ◆ **Studios and Control Rooms**
  - Studio Plans, Saecollege.de
  - Representative Control Rooms, *Master Handbook of Acoustics*
  - Modern Control Room Design and Construction
  - Speed Tuning a Room

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**Readings (cont'd)**

- ◆ **Power and Wiring**
  - Introduction to Audio Wiring
  - Introduction to Power and Lights
  - Ground Loop Problems and How to Get Rid of Them
  - A Clean Audio Installation Guide
  - Getting a Perspective on Noise
  - Digital Audio Formats and Cables
  - Common Pro Audio Plugs and Connectors,
  - Interconnection of Balanced and Unbalanced Equipment

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**Studios and Control Rooms**

- ◆ Studio and theater architecture and layout
  - History and context
  - Modern recording studios
  - Modern concert halls and performance spaces
  - Modern theaters
- ◆ Architectural acoustics for music spaces
  - Basic acoustics
  - Live and dead rooms
  - Reflection, absorption, and diffusion
- ◆ Examples (see below)

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**Basics of Recording Studio Design**

- ◆ Changes over history
  - Concert halls and early recording
  - Dedicated studios and control rooms
- ◆ Modern multi-room recording suites
  - Main studio
  - Vocal booth
  - Drum booth
  - Control room
  - Equipment room(s)

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## Recording Studio Acoustics

- ◆ Basic categories
  - Live sound
  - Dead sound
  - Live-end/dead-end rooms
  - Live-top/dead-bottom rooms
- ◆ Configurable rooms
- ◆ Isolation and visual contact
- ◆ Cabling and proximity



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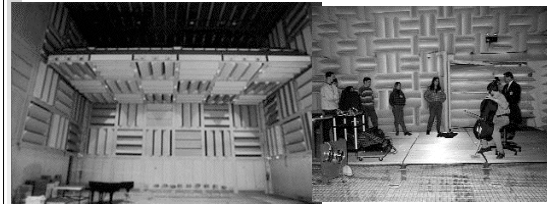
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## Room Treatment

- ◆ Live (end, top)
- ◆ Dead (anechoic)
- ◆ Configurable (panels, curtains, etc.)



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## Room Requirements

- ◆ Main studio
  - Size, live or live/dead acoustics (configurable), line of sight to CR, easy cabling, fold-back monitoring
- ◆ Vocals/isolation booth
  - Small, very dead, very isolated, I-o-s, few cables, headphone fold-back
- ◆ Drum booth
  - Medium-size, moderately isolated, more cables
- ◆ Control room
  - Larger, good listening acoustics (imaging, symmetry), isolation from studios and equipment

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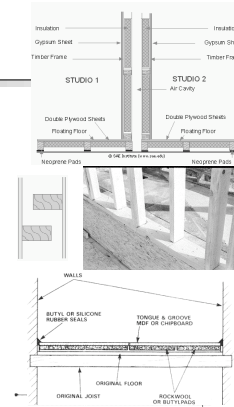
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## Construction for Isolation

- ◆ Minimize acoustical transmission of energy through walls
- ◆ Floating floors
- ◆ Separate walls via staggered studs
- ◆ Construct a suite of several isolated floating rooms



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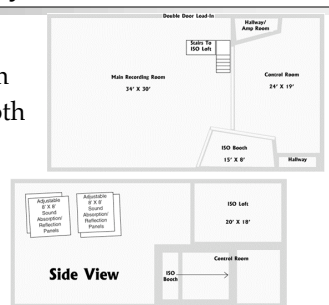
ORIGINAL JOIST

ROCKWOOL OR BUTYL PADS

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### Example Layouts: Small Suite

- ◆ Studio
- ◆ Control room
- ◆ Isolation booth
- ◆ Equipment



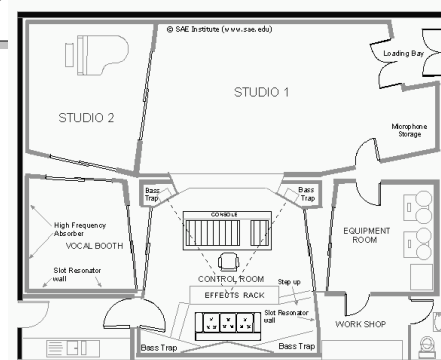
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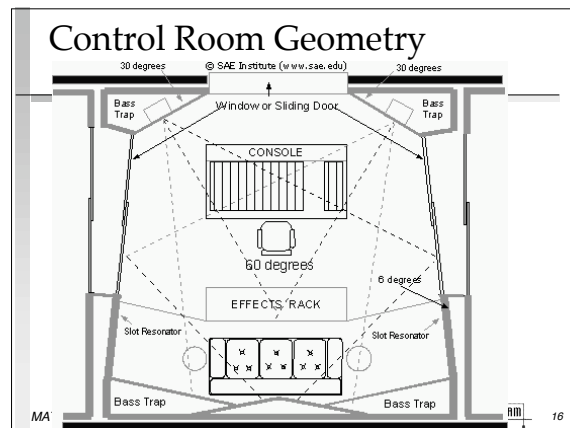
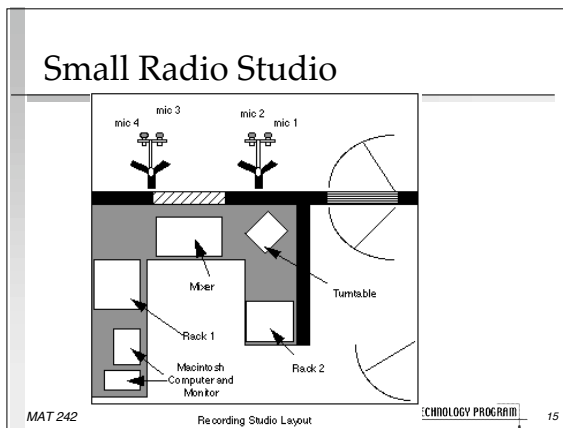
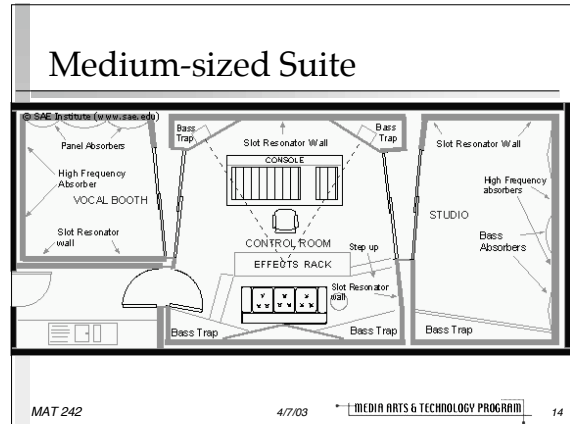
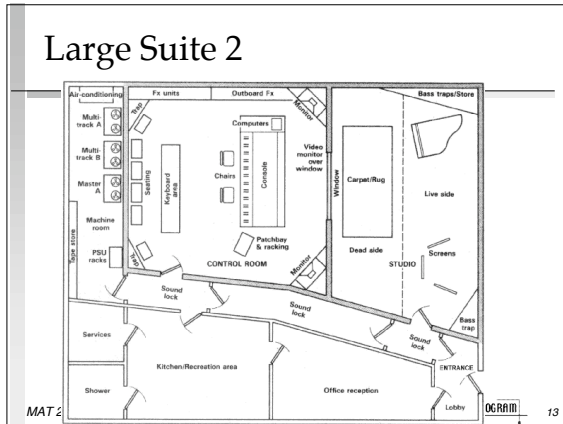
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## Larger Suite



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### What's there?

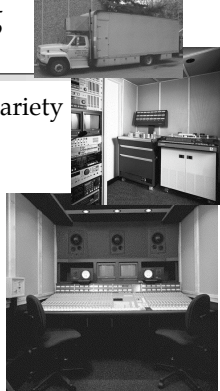
- ◆ In order of importance:
  - Mixer
  - Monitors
  - Processors
  - Routing
  - Recorder control
  - Recorders
- ◆ Considerations
  - Size
  - Noise
  - Cabling
  - Room treatment

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## Mobile Recording Trucks



◆ Large variety



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## All-in-one Project Rooms

- ◆ Instruments
- ◆ Live mics (?)
- ◆ Silent electronics and recorders
- ◆ Treatment as dead studio (?)
- ◆ Typically (though not always) DAW-based
- ◆ Popular, not just with the budget-conscious

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## Challenges to Design

- ◆ Isolation and intimacy / communication (between the musicians and with the engineer/producer)
- ◆ Range of size and loudness of instruments
- ◆ Size of ensembles
- ◆ Size of equipment
- ◆ Location and peripheral facilities
- ◆ ...much more to discuss here

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## Evaluation of CREATE's Main Suite

- ◆ Studio
  - Small, well-isolated, good for sampling single instruments, good visibility, low noise (sans AC)
- ◆ Control Room
  - Good size (too small for 8 B&Ws), asymmetrical, synth/control as well, low noise (sans AC)
- ◆ Treatment
  - Moderate boom, some flutter, needs diffusors and EQ
- ◆ Cabling/routing
  - No fixed panel in studio, snakes to ProTools, decent (noisy, fragile) patch bay, some grounding and digital RFI issues
- ◆ Electronics
  - Good mic preamps and compressor, few processors (DAW-based), (almost) all balanced routing

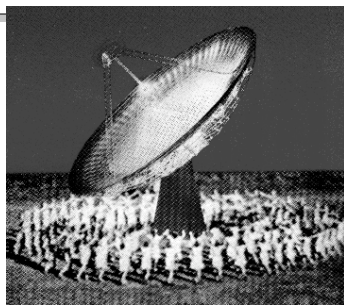
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## Electronics (from MAT 242-AE)

- ◆ Voltage and Current
  - Pressure and flow
- ◆ Batteries and Resistors
  - Sources and sinks
- ◆ Capacitors and Inductors
  - Frequency-dependent resistance = impedance
- ◆ Transformers
  - Conserve power, not R or I
- ◆ Circuits and systems

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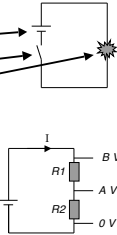
## Simple Circuits as Schematics

### ◆ Flashlight

- power source
- switch
- load

### ◆ Voltage Divider

- Water valve analogy



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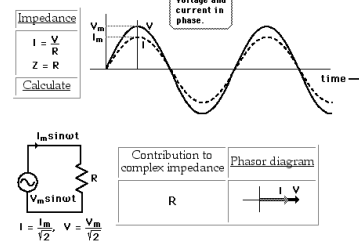
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## Resistors

### ◆ $I \propto V$

### Resistor AC Response



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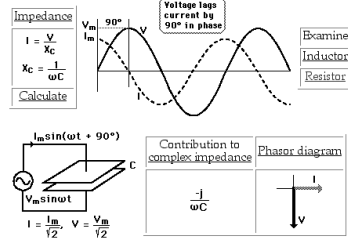
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## Capacitors

### ◆ $I \propto \frac{dV}{dt}$

### Capacitor AC Response



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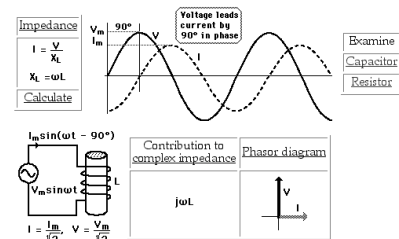
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## Inductors

### ◆ $I \propto -\frac{dV}{dt}$

### Inductor AC Response



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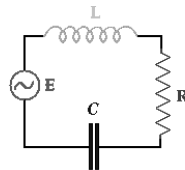
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## RC, RL, and RLC Circuits

- ◆ <http://webphysics.ph.msstate.edu/jc/library/21-5/CircuitiE.html>
- ◆ Source is sine
- ◆  $V_R$  and  $I$  depend on its frequency



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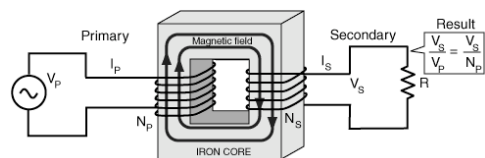
## Transformers

From Faraday's Law:  $\frac{V_S}{V_P} = \frac{N_S}{N_P}$

For ideal transformer: The voltage ratio is equal to the turns ratio, and power in equals power out.

From conservation of energy:  $P_P = V_P I_P = V_S I_S = P_S$

Show



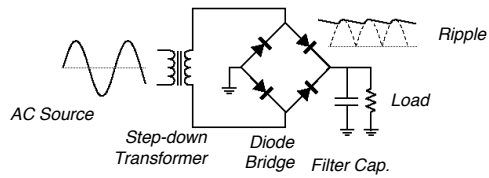
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## Power Supplies



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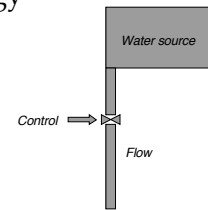
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## Tubes and Transistors

### ♦ The valve analogy

- Reservoir
- Control
- Output



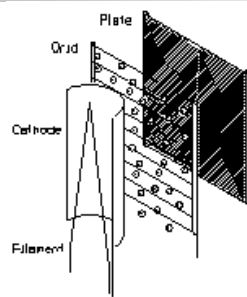
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## Tube (simplified)



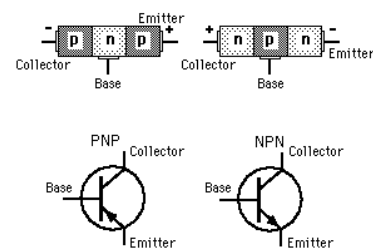
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## Transistors



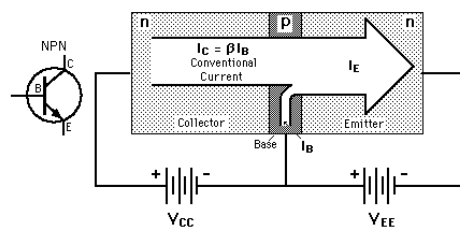
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## Transistor current control



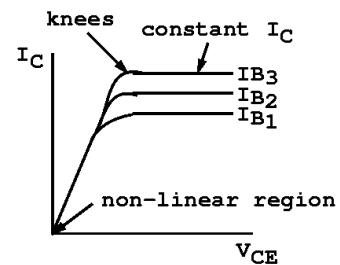
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## Transistor Transfer function



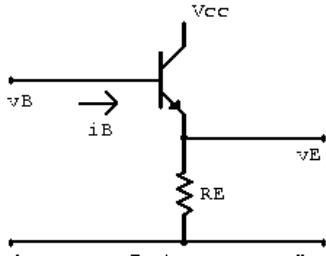
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### A Simple CE Amplifier



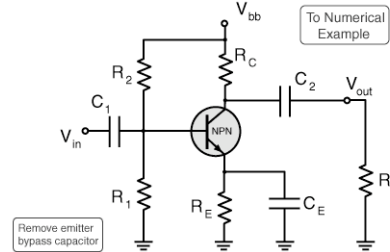
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### A Real CC Amplifier



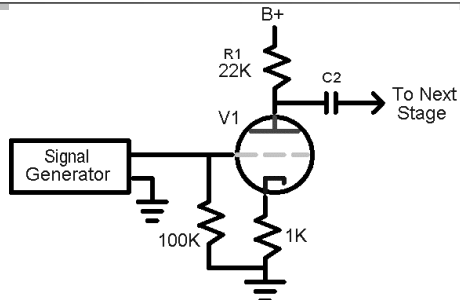
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### A Basic Tube Amplifier



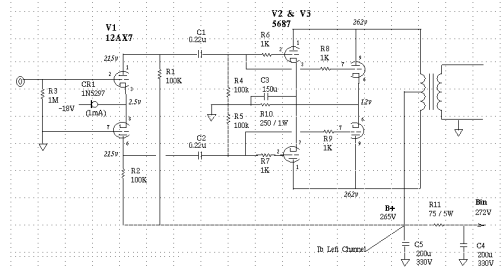
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### Push-Pull Tube Amplifier



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## Analog Design

- ◆ Amplifiers
  - I/O Z (source/driver impedance)
    - Desired: high in Z, low out Z
  - Freq/Phase responses
- ◆ Buffers
- ◆ Filters
- ◆ Power supplies

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## Practical Designs

- ◆ Single-stage amplifier
- ◆ Differential designs
- ◆ Multi-stage designs
- ◆ Balanced (differential) vs. Unbalanced (single-ended) systems

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## Balanced vs. Single-ended

- ◆ SE = single voltage relative to ground
- ◆ Balanced = +, -, and shield (reference)
- ◆ Cabling: SE is more susceptible to RFI
- ◆ Cost: Balanced is twice the electronics and wiring, but good "CMR"
- ◆ In studios: balanced is always preferred

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## Connectors

- ◆ RCA/phono
- ◆ XLR/Canon
- ◆ Spade, Banana



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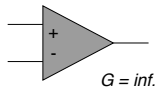
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## Operational Amplifiers

- ◆ Allow different input and output impedance
- ◆ Isolate up-stream and down-stream components
- ◆ Gain and feedback
- ◆ Design issues
- ◆ Typical circuits have many stages



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## System Architecture

- ◆ Source, Processing, Transducers
- ◆ Components
  - Sources
  - Pre-pre amplifiers
  - Switchers
  - Volume controls
  - Equalizers
  - Preamplifiers
  - Crossovers
  - Power stages
  - Speakers
  - Headphones

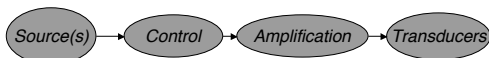
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## Configuration Examples



- ◆ Hybrid/Composite components
  - All-in-one systems
  - Receivers
  - Integrated amplifiers
  - Digital processors
  - Active speakers

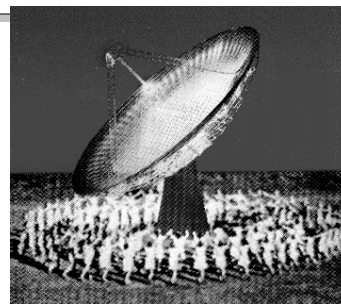
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## Power and Wiring, Noise, Lighting

- ◆ Power, grounds, and audiophile analog equipment
  - Basics of power (see above)
  - Grounding and ground problems
- ◆ Mixing analog, digital, and high-power equipment
  - Requirements of each
    - Audiophile electronics (no ripple, dynamic load)
    - Digital audio electronics (add high-freq noise)
    - Power (lighting, sound reinforcement) (high reactive load)
- ◆ Kinds of power conditioning
  - Surge suppression
  - AC filters
  - AC reconstitution
  - Uninterruptable power

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## Theater and concert power

- ◆ Issues
  - Portability (if needed)
  - High power (lights, sound reinforcement)
  - Environmental (size, acoustical and RF noise, efficiency)
  - Power quality
    - HF (lighting switching) noise
    - Dynamic reactive loads

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## Basics of Power

- ◆ (Customer speaking) It's simple: just supply ultra-pure ( $< 0.5\%$  THD)  $60 (\pm 0.1\%)$  Hz sine waves at  $110 (\pm 0.2\%)$  V peak-to-peak at several 10s (or 100s) of kW into rapidly changing reactive loads.
- ◆ (EE speaking) Wait a minute, that's *really* hard!
- ◆ Requirements of purity, reactive load, dynamic load, high power make it quite a task
- ◆ Once you look at the requirements of stage power, you'll think studio power is easy!

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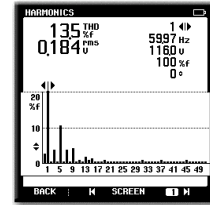
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## Power in the Real world

- ◆ 14% THD
- ◆ Not 60 Hz inst. Freq.
- ◆ Not  $0 \Omega$  internal resistance
- ◆ Poor supply for reactive loads
- ◆ Surges, brown-outs, etc. (esp. in cities)



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## Power Isolation

- ◆ Make the most independent power supplies possible for audio, lighting, and amplification
- ◆ Isolate grounds as well as feeds
- ◆ Handle rapidly changing loads and high frequency noise
- ◆ It's easy to do, if you have loads of \$, a large space, and can stand the noise
- ◆ Complete isolated signal recreation = a set of separate 60 Hz sine oscillators and 10 kW LF amplifiers



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## Power Isolation for the Masses

- ◆ Ground de-coupling
- ◆ Transformer isolation
- ◆ Ganged storage (capacitor racks)
- ◆ Multi-phase down-step transformation
- ◆ Other techniques found in theaters (lighting + audio = big problem)

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## Power Conditioning

- ◆ Provide local (e.g., to a room) isolation and noise filtering for several kW of (non-reactive, 2-phase) power.
- ◆ Easier (though still expensive) to do well
- ◆ Larger market (audiophiles, home theater, computer farms)
- ◆ May involve signal re-creation
- ◆ May involve surge suppression

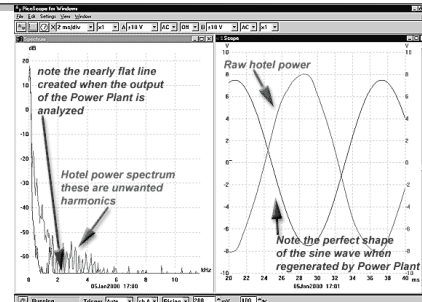
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## Spectral Power Conditioning



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## Standard Power Conditioners

- ◆ AC filtering
- ◆ EMI/RFI rejection
- ◆ DC suppression
- ◆ Multi-outlet isolation
  - Source components
  - Amplifiers
  - Digital components
- ◆ Storage of several 10kJ ( $\geq 1F$  capacitance)
- ◆ Surge suppression (rapid trigger)



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## Related (but different) Issues

- ◆ Surge suppression (must be very fast)
- ◆ Battery back-up (UPS)
- ◆ Load balancing (inter-phase, time-averaged)
- ◆ Remote (diesel, solar) generation
- ◆ Large-scale battery-based systems
- ◆ Battery-based (DC-only) components
  - For portability
  - For supply purity
- ◆ Grounding and ground loops (see below)

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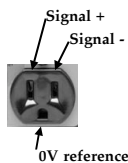
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## Grounding and Ground Loops

- ◆ Standard AC power = 2 differential signals ( $180^\circ$  out of phase) relative to ground
- ◆ Ground defined as 0 V
- ◆ See diagram on the right (look familiar?)
- ◆ The problem: "ground" or "earth" is relative, not absolute



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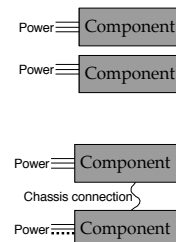
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## Ground Loops

- ◆ **Good**
  - Components separately grounded
  - Good ( $0\Omega$  earth) ground connections
- ◆ **Baaaad**
  - Multiple ground loops
  - Several different resistances to earth



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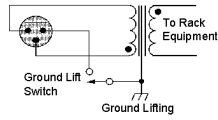
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## Ground Loops in Balanced Signals

- ◆ See above, but with balanced signal connections
- ◆ Balanced signal grounds + chassis grounds + earth connections = ground-loop-hell
- ◆ Solutions
  - Ground lift switches (in cables, DIs, mixers, etc.)
  - Insulated (plastic) relay racks or mounts
  - Good power isolation (expensive conditioners)
  - No unbalanced signals (ever! anywhere!)



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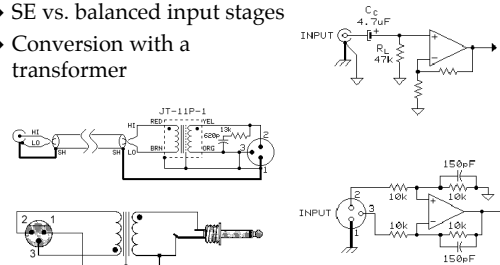
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## Balanced and Unbalanced Signals

- ◆ SE vs. balanced input stages
- ◆ Conversion with a transformer



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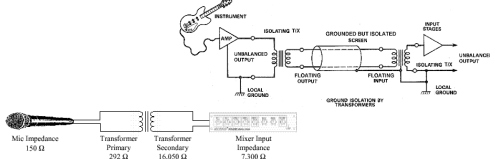
Balanced to Unbalanced Connection

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## A DI Box in Action

- ◆ Dual isolation transformers
- ◆ Cable screen connected at destination (may be switched altogether)
- ◆ Different: transformer for impedance matching



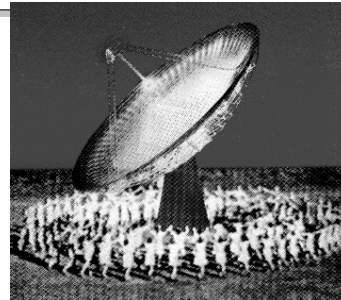
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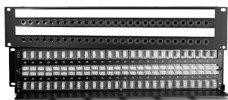
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## Interconnection

- ◆ Cabling and A/D interconnection
  - Interconnection for audiophile analog gear
    - Goals
    - Trade-offs
  - Digital interconnection and routing
- ◆ Patch bays and routing
  - Analog patch bays
  - Digital routing
  - MIDI routing
  - Networks in studios and performance spaces



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## Issues in Interconnects

- ◆ See MAT 242-AE
  - Conductors, geometry, termination
  - Multi-wiring
  - Shielding and isolation
- ◆ Special issues in studios
  - Low-level signals (< 10 mV)
  - Relatively long distances (> 20 ft.)
  - Mix of levels and of analog/digital signals
  - Multiplicity of signals (32 mics, 24 channels, 32 auxes, 16 busses, etc.)

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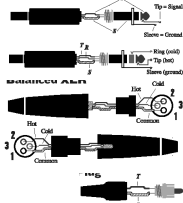
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## Interconnects and Termination

### ◆ Kinds of plugs

- TS (tip-sleeve): mono, unbalanced; used for unbal. mics, guitars (1/8" as well)
- TRS (tip-ring-sleeve): mono balanced, or stereo unbalanced (as in 1/4" headphone plug); used for balanced line-level signals (1/8" as well)
- XLR or Canon: mono balanced; used for balanced mic. and line-level signals
- RCA or phono: mono, unbalanced; used for consumer audio and S/P-DIF digital signals
- Others: SpeakOn, BNC, 3/16"



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## Power and Signal Levels

### ◆ Mic. Level

- 2-40 mV (into 100 kΩ)
- Balanced
- XLR termination

### ◆ Line level

- 100 mV - 4V -- stds. at -10 and +4 dB(V)
- Balanced or unbalanced
- XLR, TRS, or TS termination (or even RCA)

### ◆ Power-level

- 20 - 70V (1-20 A)
- Unbalanced
- Spades, banana, SpeakOn, or other termination

### ◆ 48V "phantom" power

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## Signal Level Standards

### ◆ Flavors of dB and power levels

	Sensitivity (typical, for 0 dB FS)		Clip Level (1% THD)	Impedance (actual)
	min. gain	max. gain		
MIC	-10 dBu	-53 dBu	-12 dBu (195 mV rms)	2k ohm active-balanced
LINE	+24 dBu	+7 dBu	+24 dBu (12.3 V rms)	65k ohm active balanced
DI	+8 dBu	-9 dBu	+9 dBu (2.2 V rms)	10k ohm unbalanced
TAPE	+8 dBu	-9 dBu	+9 dBu (2.2 V rms)	110k ohm unbalanced

Summary of typical signal level types.

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## Studio Interconnection

### ◆ Studio-to-control-room

- Mics to control room, headphones for fold-back
- Wall panels + snakes
- Fixed-to-patch-bay

### ◆ Mixer I/O and routing

- Central patch bay
  - Sources, mixer, auxes, recorder, group outputs
- Specialized patch bays for different levels (mics, auxes, inserts, tape returns)
- Digital and MIDI patching
  - AES/EBU or optical patching
  - Digital routers

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## Patch Bays

### ◆ Front panel

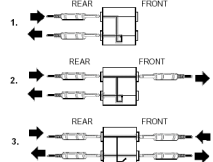
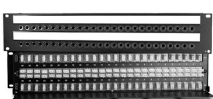
- TS, TRS, or MINI (3/16)

### ◆ Rear

- Wired, TRS, Special (e.g., ADAT)

### ◆ Wiring

- Normal wiring: top row connected to next row unless a plug is inserted



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## Snakes

### ◆ Between a patch bay and multichannel equipment

### ◆ Between rooms in a suite

### ◆ Between stage and mixer

### ◆ E.g.,

- TRS-XLR for equipment patching
- TRS-termination-box for studio routing
- ADAT-XLR for patching



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## Snakes, cont'd

- ◆ Termination boxes
  - Studio: mic. input, 'phone output
  - Stage: mic. input, speaker output
  - Stage: output-only
  - Other combinations and custom snakes and boxes



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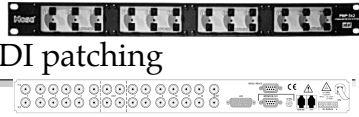
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## Digital/MIDI patching

- ◆ Digital routing and patching
  - Sample stream routing
  - Format converters
  - Word clock generators
  - SMPTE repeaters
- ◆ MIDI routers
  - Multi I/O and routing
  - Channel reassignment



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## Networking in Studios

- ◆ Analog audio
  - Distribution amplifiers
  - Signal routers in large facilities
- ◆ Ethernet
  - OSC, AES/EBU-over-TCP/IP
- ◆ FireWire/LightPipe
  - Extenders available
  - Yamaha mLAN-on-FireWire "on its way"

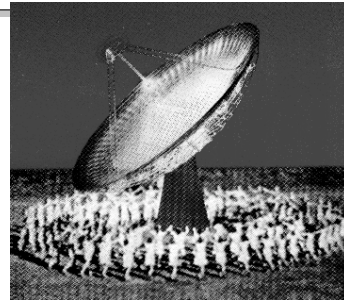
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## What's Next?

- ◆ Source Components and the input chain
  - Microphones, pick-ups, and sources
    - Types
    - Applications
    - Special-purpose
  - Pre-amplifiers, input, and routing
  - Consoles

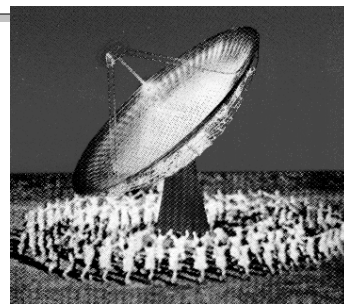
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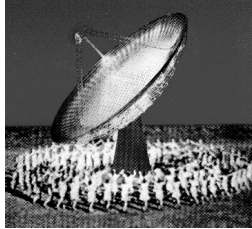
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**MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering**



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Lecture 3 Outline

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- ◆ Microphones, pick-ups, and sources
  - Types of microphone capsules
  - Directional patterns
  - Microphone selection and placement
  - Special-purpose microphones
- ◆ Pre-amplifiers and input routing
  - Processing low-level signals
  - Input chain management

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Readings

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- ◆ **Microphones and Pre-amps**
  - Introduction to Microphones, Capsule Technology and Types
  - Cardioid Carrying Member (Proximity effects)
  - Microphone "Undressed,"
  - Microphones and Wind
  - Earthworks Measures Microphones
  - The Boston PRE Party
  - Earthworks ZDT Preamp Data Sheet
  - Earthworks Omni Applications Guide
  - A Direct Box Can Be Indispensable
  - Direct Feeds, Bellari ADB3b Direct Box Brochure

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Other Materials

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- ◆ Microphone manufacturer web sites
- ◆ Microphone reviews
- ◆ Measurements at CREATE
- ◆ AES literature
- ◆ Your own R&D

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Microphones as Transducers

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- ◆ Translate air-pressure variations (pressure gradient) into an AC voltage
- ◆ Characteristics
  - Spatial average (size of diaphragm)
  - Frequency response
  - Transient response
  - Directionality (frequency dependent)
  - Self-noise, THD, etc.

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Typical Characteristics

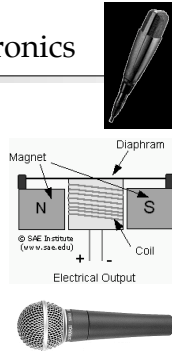
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- ◆ Input: 6 dBA - 130 dBA
- ◆ Max level: (for 1% THD @ 1 kHz): ~120 dB
- ◆ Output: ~ 10 mV
- ◆ Impedance: ~500Ω
- ◆ SNR: ~70 dB
- ◆ Dynamic Range: >= 100 dB
- ◆ Directionality: variable

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## Basic Microphone Electronics

- ◆ The dynamic microphone
  - Move a coil of wire in a magnetic field -- generates a current in the wire
    - Works like a generator
    - The opposite of a loudspeaker
- ◆ Features
  - Simple/inexpensive
  - Robust
  - Flexible
  - Freq. and transient resp. issues (weight of vibrating components)
  - Relatively high output (~50 mV)



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## OK, but how is it mounted?

- ◆ Simplest solution: in a wall
  - 180° unidirectional
- ◆ Or in free air
  - Bidirectional
- ◆ Or at the end of a long tube
  - Narrow cardioid
- ◆ Or a tube with regular slits
  - Transmission-line shotgun
- ◆ Or...

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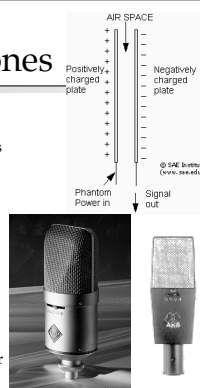
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## Condenser Microphones

- ◆ Flexible capacitor
  - Change in distance between elements (plates) changes the capacitance
- ◆ Features
  - Low vibrating mass
  - Complicated/expensive
  - Inherently bidirectional
  - Common
  - Low output (~10 mV)
  - Require power (battery, phantom) for charge and amplification



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## Diaphragms

- ◆ Thickness
  - ~4μ (0.00016")
- ◆ Material
  - Metal
  - Plastic with "applied" metal
- ◆ Small vs. large
  - See DPS reading
- ◆ One vs Many

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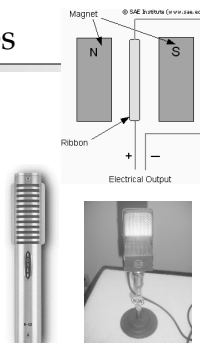
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## Ribbon Microphones

- ◆ Conductive ribbon in a magnetic field (like the generator principle)
- ◆ Features
  - Very low vibrating mass
  - Fragile
  - Bidirectional
  - Simple
  - Low output
  - "Sweet"



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## Others

- ◆ Electret
  - Variation on the condenser
  - Uses permanent charge (so low voltage requirement)
  - Cheap, tiny, ubiquitous
- ◆ Piezo-mechanical elements
  - Flexion vs. movement (quartz)
  - Also reversible (piezo tweeters)
  - Very high frequency response
- ◆ Others: way alternative
  - Laser-based
  - Surface
  - Plasma (flame, spark)

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## Pick-ups

- ◆ Guitar pick-ups
  - String as exciter
  - Pick-up is stationary coil and magnet
- ◆ Contact microphones
  - Surface as element
  - May be dynamic or piezo-electric
- ◆ Many other technologies

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## Frequency Response Issues

- ◆ Proximity Effect
  - Low-frequency “boom” at close range
  - Why so many mics have HP filters
- ◆ Low-mid boost
  - “Warmth”
- ◆ Mid/hi boost
  - Sharpness
- ◆ Hi-freq boost
  - Brightness

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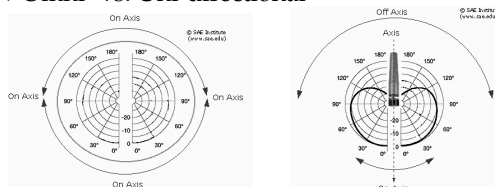
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## Microphone Directionality

- ◆ Direction- and frequency-dependent sensitivity
- ◆ Omni- vs. Uni-directional



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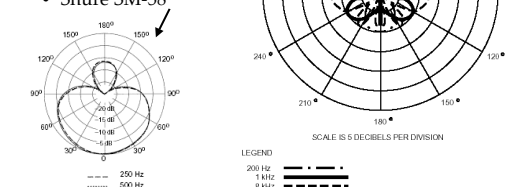
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## Frequency-Dependency

- ◆ Example
  - AT shotgun microphone
  - Shure SM-58



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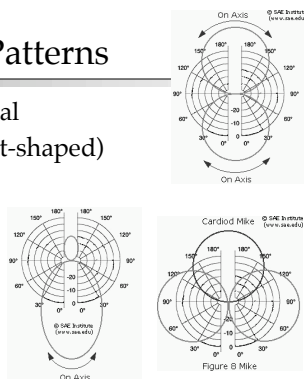
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## Directional Patterns

- ◆ Omnidirectional
- ◆ Cardioid (heart-shaped)
- ◆ Ultra-cardioid
- ◆ Figure-8
- ◆ Others



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## Shot-gun Microphones

- ◆ Acoustical filter (interference tube) for very tight directional pattern
  - Side-rejection is paramount
  - Handling noise and other problems
- ◆ Parabolic lens
  - Directionality at a distance



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## Multi-Capsule Microphones

- ◆ Dual-capsule designs
  - M/S (cardioid + figure-8)
  - OCT (cardioid + omni)
- ◆ Multi-microphone enclosures
  - E.g., Soundfield (tetrahedral)
  - Microphone arrays



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## Microphone Options

- ◆ Attenuator (pad)
- ◆ Hi-pass filter (pop, proximity effect)
- ◆ Wind screen/pop filter (reading)
- ◆ Built-in pre-amplifier
  - Battery or phantom powered
- ◆ Mounting hardware, shock mounts
- ◆ Cable connection
- ◆ ...more

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## Popular Recording Microphones

- ◆ Shure
  - SM57, SM58
- ◆ AKG
  - C414, D112, C4500
- ◆ Sennheiser
  - 421
- ◆ Neuman
  - U47, KM84, U87
- ◆ All designs still popular
- ◆ See readings and references

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## Microphone Selection

- ◆ Criteria (see readings)
  - dB range (how soft or loud?)
  - Frequency response (mid hump? Brightness?)
  - Transient response
  - Proximity effect
  - Handling noise
  - Built-in pre-amp (long cables)
  - Wireless

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## Table of Popular Microphones

Manufacturer	Model	Pattern	Studio	Freq. Resp. (Hz)	Pattern	Sens. (mV/Pa)	Z (ohms)	Noise (dB)	Max SPL (dB)	PS	Notes
AKG	C414/435	C/RET	A/B	20-20K	O.C./B.R.	12.5	180	14	134 (134)	y	HPF, pad
AKG	C414/438	C/RET	C	20-20K	O.C./B.R.	n/a	n/a	n/a	n/a	y	HPF, pad
AKG	C414/439	C/RET	A/B/C	20-20K	C	7	120	14	134 (134)	y	HPF, pad, HPF
AKG	D112	D/MC	A/B	30-17K	C	2.2	250	n/a	128	n	back drum / LP apps.
AKG	D112	D/MC	A/B	20-17K	C	1.8	210	n/a	n/a	n	back drums
AKG	D2120	D/MC	C	40-20K	C	2.5	600	20	127 (126)	y	HPF, press boost
Audio Technica	AT4033	C/RET	A/B/C	30-20K	C	n/a	100	17	140 (139)	y	HPF, pad
Countryman	8000-BC	C/E	A/B	50-20K	C	n/a	600	29	130	y	immature discolor
EV	BE20	D/MC	A/B/C	45-18K	C	n/a	250	n/a	n/a	n	HPF
Neumann	KM84	C/RET	C	40-20K	C	10	200/50	17	129 (128)	y	HPF, pad
Neumann	KM140	C/RET	A/B	20-20K	C	15	50	36	138 (137)	y	updated KM84
Neumann	U87	C/RET	A/B	20-20K	O.C./B.R./C.R.	8	100	14	140 (139)	y	low noise
Realistic	REM	C/E	A	20-18K	hemispherical	n/a	600	n/a	135	y	secondary mic
Schoeps	CMC 4U	C/RET	B	-	O.C./B	-	-	-	-	y	-
Schoeps	CMC 4U	C/RET	A	-	O.C.	-	-	-	-	y	-
Sennheiser	MD221	D/MC	A/B/C	30-17K	C	2	200	n/a	n/a	n	1 pin HPF
Sennheiser	MD221	D/MC	B	40-18K	C	1.6	350	n/a	n/a	n	new mic
Sennheiser	MD222	C/RET	B	40-20K	C	25	150	12	134 (132)	y	HPF, pad
Shure	SM57	D/MC	A/B	40-15K	C	1.7	150	n/a	n/a	n	-
Shure	SM58	D/MC	C	40-15K	C	1.7	150	n/a	n/a	n	-
Shure	SM57	C/E	B	20-20K	C	6.3	150	36	135 (132)	y	HPF, pad, 2 pins HPF
Shure	SM58	C/E	A/B	20-20K	C	1.3	150	n/a	133	y	immature discolor
Yamaha	MG204	D/MC	A/B	20-18K	C	n/a	250	n/a	n/a	n	similar to SM57

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## New-comers

- ◆ BLUE
- ◆ Rode
- ◆ Earthworks
- ◆ Royer
- ◆ ATC
- ◆ Specialty shops
  - Vintage restorations
  - Vintage copies

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## Special Applications

- ◆ Instrument-specific
  - Kick drum -- loud, good transients
  - Vocal -- low proximity, "warm"
- ◆ High-frequency
  - Up to ~50 kHz
- ◆ Low-level
  - Down to ~6 dBA

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## Measuring Microphones

- ◆ Measuring speakers
- ◆ Measuring rooms
- ◆ Src/filter/listener model
- ◆ Tuned systems for tuning
- ◆ "Instrumentation" microphones
- ◆ See reading from Earthworks

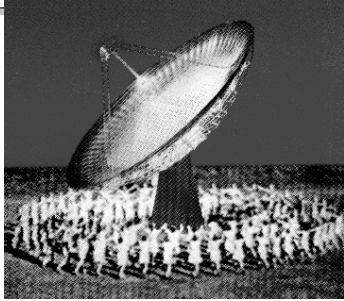
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## Microphone Pre-amplifiers

- ◆ Take a low-level signal (<10 mV) and amplify it up to ~1 V
- ◆ Take a medium-impedance source and isolate it from the mixer's input stage
- ◆ Place the first stage close to the source
- ◆ Be noise- and hum-free
- ◆ Many designs in use
- ◆ May be part of a "channel strip"

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## Mic Pre-amps

- ◆ Basics:
  - Level
  - HPF
  - Pad
  - Phantom power



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## Input Options

- ◆ Channel strip
  - Mic Pre +
    - Filter/EQ
    - Compressor/limiter/gate
    - Routing
    - A/D convertor
- ◆ Vocal Processor
  - As above + de-esser
- ◆ Instrument input
  - Line-level unbalanced input
  - Guitar effects

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## Pre-amp Designs

- ◆ See MAT 242-AE
- ◆ Design Alternatives
  - Simple vs complex
  - Tube vs transistor
  - Fixed vs variable
  - Transformers vs none
  - Capacitors vs none
  - Infra/ultra response
  - EIN (1/f)
- ◆ Prices: \$1k - \$2k / channel
  - ~same as good mics

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## Direct Boxes

- ◆ SE/balanced conversion
- ◆ Ground decoupling
- ◆ Level matching
- ◆ Passive vs active
- ◆ Guitar amp (mix with mic)
- ◆ Why?
  - Crosstalk
  - Capture amp snd (+/-)
  - Record raw effects
- ◆ Many options

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## Input Routing

- ◆ Low-level patching
  - Avoid it!
- ◆ Distributed pre-amps
  - Common
- ◆ DI boxes
  - ..if the guitarist will let you
- ◆ Digital routing
  - A/D in the microphone!

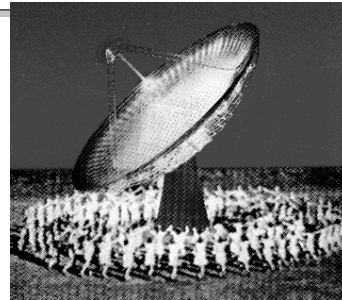
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## What's Next?

- ◆ Mixing consoles
  - Studio design and console specification
  - Console architecture: busses and I/O
  - Channel strip design
  - Auxes and busses, groups and outputs
  - Matrix designs and alternatives
  - Console automation
- ◆ Readings (!!)

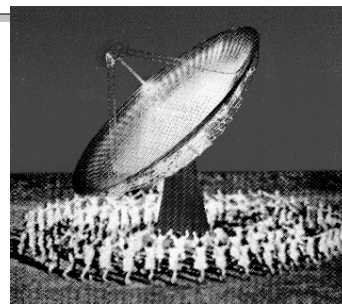
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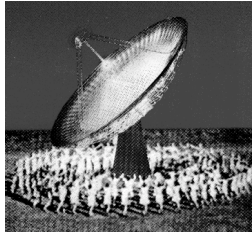
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## MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering



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## Lecture 4 Outline

---

- ◆ Consoles
  - Uses in recording, mixing, mastering, and sound reinforcement
  - Basic architecture and ergonomics
  - Examples
  - Channel strip design criteria
  - Input chain management
  - Master blocks
  - Busses, auxes, and routing

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## Readings

---

- ◆ **Mixing Consoles and Channel Strips**
  - Mixing Consoles 1 & 2
  - Introduction to Consoles, Mixing, & Equalization
  - Console Ergonomics
  - Channel Strip Buyer's Guide
  - Designing the Large-Format Digital Console
  - Yamaha 02R96 and DM2000 Information
  - Soundcraft D328 Brochure
  - Mackie DB8 Setup Instructions
  - Understanding Console Automation
  - Bass Management Electronics

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## Console Functions

---

- ◆ Input control, preamplification, gain (2-stage)
- ◆ Basic processing (EQ)
- ◆ Routing
  - Auxes and out-board effects
  - Main groups
- ◆ Tape I/O
- ◆ Monitoring
- ◆ Machine Control
- ◆ Talk-back

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## In the Abstract

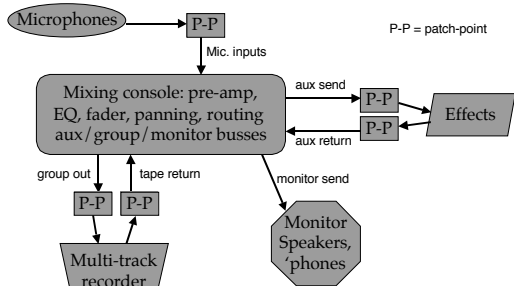
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- ◆ I/O and patching
- ◆ General control surface
- ◆ Input gain controls
- ◆ Per-channel control
- ◆ Integration with other equipment (signal, control, clocks, etc.)
- ◆ Configuration and ergonomics

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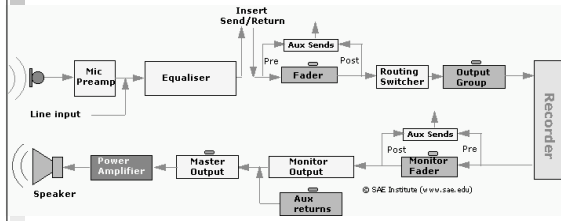
## Signal Chain (reminder)

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## Signal Flow (reminder)



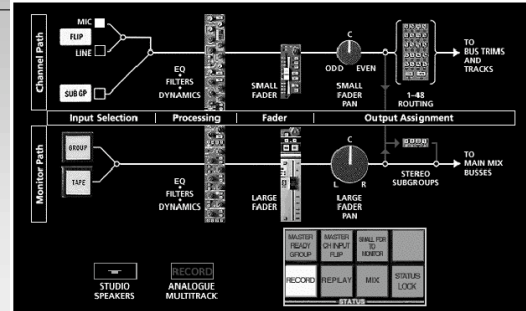
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## Signal Flow (detail)



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## Console Applications

- ◆ Basic recording (raw tracks)
- ◆ Mix-down (process/mix)
- ◆ Front-of-house (many inputs, simple routing)
- ◆ Broadcast (simple, inputs and gain)
- ◆ Routing (flexible)
- ◆ Digital versions of the above
- ◆ "Software consoles"

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## Console Criteria

- ◆ Basic recording
  - Pre-amp, EQ, routing, flexibility, fold-back, machine control, A/D
- ◆ Mix-down
  - Routing, effects, panning, automation, DAW integration
- ◆ Mastering
  - Level control, metering, EQ, surround/spatial formatting, monitoring
- ◆ Front-of-house
  - Size/scalability, simplicity/robustness, automation
- ◆ Broadcast
  - Routing, multi-format A/D
- ◆ Project Studio
  - All of the above...

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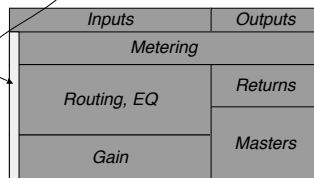
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## Console Architecture

- ◆ Channel strips
- ◆ Master groups
- ◆ Aux sends/returns
- ◆ Monitoring
- ◆ Metering



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## Example: Mackie 1602

- ◆ Rear panel



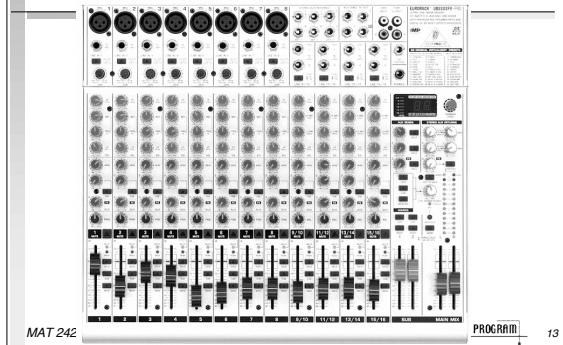
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Example: Behringer UB2222



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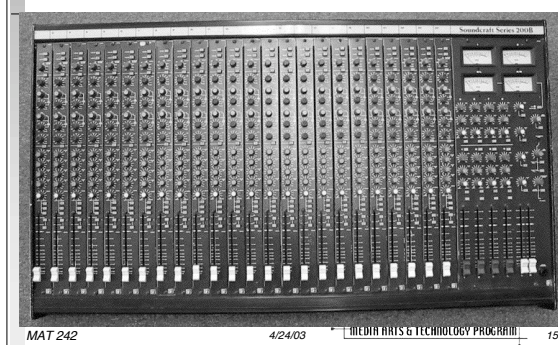
Example: Neve V88r



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Example: Soundcraft 200B



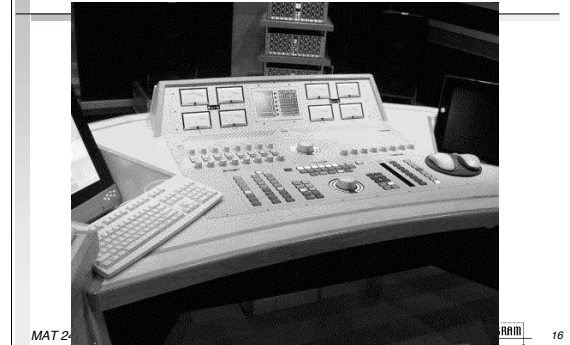
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Example: Euphonix MMC1



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Example: Manley Custom



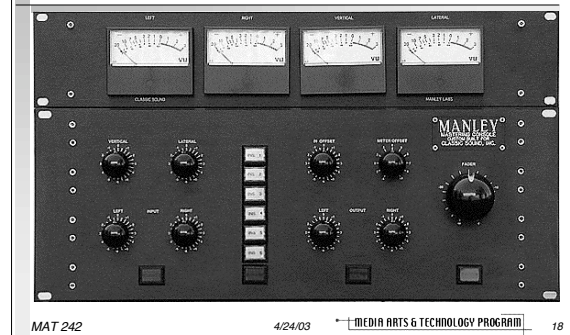
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Example: Manley Custom



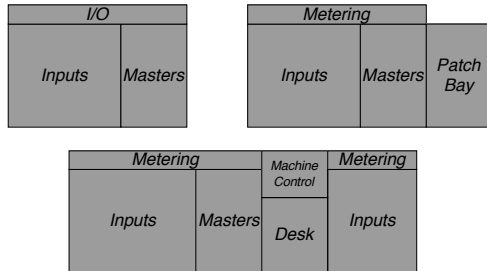
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## Console Layout & Ergonomics



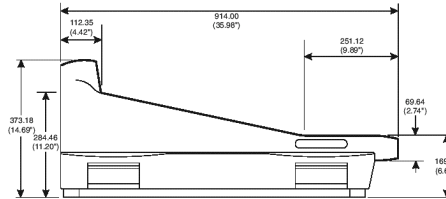
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## Typical Dimensions



All dimensions are in millimeters (inches in brackets)

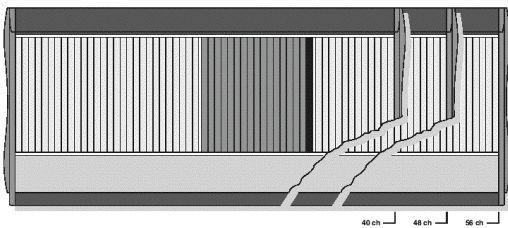
CONSOLE	TOTAL WIDTH	WEIGHTS
30-bus, (24-bus, 44ch), 40ch	2007.80 (79.05")	156kg (343lbs)
32-bus, (24-bus, 50ch), 48ch	2269.80 (89.36")	170kg (374lbs)
32-bus, (24-bus, 60ch), 56ch	2531.80 (99.67")	185kg (407lbs)

MA

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## Layout Example

Mono Input  
 Output  
 Master



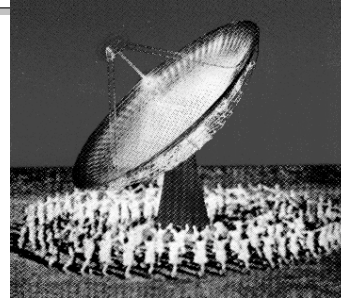
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## The Channel Strip

- ◆ Design criteria
- ◆ Options
- ◆ Configuration
- ◆ Integration
- ◆ Stand-alone channel strips
- ◆ Standard vs novel vs digital vs software



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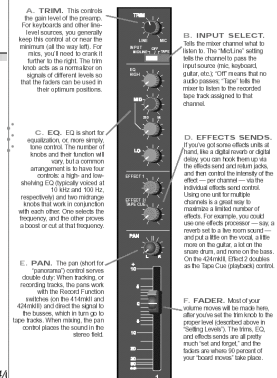
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## Anatomy

- ◆ Input
  - Selection
  - Raw gain
- ◆ EQ
- ◆ Routing
  - Aux sends
  - Panner
- ◆ Gain

FIGURE 7:  
ANATOMY OF A MIXER CHANNEL



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## Channel Strip Design

- ◆ Fader
  - 100 mm or smaller
  - Metering built-in
- ◆ Panning
  - 1 or 2 stereo pans, quad-pots, out selection
- ◆ EQ
  - Fixed vs parametric
- ◆ Routing
  - Level of flexibility
- ◆ Input
  - Selection, basic gain

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## Special Functions

- ◆ Solo
- ◆ Mute
- ◆ EQ in/out
- ◆ Send pre/post fader
- ◆ Metering pre/post fader
- ◆ L/R channel select
- ◆ Inserts/direct outs
- ◆ Phantom microphone power
- ◆ Phase reversal
- ◆ ...many other options

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## Routing and busses

- ◆ Simplest
  - Aux send/return
  - Channel-to-group assignment/panning
- ◆ Fancier
  - Direct I/O
  - Channel inserts
- ◆ Way fancy
  - Matrix busses
  - Digital routing

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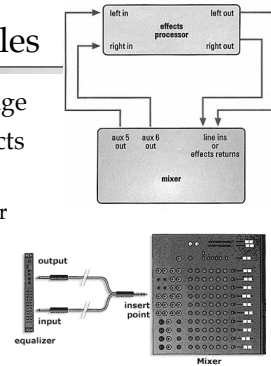
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## Routing examples

- ◆ Traditional aux usage
- ◆ Channel insert effects
  - EQ
  - Compressor/limiter
- ◆ More sophisticated
  - Multi 'phone mix



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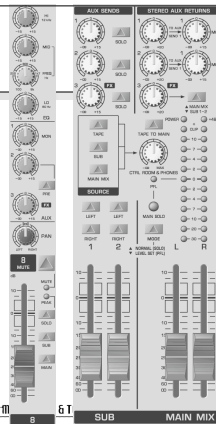
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## Example: Behringer 2222

- ◆ Channel strip and output block



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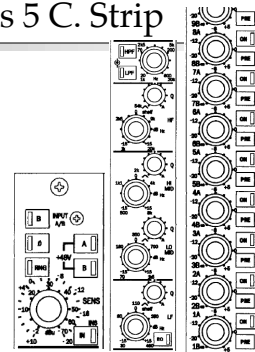
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## Soundcraft Series 5 C. Strip

- ◆ Input switching
- ◆ 4-way EQ + shelf
- ◆ Aux sends

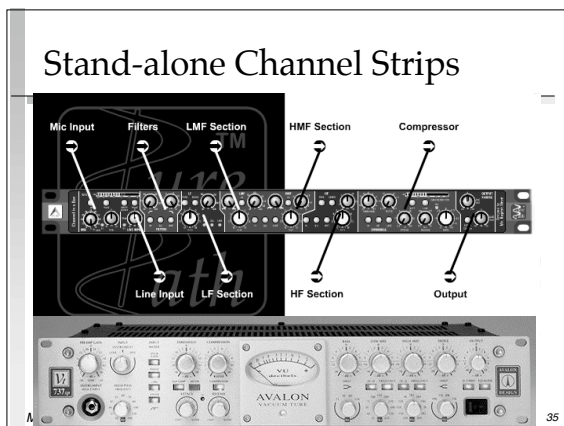
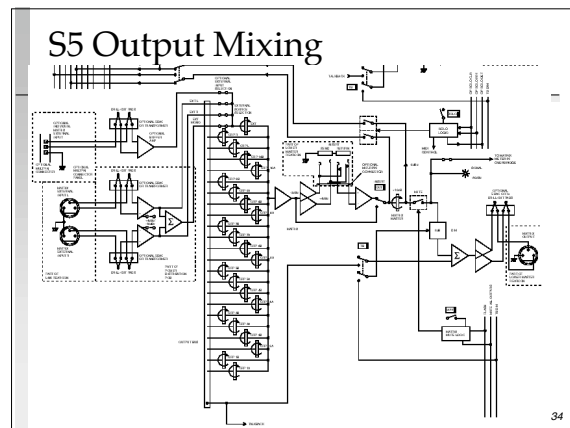
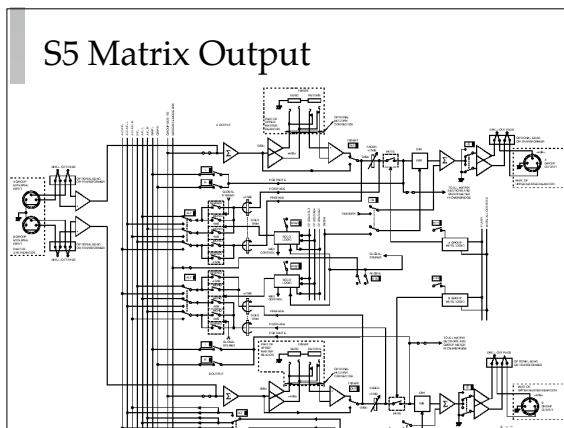
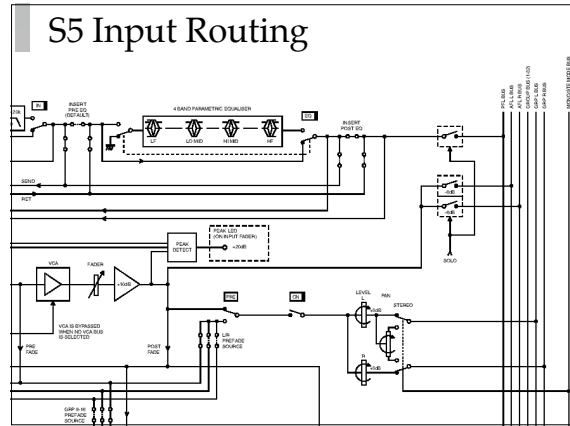
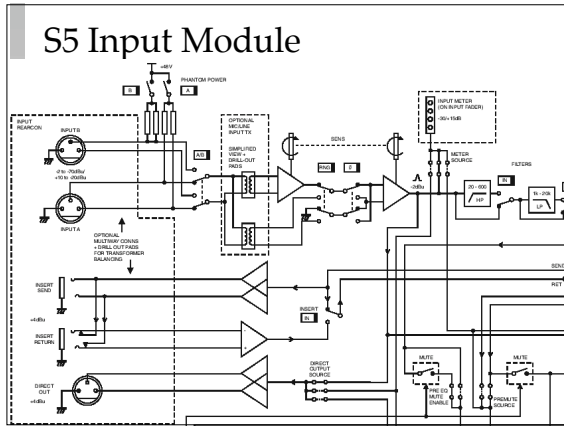


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### The Master Block

- ◆ Aux send/return
- ◆ Group gains
- ◆ Metering
- ◆ Monitoring
- ◆ Talk-back
- ◆ Others
  - Machine/computer control
  - Oscillator

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The photograph shows the Mackie 2448 master block, which is a central component of the recording studio. It features a large array of controls, including faders, knobs, and meters, used for monitoring and controlling the audio signal. The unit is labeled 'MACKIE 2448' and '4/24/03 MEDIA ARTS'.

## Console Automation

- ◆ Goes back to the pre-digital era
- ◆ Record control voltages for channel and group VCAs (not all settings)
- ◆ Faders with matching LEDs
- ◆ Need to record data in sync with music
  - Need for universal SMPTE timecode
- ◆ Lately
  - Mute automation
  - Moving faders
  - DAW & SW consoles

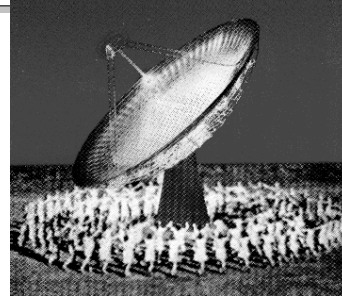
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## Digital Consoles

- ◆ Many options
  - # inputs vs # faders
  - A and D I/O
  - Built-in DSP for effects
  - Very flexible routing (soft matrix patching)
  - DAW SW integration (signal IO, control)
  - Digital recorder integration (ADAT, DA-88, HD-based)

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## Digital Channel Strip

- ◆ Level fader
- ◆ Pan pot
- ◆ Channel select for other functions
  - GUI for selected channel is shown on main screen
- ◆ Advantages
  - Flexibility (e.g., different kind of EQ per channel)
  - Lower control surface complexity
- ◆ Disadvantages
  - Multiple clicks to access a given control
  - Need history stack of screens

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## Digital Console as Control Surface

- ◆ At the minimum
  - Level faders for 16 or so inputs
  - May support many more channels via bank switching
  - Basic GUI for per-channel functions
  - Machine control, scrub wheel
  - Displays and readouts
  - MIDI faders vs control surfaces

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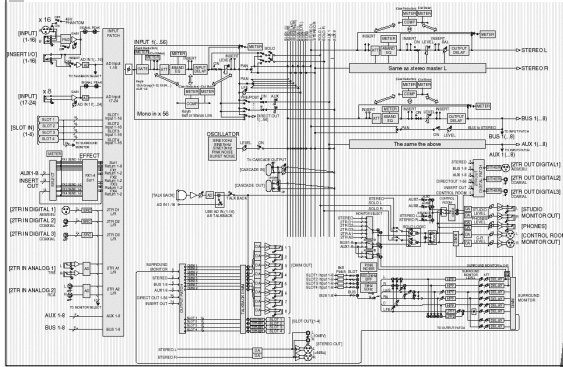
## Example: Yamaha 02R/96



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## Yamaha 02R/96 Routing



## Example: Mackie HUI

- ◆ Inputs
- ◆ Control
- ◆ DSP
- ◆ Computer interface
- ◆ Metering



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## Example: Sony DMX-R100



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## Soft Consoles

- ◆ Most still mimick hardware
- ◆ Integrated with time-line and signal editors

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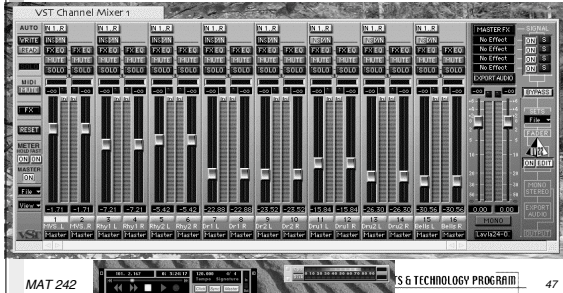
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## Example: Cubase Views

- ◆ Channel mixer & control views



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## Cubase Channel Settings etc.

- ◆ EQ, routing, plug-ins
- ◆ Plug-in control panel



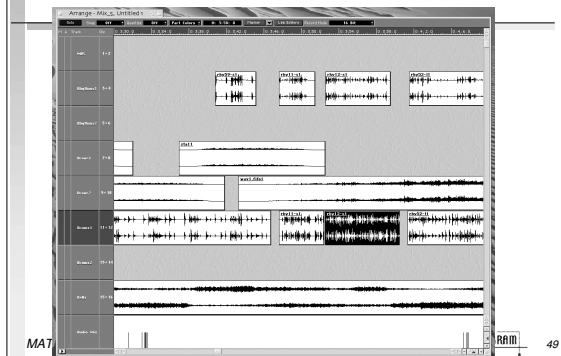
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## Cubase Time-line



## Summary

- ◆ There are many, many options
- ◆ Even the basic building blocks are flexible
- ◆ Digital and software solutions are still in their infancy
- ◆ Future: SW DAW + flexible control surface (?)

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## What's Next?

- ◆ Console discussion
  - Routing
  - EQ options
  - New applications
- ◆ Recording formats and media
- ◆ Analog and digital recorders
- ◆ Next readings

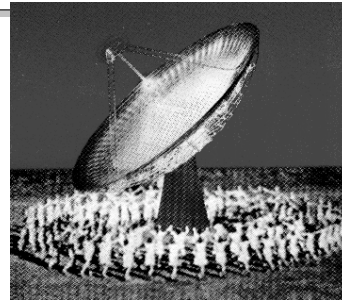
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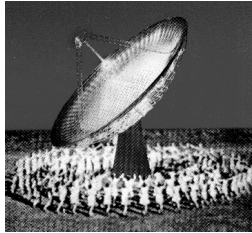
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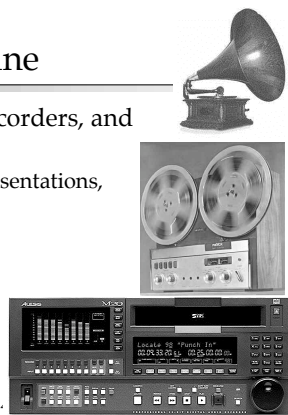
## MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering



MAT 242 4/28/03 MEDIA ARTS & TECHNOLOGY PROGRAM 1

## Lecture 5 Outline

- ◆ Storage formats, recorders, and media
  - Digital sound representations, formats and media
  - Analog recording
  - Digital recording
  - Noise reduction
  - A/D and D/A conversion



MAT 242


## Readings

- ◆ **Recording, Storage Formats and Media**
  - Analog Recording, Digital Recording
  - Introduction to Recorders
  - Analog Tape 101
  - Digital-Analog Conversion
  - AU and RME ADC Data
  - Mixdown Tools
  - ADAT vs. DA-88, DA-88 Hook-up
  - Mackie HDR24/96 Brochure
  - Synchronization and Timecode Basics
  - Dolby Noise Reduction, Noise Reduction Systems

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## Sound Representation

- ◆ Abstract representation
- ◆ Storage format
- ◆ Interchange format
- ◆ Dimensions
  - Structural generality
  - Expressive completeness
- ◆ Examples
  - Musical score
  - Spectrogram
  - Recorded waveform



Studer A-80

MAT 242 4/28/03 MEDIA ARTS & TECHNOLOGY PROGRAM 4

## Analog Audio Standards

- ◆ Aspects
  - Signal model (point-receiver microphone, point-source speaker, LFE channel, etc.)
  - Signal levels
  - Connections, termination
  - Circuit impedance, etc.
- ◆ Handling multi-channel sound

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## Digital Audio Representations

- ◆ Basic properties
  - Sampling rate (freq. Response, Nyquist)
  - Sample format (resolution, quantization, encoding)
  - Number of channels (and signal model)
  - Jitter spec., word clocking
  - Encoding
    - Linear samples
    - Sample value look-up tables
    - Statistical compression
    - Perceptual coding

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## Digital Audio Formats

- ◆ S/P-DIF (RCA coax, TosLink optical)
- ◆ AES/EBU (XLR)
- ◆ Alesis LightPipe (optical)
- ◆ Tascam TDIF (electrical)
- ◆ USB Audio
- ◆ FireWire, and M-LAN
- ◆ Several others in common use

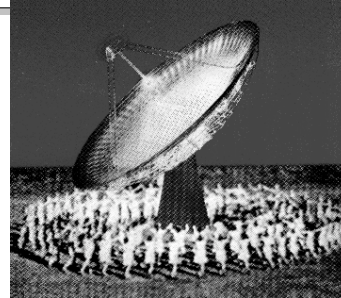
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## Analog Tape

- ◆ History:
  - Wax cylinders, shellac disks, wire, paper tape, etc.
- ◆ Recording tape
  - Plastic tape (BASF, 1930s)
  - Backing material
  - Magnetic coating
  - Analog recorders
  - Tape width
  - Track format
  - Tape speeds
  - NR options

AEG Magnetophon, 1935



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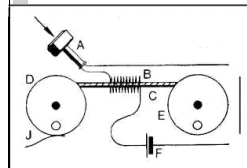
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## Early Magnetic Recording

- ◆ 1888: String recorder
- ◆ 1930s: Webster Wire Recorder



1935 Recording



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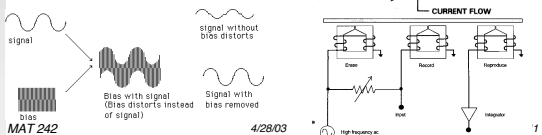
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## How Analog Tape Works

- ◆ Heads are electromagnets with a small gap (across which a magnetic field can be created)
- ◆ Tape moves across head gap at a constant rate
- ◆ Issues
  - Noise
  - Freq. response
  - Wow/flutter



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## Anatomy of a Tape Recorder

- ◆ Tape-handling mechanism
- ◆ (2-4) Tape heads
- ◆ Electronics
  - Input stage
  - Amplification
  - Bias oscillator
  - Level control and meters
  - Playback filter and amp.

Revox A77: 1972



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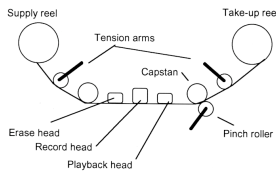
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## Tape Handling

- ◆ Large, heavy reels (2400')
- ◆ Requirements:
  - Very constant tape speed
  - Very fast FF/RW
  - Silent operation
  - Very reliable operation
  - Low tape flecion
  - Constant wind pressure



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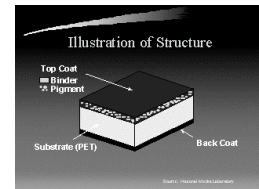
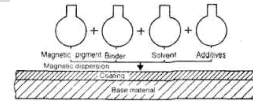
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## Magnetic Recording Media

- ◆ Recording Material
  - Capable of storing a magnetic field
- ◆ Substrate
  - "Backing" physical support (polyester or aluminum)
- ◆ Binder
  - Bonds recording material to substrate



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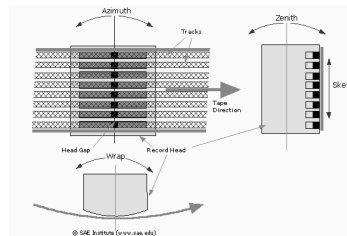
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## Tape/Head Geometry

- ◆ Many adjustments to geometry of each head



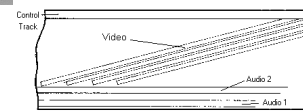
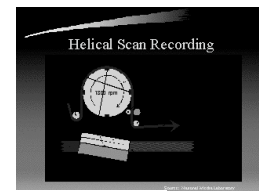
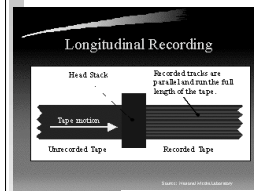
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## Longitudinal and Helical Scan



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## Analog Track Formats

2a	2b	2c	2d	2e	2f
half-inch 2-track	quarter-inch 2-track, or half-inch 4-track, or half-inch section of 2-inch 16-track	half-inch section of 2-inch 24-track	half-inch 8-track, 1-inch 16-track, consumer "quarter-track" stereo	half-inch 16-track	4mm (.157-inch) 4-track

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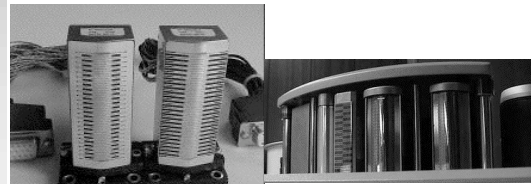
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## Tape Heads (or head stack)

- ◆ Friction and wear (reconditioning)
- ◆ Alignment and adjustment



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## Quarter-inch Formats

- ◆ Full-track (mono)
- ◆ Half-track (stereo)
- ◆ 3-track
- ◆ Quarter-track stereo 2-way (consumer)
- ◆ Quarter-track 4-channel
- ◆ 8-track



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## 2-Track Mastering Recorders

- ◆ AEG/Magnetophon
- ◆ Ampex ATR-800



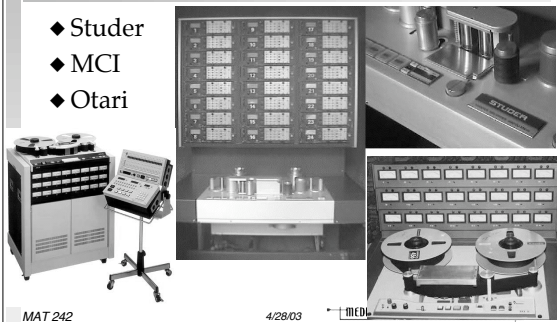
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## Multi-track Analog Recorders

- ◆ Studer
- ◆ MCI
- ◆ Otari

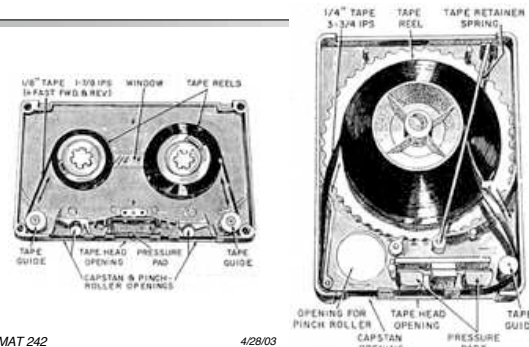


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## Cassette and 8-Track Formats

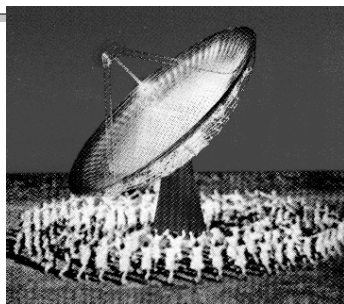


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## Recording/Storing Digital Sound

- ◆ History (9-track 1/2" mag tape)
- ◆ Early-1980s: DASH, SoundStream
- ◆ Mid-1980s: PCM on VHS (Sony PCM-F1)
- ◆ Late-1980s: DAT (new tape format)
- ◆ Late-1980s: HD-based systems (Dyaxis, ProTools) (special disks and/or file systems)
- ◆ Early-1990s: ADAT and DA-88 (video tape)
- ◆ Late-1990s: DAW on stock PCs (with stock disks)

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## Digital Audio Tape Formats

- ◆ DASH: Digital Audio Stationary Head (Sony)
- ◆ DAT: Digital Audio Tape
- ◆ Alesis ADAT
- ◆ Tascam DA-88
- ◆ Others...



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## MDMs: ADAT vs DTRS

	ADAT	DA-88/98
Tape	VHS	8 mm
Rec. time	60 min.	108 min.
Channels	8 (or 4)	Same
Format	16,20/44, 24/96	also 24/44
Operation	Loud, unreliable	Quiet, reliable
Load/unload time	Long	Longer
I/O	Optical	Electrical
Reliability	Low-medium	Medium
Uses	Project studios, pro studios	Broadcast, film-post
Biggest problem	Reliability	Track-splitting, cost

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## A and D "PortaStudios"

- ◆ Many solutions for low-budget integrated multi-track recording



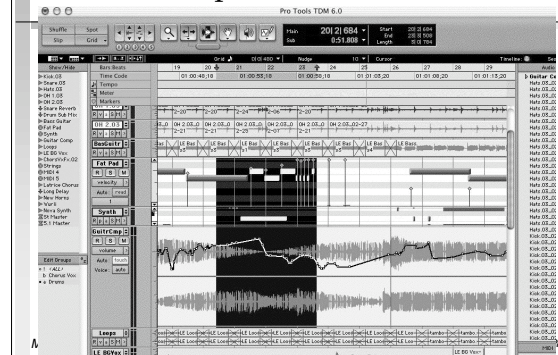
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## DAW Example: ProTools



A

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## Hard Disk Recorders

- ◆ Using hard disks for sound storage
  - Digital signal format: typically 16 (bit)/44 (kHz), 24/44, 16/48, or 24/96; others possible
  - Data throughput: 16/44 @ 16 tracks = 1.4 MB/sec (no problem)
  - File size: 20 min. "movement" @ 16/44 @ 16 tracks = 1.7 GB (no problem)
  - But: 24/96 @ 32 tracks = 9.2 MB/sec (potential problem) = 11 GB for 20 min
  - Use RAID disk arrays

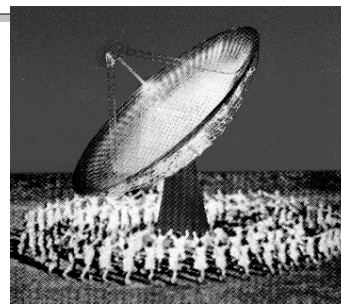
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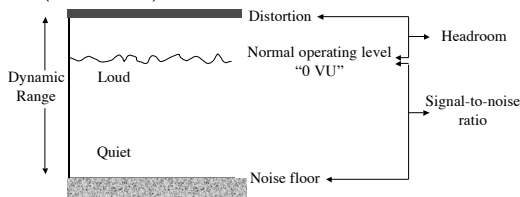
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## Noise Reduction

- ◆ The problem: recording media (esp. analog tape and A/D converters) have fixed max signal (0 dB + headroom) and fixed SNR (noise floor)



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## The Solution a la Ray Dolby

- ◆ It's very simple: dynamic range *compression* before recording, and *expansion* on playback

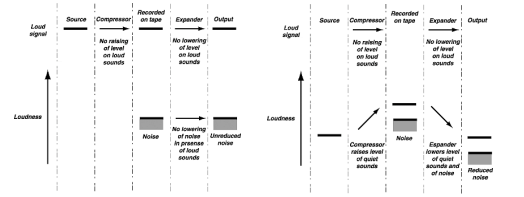


Figure 1: Wide-band compander on loud signals.

Figure 2: Wide-band compander on soft signals.

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## Dynamic Range Processing

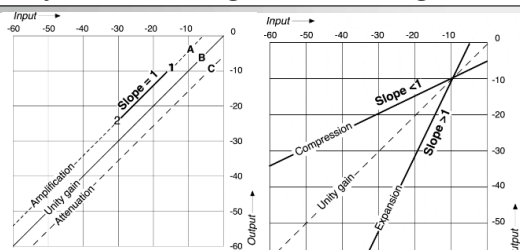


Figure 1: A straight line with a slope of 1 means that a processor acts as a constant-gain amplifier (A), a unity-gain attenuator (B), or a constant-loss attenuator (C).

Figure 3: A processor with a slope of less than one is a compressor; with a slope of more than one, an expander.

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## Now the Details (Problems)

- ◆ Timing and overshoot in compressors
  - Sharp envelopes are problems
  - Limit compressor attack time
- ◆ Compressor as AM
  - Inharmonic sidebands)

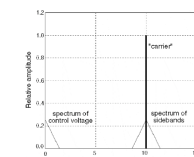


Figure 2: Slow attack time

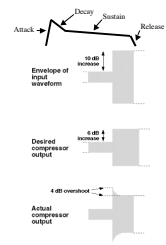


Figure 1: Compressor overshoot.

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## Dolby A Configuration

- ◆ Bilinear compression characteristic
- ◆ Multi-band compression with different compression curves and time constants

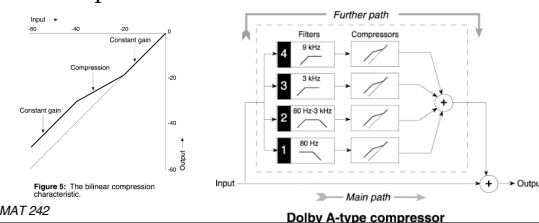


Figure 5: The bilinear compression characteristic.

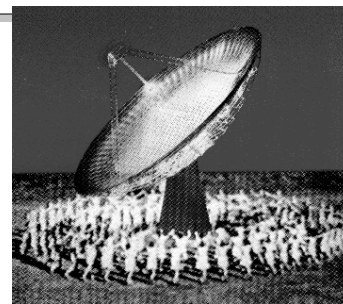
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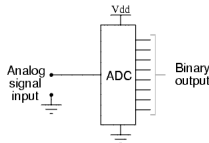
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## A/D and D/A Conversion

- ◆ Take an analog voltage and convert it to a binary number at regular intervals
- ◆ How you do this determines the digital signal representation in terms of sample resolution and sampling frequency; e.g., 16-bit 44 kHz
- ◆ Guess what: it's hard to do well!



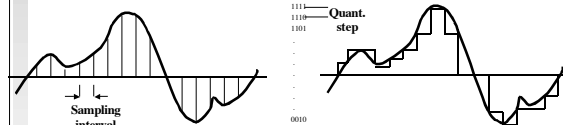
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## The A/D/A Process

- ◆ Typical digital audio is a *sampled* and *quantized* representation of a continuous (in time and value) electrical voltage.
- ◆ The processes of sampling and quantization each have their own issues and distortions.



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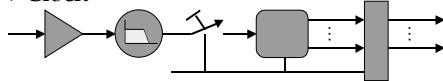
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## Parts of an A/D Convertor

- ◆ Input processing
- ◆ Anti-aliasing filter
- ◆ Sample/hold
- ◆ Convertor
- ◆ Output buffer/latch
- ◆ Clock



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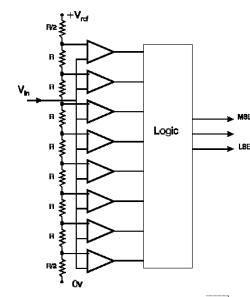
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## Simplest A/D Convertor

- ◆ Flash A/D
- ◆ Other types:
  - D/A-based
  - Ramp-based
  - V/F-based
  - $\Delta\Sigma$
  - etc...



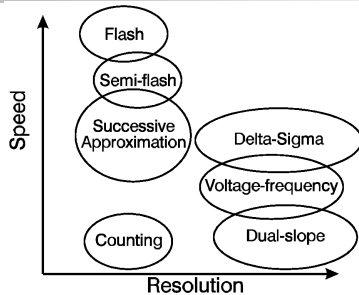
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## Comparing A/D Techniques



Summary of A/D Converter Types

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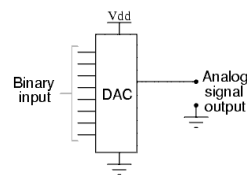
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## D/A Conversion

- ◆ Take a digital number and create an analogous voltage (real fast and accurate-like).



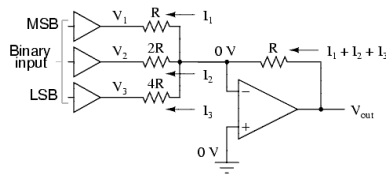
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## Summing DAC



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## Advanced A/D/A Techniques

- ◆ Oversampling and decimation
  - Reconstruction filters
  - Why do this?
- ◆ 1-bit techniques
- ◆ DSD and SACD
  - Processing oversampled data
- ◆ Filter design
  - Still a challenge

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## A/D/A Specifications

- ◆ Resolution, sample rate
- ◆ SNR and THD
- ◆ Frequency response
- ◆ Jitter, jitter spectrum
- ◆ Linearity
- ◆ Clocking

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## Summary

- ◆ Most historical formats are still in use
- ◆ Many of the basic problems are still unsolved
- ◆ Long-term archival is still done to analog R2R tape
- ◆ Disk-based systems are taking over (?)
- ◆ A/D/A conversion is still a topic of active research

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## What's Next?

- ◆ Signal conditioning and processing
- ◆ Equalization
- ◆ Reverb and echo
- ◆ Dynamic-range processing
- ◆ Advanced processing applications
- ◆ Next readings

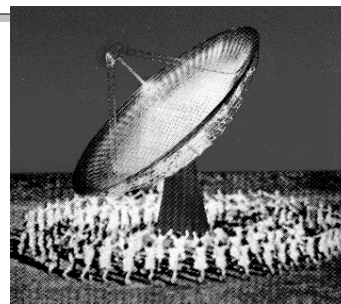
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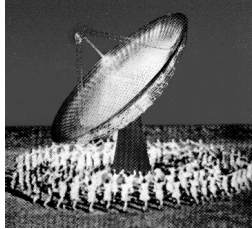
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## MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering



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## Topic 6 Outline

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- ◆ Effects and Signal Processing
  - Kinds of Effects
  - Echo, reverb, spatial processing
  - Filter-based effects
  - Dynamic-range processing
  - Special applications
    - Application-specific effects
    - Instrument effects
    - Voice processing

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## Readings

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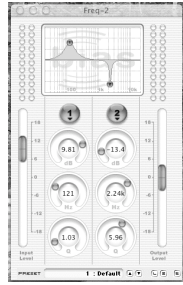
- ◆ **Processing and Signal Conditioning**
  - Guitar Effects FAQ
  - Eventide Eclipse Description and Preset Effects List
  - Introduction to Reverberation
  - Compressor/Expanders, Limiters, and Gates
  - UA 1176LN Limiting Amplifier Brochure
  - Digital Dynamics Processing
  - Audio Processing & HD Radio
  - State of the Art Speech Processing for Broadcasting

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## Taxonomy of Effects

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- ◆ Amplitude-domain effects
  - Tremolo, dynamic-range processing
  - Compressor, limiter, gate, etc.
- ◆ Time-domain effects
  - Echo, reverberation, chorusing, comb filters
- ◆ Frequency-domain effects
  - Filters, wah-wah, speaker/cabinet models
- ◆ Pitch transformations
  - Harmonizers, pitch correction, vibrato
- ◆ Others
  - Distortion-as-effect
  - “Special” effects
  - Panning

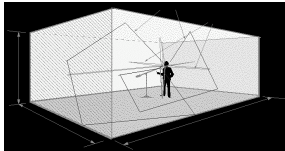


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## Echo and Reverberation

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- ◆ Time-domain and spatial processing
- ◆ Kinds of echo
  - Real rooms
  - Simulated rooms
- ◆ Reverberation
  - Physical models
  - Time-domain models
- ◆ Stereo processing
  - Decorrelation of reverb
  - Comb filter (delay) between channels
  - Physically informed early reflections

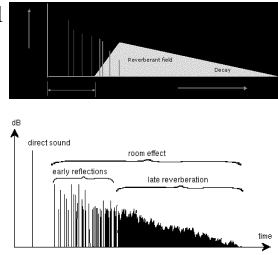


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## Reverberation

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- ◆ Delayed direct signal
- ◆ Early reflections
- ◆ Reverb tail
- ◆ Inter-aural differences
- ◆ Directionality of reflections
- ◆ Frequency dependencies



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## Tape Echo



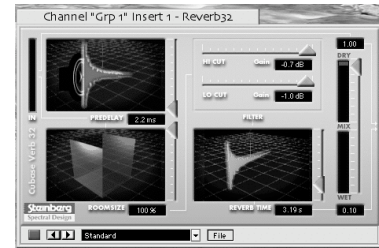
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## Digital Reverb Models

### ◆ Schröder reverberators and parameters



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## Performing Reverberation

- ◆ Parametric models
  - See above
- ◆ Room impulse responses
  - Convolution-based systems
- ◆ “Vintage” reverb
  - Models of plate and spring reverbs
  - Models of “classic” digital reverb

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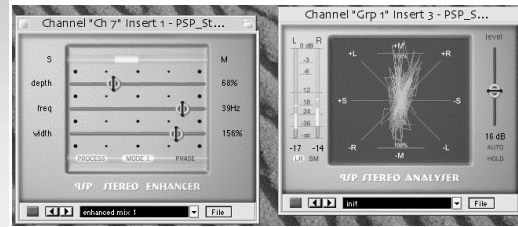
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## Stereo “Width” Processing

### ◆ Delay lines, chorussing, etc.



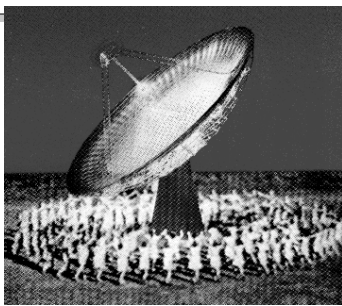
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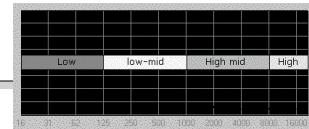
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## Equalization



### ◆ Filters

- Hi-pass, low-pass, band-pass, band-reject
- CF, BW, Q
- Slope in dB/octave (typically 6 - 24)

### ◆ Simplest tone control = spectral slope

### ◆ Two-way = bass/treble controls

### ◆ Loudness = bass/hi boost at low level

### ◆ Shelf filters (lo/hi)



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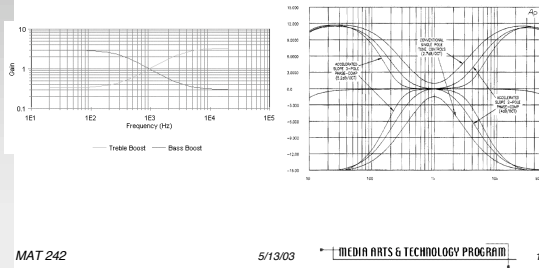
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## Simple Tone Controls

### ◆ 1-knob vs. 2-knob



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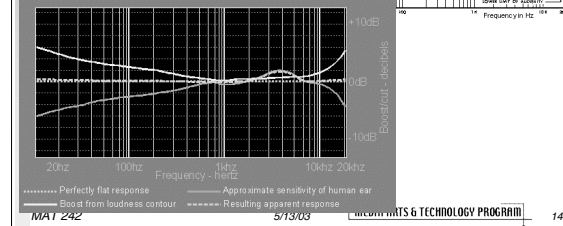
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## Loudness Contour

### ◆ Fletcher-Munson curves



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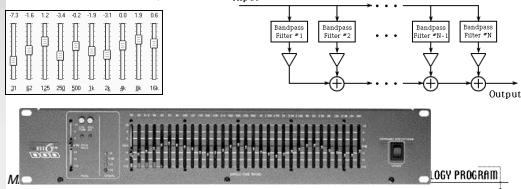
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## Graphic EQ

### ◆ Typically 6-31 bands

- Equal pitch width (ISO center freqs)
  - $2/3$ -octave = 25, 40, 63, 100, 160, 250, 400, 630, 1k, 1.6k, 2.5k, 4k, 6.3k, 10k, 16kHz
- Constant Q filters



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## Parametric EQ

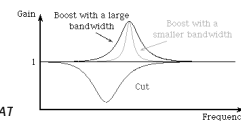
### ◆ Per-stage:

- Center frequency
- Level boost/cut
- Filter "Q"

### ◆ Typically 2-4 stages

### ◆ In-console, as-box, or as-plug-in

Possible Frequency Responses for a Parametric Equalizer



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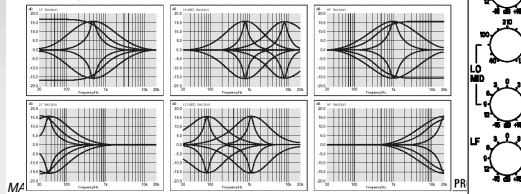
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## In-console EQ

- In/out switch
- Shelf filters
- Multi-way or parametric designs
- E.g., Soundcraft K2



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## EQ in DAWs



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## Using EQ

- ◆ Instrument qualities
- ◆ Vocal formant regions
- ◆ Conserving transients

Instrument	Cutting	Boosting	Comments
Human voice	Scratchy at 2 KHz. Nasal at 1 KHz. Popping P's below 80 Hz.	Hot at 8 KHz. Clarity above 3 KHz. Body at 200-400 Hz.	Aim for a thinner sound when blending many voices, especially if the backing track is full.
Piano	Tinny at 1-2 KHz. Boomy at 300 Hz.	Presence at 5 KHz. Bottom at 100 Hz.	Don't add too much bottom when mixing with a full rhythm section.
Electric Guitar	Muddy below 80 Hz.	Clarity at 1 KHz. Bottom at 125 Hz.	
Acoustic Guitar	Tinny at 2-3 KHz. Boomy at 200 Hz.	Sparkle above 5 KHz. Full at 125 Hz.	
Electric Bass	Thin at 1 KHz. Boomy at 125 Hz.	Growl at 600 Hz. Bottom below 60 Hz.	Sound varies greatly depending on the type of bass and brand of strings used.
String Bass	Hollow at 600 Hz. Boomy at 200 Hz.	Slap at 2-5 KHz. Bottom below 125 Hz.	
Snare Drum	Annoying at 1 KHz.	Crisp above 2 KHz. Full at 150-200 Hz. Deep at 80 Hz.	Also try adjusting the tightness of the snare wires.
Kick Drum	Flappy at 600 Hz. Boomy below 60 Hz.	Slap at 2-5 KHz. Bottom at 60-125 Hz.	For most pop music, remove the front head, then put a heavy blanket inside (resting against the front head).
Toms	Boomy at 300 Hz.	Slap at 2-5 KHz. Bottom at 80-200 Hz.	Tuning and adjusting the head tension makes a huge difference too!
Cymbals, bells, harmonicas, etc.	Annoying at 1 KHz.	Sparkle above 5 KHz.	Analog only! Record these instruments at conservative levels, especially at slower tape speeds.
Horns and Strings	Scratchy at 3 KHz. Boomy at 1 KHz. Muddy below 320 Hz.	Hot at 8-12 KHz. Clarity above 2 KHz. Strings are hot at 400-600 Hz.	

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## Filter-based Effects

- ◆ Equalizers
- ◆ Dynamic filters
  - Wah-wah (swept BP filter)
  - NR (triggered HF expander)
- ◆ Resonators
  - Amp/cabinet
  - Acoustical instrument
- ◆ Special applications
  - De-esser
  - Vocoder
  - Leslie speaker



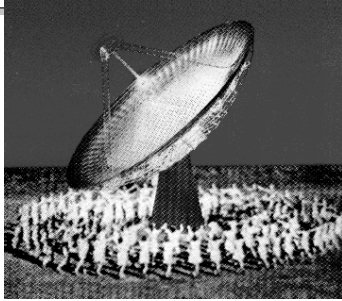
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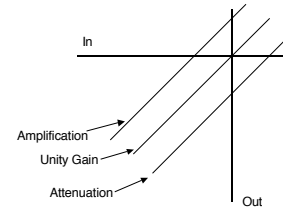
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## Dynamic-Range Processing

- ◆ The I/O graph
- ◆ Kinds of DRPs
  - Attenuator
  - Compressor
  - Expander
  - Limiter
  - Gate
  - Sustain
  - Combined effects



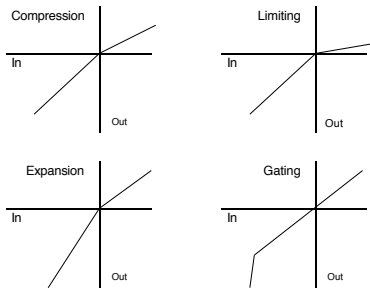
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## Basic Dynamic-Range Processing



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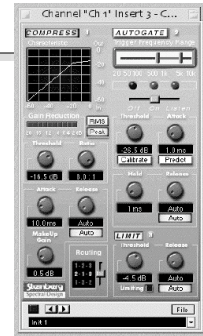
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## DRP Plug-ins

- ◆ Attack/decay times
- ◆ Frequency-dependent DRP
- ◆ "Smart" DRP
  - Context-dependent attack/decay
  - Spectral compression
  - Mixed-mode DRP



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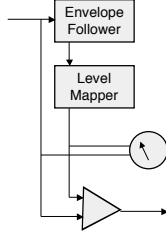
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## Building a Compressor

- ◆ Envelope extractor
- ◆ Level mapper
- ◆ VCA
- ◆ Metering (e.g., gain reduction)
- ◆ Issues
  - Time delay (att & decay)
  - Level extremes
  - Frequency dependencies



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## Advanced Dynamics

- ◆ Cross-processing of dynamics
  - VCA input  $\neq$  envelope follower input
- ◆ Swell
  - Gain boost in steady state
- ◆ ADSR DRP
  - Envelope independent of input
- ◆ Sustain
  - Compression of low-levels (with gate)

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## Channel Strips Revisited

- ◆ Putting all the pieces together
  - Mic pre-amp
  - Lo-cut filter (for mic input)
  - Dynamic range expander
  - "Tube warmth" (distortion/EQ)
  - Compressor/limiter
  - Parametric EQ
  - Vocal de-esser
  - ADC (optional)
  - Output gain control
- ◆ Effect order

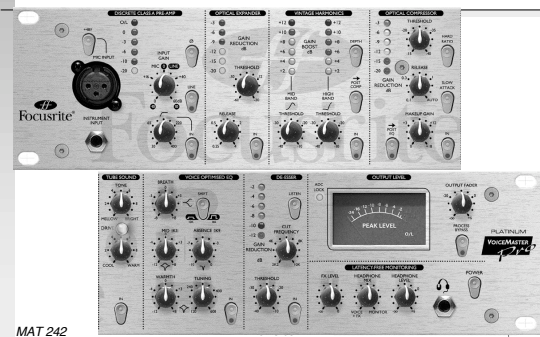
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## Focusrite VoiceMaster



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## Behringer VX2496

- ◆ Look at the order and the metering



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## Effects Processors

- ◆ ADC - DSP - DAC
  - Newer: digital I/O (DSP coprocessor)
- ◆ Effects algorithms
  - See reading
- ◆ Control
  - Eventide 4-knob control
- ◆ History
  - Eventide Harmonizer



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## Application-specific effects

- ◆ Live sound
  - Feedback control (pitch shifting)
  - Large-scale sound reinforcement (delay between speaker stacks)
- ◆ Studio recording
  - DRP, instrument/vocals processing
- ◆ Mixing/mastering
  - Spatial/stereo processing

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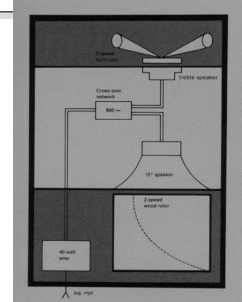
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## Instrument effects

- ◆ Guitars
  - See guitar FX FAQ
  - EQ and cabinet resonance
  - Pick-up characteristics
  - Distortion effects
- ◆ Synths
  - Keyboard effects
- ◆ Live instrument effects
  - Octave doubling



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## Voice processing

- ◆ Voice EQ
  - Presence, warmth, lo-cut
  - Mid-hi range (formants)
- ◆ De-essing
  - Energy of sibilance
- ◆ Chorussing
  - Voice textures

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## Summary

- ◆ Time-domain processing
- ◆ Frequency-domain processing
- ◆ Dynamic-domain processing
- ◆ Special effects

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## What's Next?

- ◆ Mastering for encoding and distribution
- ◆ Distribution formats
  - Broadcast and streaming
- ◆ Sync. With other media
- ◆ Next readings

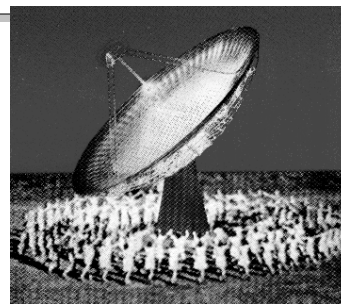
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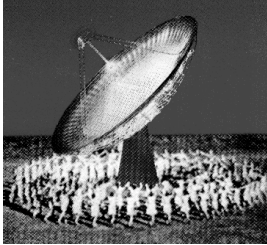
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## MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering



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## Topic 7 Outline

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- ◆ Monitoring
  - Playback in the studio
  - Playback in the control room
  - Stage monitoring
- ◆ Mastering
  - Why mastering?
  - Steps and processes
  - Mastering and distribution formats

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## Readings

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- ◆ **Mixing and Mastering**
  - Overview of CD Mastering
  - Secrets of Doing Surround Sound on your Existing Console
  - You're Surrounded
  - Signal Processing and Methods in Surround Mixing
  - Whatever Happened to Dynamic Range on Compact Discs?
  - Surround Sound: Past, Present, and Future
  - Some Guidelines for Producing Music in 5.1-Channel Surround

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## Monitoring

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- ◆ Performer monitors
  - Headphones and distribution
- ◆ Control room monitors
  - For recording, mix-down, mastering
- ◆ Talk-back
  - To studio, stage
- ◆ Stage monitors
  - Separate topic




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## Studio Monitoring

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- ◆ Problem: studio performers are often isolated from each other, and (obviously) cannot use loudspeakers for monitoring during recording.
- ◆ Answer: give them each headphones!
- ◆ Requirement: light-weight, comfortable, good-sounding, inexpensive, robust, isolating headphones with individual control

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## Headphone Options

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- ◆ Mounting/isolation
  - In-ear (ear-bud) (stage use)
  - Over-ear (pushing on ear)
  - Around-ear (circum-aural)
- ◆ Open vs. isolating
- ◆ One-way vs. multi-way
- ◆ Dynamic vs. electrostatic
- ◆ Two-channel vs. more

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## Classic Headphones

- ◆ From Shure, Sony, Sennheiser, and AKG



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## Amplification and Distribution

- ◆ Headphone fan-out boxes, distribution amps, and mixers come in many flavors



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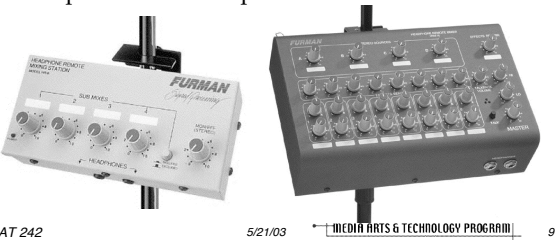
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## Advanced: Custom Mixers

- ◆ Multi-way snake to each performer
- ◆ Separate effects send / return per-performer
- ◆ Expensive and complicated



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## Control-Room Monitoring

- ◆ Many options
  - Near-field vs. room-field
  - Stereo vs. N-channel
  - Sub-woofers?
  - Supporting various monitors (including headphones) and formats (including mono)
  - Cross-over (bleed-through) with audiophile speakers and technologies
    - B&W, Tannoy, NHT, Dynaudio, JBL
    - (but) Genelec, Westlake, EAW, ATC, Audix

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## Monitoring in Recording Stages

- ◆ Recording
  - Focus on getting clean basic tracks
- ◆ Mix-down
  - Focus on creating a wide / deep stereo spatial image
- ◆ Mastering
  - Focus on balance and support for chosen distribution formats
- ◆ These may each require different monitoring solutions!
- ◆ Examples: see Topic 1 slides: Studio Examples

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## Stage Monitoring

- ◆ Issues in live sound
  - Sound reinforcement (off-topic, but interesting)
  - Stage monitors (many of their own issues)
- ◆ Speaker shape
  - E.g., wedge for floor
- ◆ Signal processing
  - Feedback control with pitch shifting

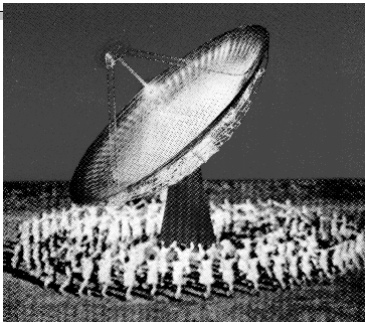
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## Mix-down and Mastering

- ◆ Now that you've got clean basic tracks, you're done, right?
- ◆ NOT!
- ◆ Mix-down issues
  - Beyond setting levels and panning
- ◆ Mastering and distribution formats
  - Programming, mastering, and preparation

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## Mix-down issues

- ◆ Control of levels (obviously)
- ◆ Spatial position: 2- or N-channel panning
- ◆ EQ for spectral balance, separation, clarity, punch, slam, etc.
- ◆ Dynamic range processing in the mix
- ◆ Reverb and other effects
- ◆ Creating a stereo spatial image
- ◆ Mixing to surround sound

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## EQ at Mix-Time

- ◆ General spectral balance
  - Make it sound consistent
- ◆ Separation of instruments
  - Make them distinct
  - Source clarity (same as "distinct?")
- ◆ Instrument-specific: punch, slam, etc.
  - See EQ table in topic 6
- ◆ EQ of effect returns (can be an issue)
  - Especially reverb

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## Processing in the Mix

- ◆ Reverb and spatial images
  - Creating the space
  - Placing instruments in it
- ◆ Processing solo instruments and voices
  - EQ for clarity and distinction
  - Special effects (and their placement and EQ)
- ◆ Dynamic-range effects at mix-time
  - Compression/limiting of solo instruments
  - Effect on perceived tempo

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## Content Mastering

- ◆ What is mastering? Why do we need it?
  - History: vinyl mastering engineer checked levels and EQ
  - Gradually, he/she did more preparation for the mastering (e.g., changing settings between songs)
  - Then, it became a separate process altogether (on special equipment, see above)

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## Mastering Issues

- ◆ General “good sound”
  - (Appropriate for the genre; not always “sweet”)
- ◆ Continuity between songs
  - Not always same performers, instruments, studio, engineer, producer, etc.
- ◆ Prepare for distribution
  - Listen with end-user’s ears and considering “delivery system”
  - May involve compression (limiting the dynamic range) and EQ (bass control)

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## The Mastering Process

- ◆ Generally a stereo-stereo transfer / copy
- ◆ May be D/D or D/A/D (specialists)
- ◆ Generally simple signal path with high-quality EQ and dynamic range processor
- ◆ Mastering engineer may be supervised by executive producer
- ◆ Results auditioned / approved by musicians and recording engineer
- ◆ May be iterative: “send it back to the mixer”
- ◆ See David Torrey’s comments in the readings

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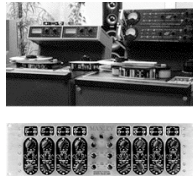
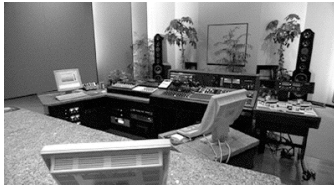
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## Gateway Mastering Studio

- ◆ Digital I/O in all known formats
- ◆ Analog I/O on Ampex ATR tape
- ◆ Custom Manley EQ and other processors
- ◆ Eggleston Savoy monitor speakers



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## DSP in Mastering

- ◆ EQ: See comments above on mix-down
  - Bass: boom and bloom, slam, tightness
  - Mid: vocal brightness
  - Highs: extend or dampen
- ◆ Dynamic range
  - Generally compressed (relative to studio mix)
- ◆ Stereo image
  - May decorrelate, rotate, or otherwise process stereo image
  - Ambience/reverb processing in mastering

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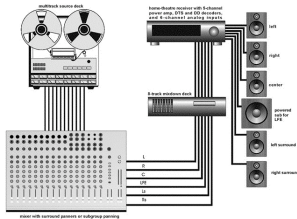
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## Mastering for Surround

- ◆ Much of the surround-sound content today is based on stereo mix-downs
  - Even much of the newly-mixed content!
- ◆ Questions (for standard content):
  - How is the center channel different from the L+R mono signal?
  - How are the surround signals different from the reverb returns?
  - Is the LFE channel different from the LP-filtered mono signal?
  - Comments of “golden ears” on AES panel and in *Mix* article...
- ◆ Automatic 2-5 “matrix” up-mix possible (see MAT 240C)



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## Specific Distribution Formats

- ◆ Always get feed-back: iterative process
- ◆ Issues:
  - Vinyl: levels and bass control
  - CD: compression and anti-aliasing filter (in case of AAD process)
  - Radio: compression, limited freq. response
  - Surround sound: surround encoders (and their distortion), LFE and sub-woofers
  - Streaming: MP3 encoders (and their distortion)

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## Special-Case Mastering

- ◆ Mastering for radio
  - Heavy compression
  - Song-length editing
- ◆ Mastering for streaming distribution
  - Take encoder into account
  - Pre-process sound for MP3 or AAC
- ◆ Other cases
  - Mastering for loudspeaker performance (electroacoustic music)
  - Mastering for lip-syncing

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## In the Real World

- ◆ Many low-budget productions are not formally mastered
- ◆ Services such as DRT Mastering exist to help unsigned acts
- ◆ Many smaller surround and film projects are mixed to the integrated DVD
- ◆ Many CDs suffer because of this!

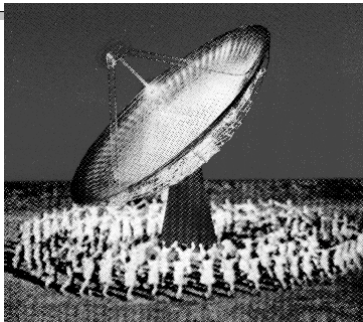
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## Summary

- ◆ Mixing
  - There are many processes and trade-offs beyond “getting the levels right”
  - Many of the special techniques are based on the experience of the mixing engineer
- ◆ Mastering
  - This process can be simple or very involved
  - It can greatly enhance the listenability of the content
  - There are special processes for various distribution formats

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## What's Next?

- ◆ Formats and distribution media
- ◆ Surround sound and home theater
- ◆ Software-based digital audio workstations
- ◆ Next readings

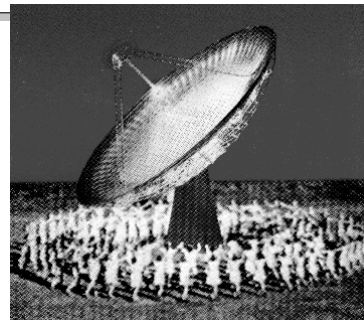
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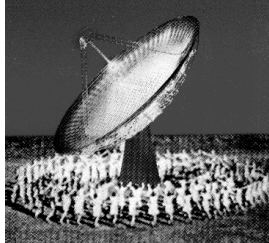
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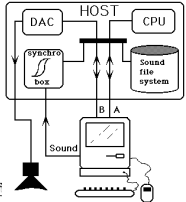
## MAT 242: Special Topics in Digital Multimedia: Recording Studio Engineering



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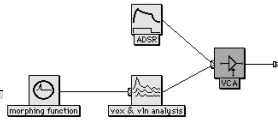
## Topic 8 Outline

- ◆ Computers and digital audio workstations
  - Software solutions
    - Standard Features
  - OS Support for Digital Audio
  - Hardware
    - Main CPU
    - Storage
    - IO
      - Sound IO
      - GUI IO
      - MIDI
    - Other features





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## Readings





- ◆ **Computers and Digital Audio Workstations**
  - Recording, Mixing, and signal processing on a Personal Computer
  - Build It: DAW
  - Ardour brochure,
  - Linux Applications using jack



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## (As always) History

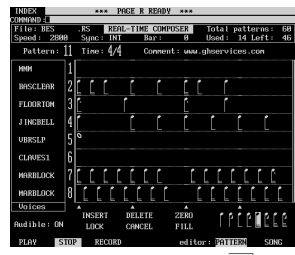
- ◆ Digital audio background
  - 1960s: software sound synthesis vs analog electronic music (total control vs real-time performance)
  - 1980s: real-time digital synthesizers/mixers (Fairlight, Synclavier, Dyaxis, etc.)
  - 1990s: Real-time software on standard PCs with/without hardware acceleration (e.g., NeXT, DSP sound cards, ProTools DSP, Kyma)
  - Current: Many applications possible on off-the-shelf PC

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## Digital Audio Software

- ◆ Computer-aided composition
  - ...a whole separate topic
- ◆ Synthesis
  - SW sound synthesis
  - DSP-assisted
  - Control of dedicated synthesis HW
- ◆ Control, performance
  - MIDI sequencers, OSC
- ◆ Recording/mixing
  - DAW applications
- ◆ Score printing



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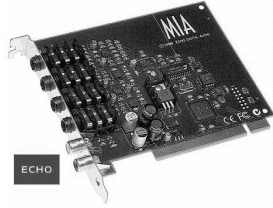
## Computer Sound Synthesis

- ◆ SW sound synthesis “languages”
  - Music-N family
  - Modern relatives (SuperCollider, CSL, Jsyn)
- ◆ Computer control of synthesis HW
  - MIDI
  - DSP-based synthesizers
- ◆ Control processing and mapping
  - Max/MSP

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## Computers and Recording

- ◆ History (see above)
- ◆ Storage issues
  - Volume
  - Throughput
  - Noise level
- ◆ GUI issues
  - Model
  - Interaction



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## Data and Interaction Models

- ◆ Sound objects
  - Sampled sound (the norm)
  - Feature extraction and parametric models
  - Mixed-mode (e.g., sound + MIDI)
- ◆ Operations and their semantics
  - Copy/cut/paste
  - Fades (in/out/cross)
  - Mixing
- ◆ Tasks and task models
  - Tape recorder
  - Mixing console
  - Cue sheet, score

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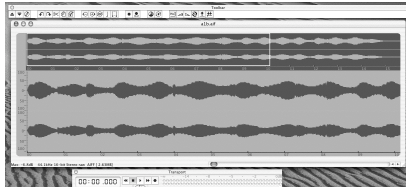
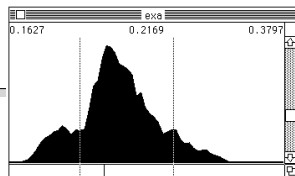
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## Sound Objects

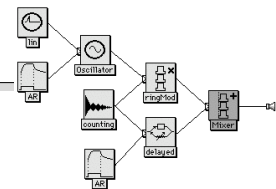
- ◆ See P. Schaeffer
- ◆ Sampled sound
  - High expressive completeness
  - No structural generality
- ◆ No spatial data



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## Control Models

- ◆ MIDI commands
  - Note on/off
  - Controllers
  - System exclusive commands
  - Sample dumps
- ◆ OSC and other fine-grained parametric models
  - Separate control from triggers



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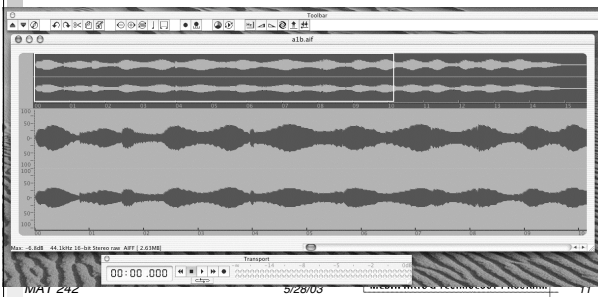
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## Sampled Sound Editors

- ◆ Example: BIAS Peak 3.0



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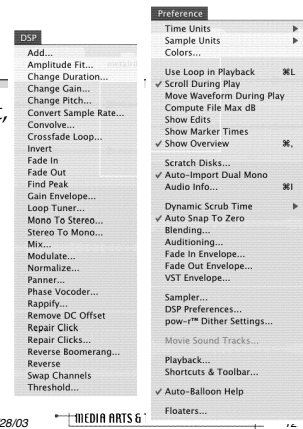
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## Operations

- ◆ Cut/copy/paste, insert, reverse
- ◆ Envelopes, fades, normalization
- ◆ Stereo <--> mono
- ◆ Pitch/time processing
- ◆ Analysis/resynthesis
- ◆ Sampler-specific processing
- ◆ Other operations



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## Digital Mixers

- ◆ Tape recorder model
  - Record onto one or many tracks
- ◆ Mixing console
  - Mix separate tracks to groups
- ◆ Plug-in effects
  - Aux sends and inserts on channels
  - Channel and group effects
- ◆ File management
  - Data pool, project files, backup/deletion
- ◆ Data export
  - Save mix as AIFF, MP3, etc.

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## DAW Software GUIs

- ◆ Cue sheet view
  - Tracks (audio, MIDI, video)
- ◆ Mixer view
  - Channel strips
- ◆ Parameter dialog boxes
  - Various kinds
- ◆ Transport controls
  - Transport control, metering, metronome

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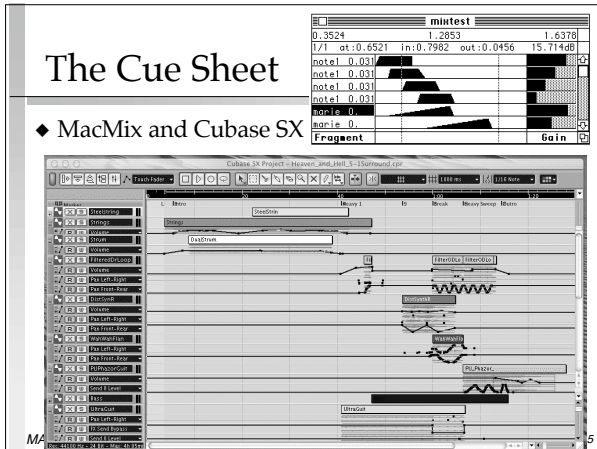
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## The Cue Sheet

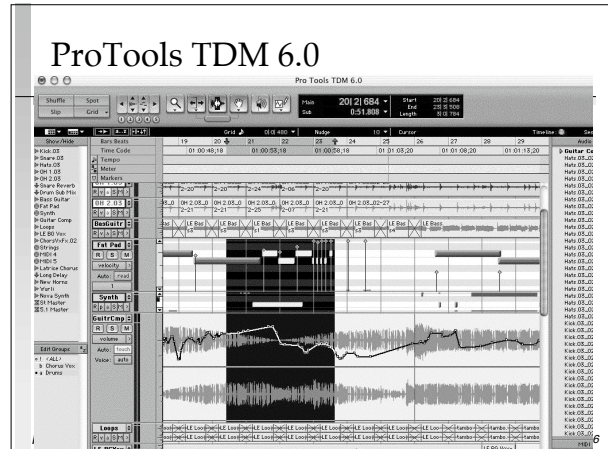
- ◆ MacMix and Cubase SX



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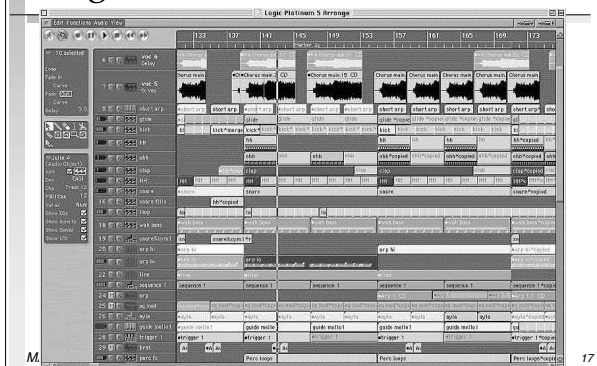
## ProTools TDM 6.0



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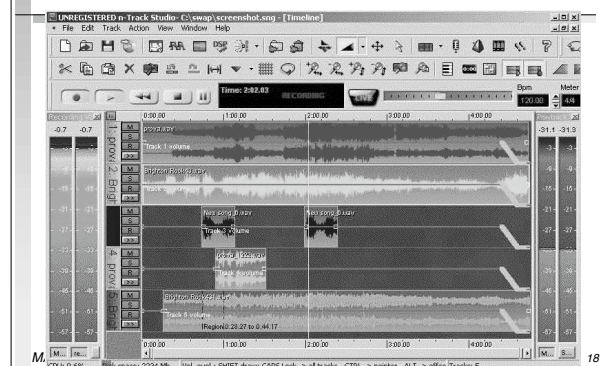
## Logic Cue Sheet View



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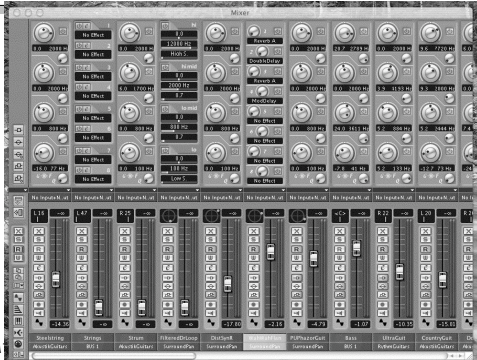
## N-Track Studio GUI



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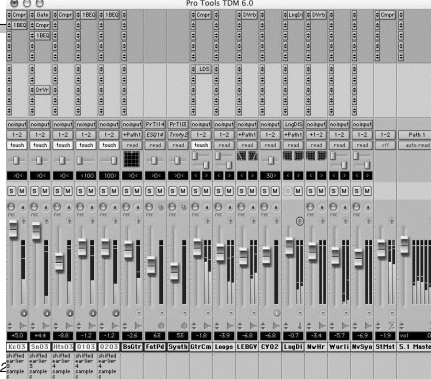
## The Mixer (a la Cubase SX)



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## ProTools TDM 6.0

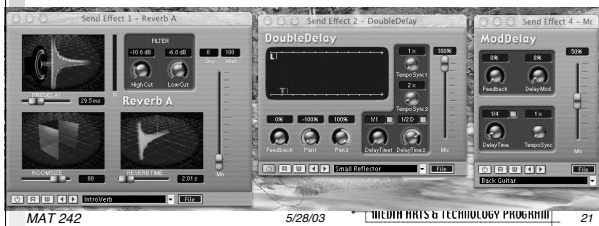


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## Parameter Dialogs

- ◆ Per plug-in control surface
- ◆ Parameters may be linked to MIDI or HUI controls



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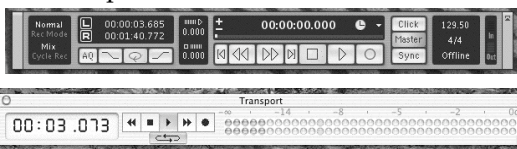
## ProTools TDM Plug-ins



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## Transport Controls

- ◆ Start/stop FF/rew controls
- ◆ Time counter
- ◆ May include metering, metronome, etc.
- ◆ Examples: Cubase and Peak



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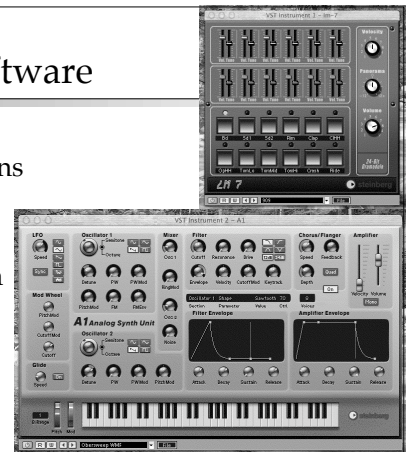
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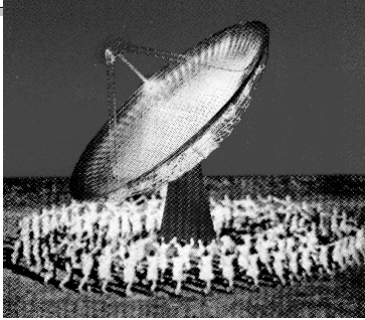
## Other Software

- ◆ SoftSynths
- ◆ DSP plug-ins
- ◆ Looping, DJ SW
- ◆ Restoration
- ◆ Others?



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## DAW Hardware

- ◆ PC configuration
  - CPU, motherboard, etc.
- ◆ Storage
  - The storage pyramid
- ◆ DSP coprocessors
  - IO “sound cards” vs DAW coprocessors
- ◆ Control IO
  - MIDI controllers, tablets, control surfaces, etc.
- ◆ Configurations
  - ExtremeTech systems, Chris U’s paper

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## PCs for DAWs

- ◆ Processor: number, type, and speed
- ◆ Caches and RAM (big and fast)
- ◆ Hard disks: system and sound file
- ◆ Environmental issues:
  - Power consumption
  - Portability
  - Fan noise
- ◆ Reliability/robustness (MTBF, MTTR)

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## Storage Solutions

- ◆ FireWire, RAID, DVD-RAM, Magneto-optical, DLT, etc.
- ◆ Reliability, hot-swapping
- ◆ Daily use vs archival



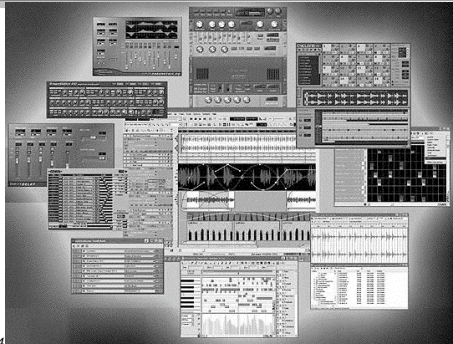
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## Operating System Issues

- ◆ Kernel services
  - Threads, file system, etc.
- ◆ Audio/video/MIDI APIs
  - Minimum latency and latency jitter
- ◆ GUI framework
- ◆ Language support
- ◆ Bottom line: “Which OS sucks the least?”

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## Integration (e.g., Sonar 2 XL)



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## Portable Systems

- ◆ DAW on lap-tops
  - Sound IO (FireWire, PC-card interfaces)
  - Control IO (MIDI, USB)
  - Storage (built-in vs external)
  - Noise issues
  - Expansion boxes (for PCI cards)

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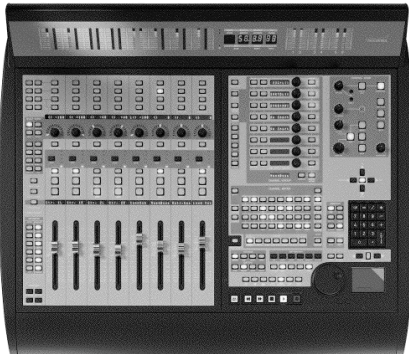
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## Digital Mixers and DAWs

- ◆ Digital mixer
  - Control surface
  - DSP coprocessor
  - Many channels of IO



## Digidesign ProControl Surface



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## The Future

- ◆ Back to the basic models
  - Performance synthesizer
  - Recorder/mixer
- ◆ Will the computer disappear?
- ◆ What will the task model(s) and interface(s) be?



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## Summary

- ◆ DAW models
- ◆ DAW SW solutions
- ◆ Configuring a PC as a DAW
- ◆ Future DA SW solutions

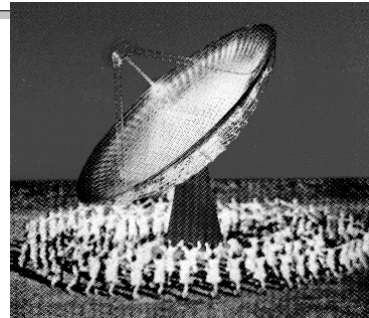
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