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21M.380 Music and Technology
Recording Techniques & Audio Production (Fall 2016)

Instructor: Florian Hollerweger

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21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 1: The art of sound recording

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, September 7, 2016

Description

In this course, you will be introduced to music recording and audio production from a practical and theoretical perspective. You will learn about the physical nature and human perception of sound, how it is transformed to and from electrical signals by means of microphones and loudspeakers, and how it can be creatively modeled through mixing consoles, signal processors, and digital audio workstations. You will learn to make informed choices about microphone selection and positioning, and we will cover various editing, mixing, and mastering techniques.

Intended learning outcomes

1. An understanding of basic principles of acoustics and auditory perception
2. A practical and theoretical understanding of basic audio recording and production techniques
3. The ability to use digital audio workstation (DAW) software for the purpose of manipulating audio data
4. A critical awareness regarding the cultural, social, and historical context of music technology

Student selection process

Figure: Bonne chance! (Courtesy of Casey Bisson.)

Locations of interest

Image removed.

Figure: 21M.380 course locations

Locations of interest

Figure: Killian Hall, [redacted] ()

Locations of interest

Figure: Music Library, [redacted] (Courtesy of Lewis Music Library.)

Recording equipment at MIT

Figure: The MObile Sound System (MOSS), designed by Chris Ariza (Image by MIT OpenCourseWare)

Recording equipment at MIT

Figure: Zoom H4n portable audio recorder (© Zoom North America. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Desktop or laptop computer

Figure: Music Library, [redacted] (Courtesy of Lewis Music Library. BY-NC)

Studio headphones (or nearfield monitor loudspeakers)

Manufacturer and model	Price	Back
Beyerdynamic DT770 Pro 80 Ω	$175	closed
Beyerdynamic DT770 Pro 250 Ω	$175	closed
Audio-Technica ATH-M series	$50 – $170	closed
Sennheiser HD 25-1 II	$170	closed
Sennheiser HD 25-SP II	$120	closed
Sennheiser HD280 Pro	$90	closed
Shure SRH440	$100	closed
AKG K240 MKII	$150	semi-open
AKG K240 Studio	$85	semi-open
AKG K99	$80	semi-open
AKG K77	$50	semi-closed
AKG K44	$30	closed

Table: Some headphones suitable for use in this course

Digital Audio Workstation (DAW) software package

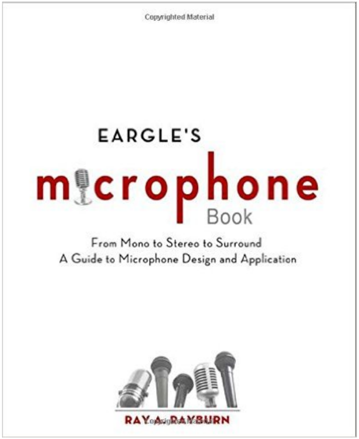
Figure: Reaper (© Cockos. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Digital Audio Workstation (DAW) software package

Software package	Linux	Mac	Win	Price
Cockos Reaper	(✔)	✔	✔	from $60
Ardour	✔	(✔)	(✔)	from $0
Apple Logic Pro X		✔		$199
Bitwig Studio	✔	✔	✔	from $269
MAGIX Samplitude Pro X			✔	$499
Avid Pro Tools 12 series		✔		depends
Steinberg Cubase 7 Elements		✔	✔	$99.99

Table: DAW packages suitable for use in this course (recommended ones on top)

Recommended textbooks



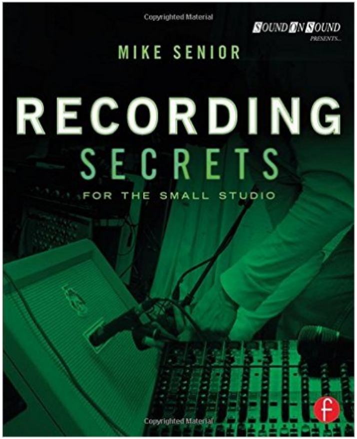
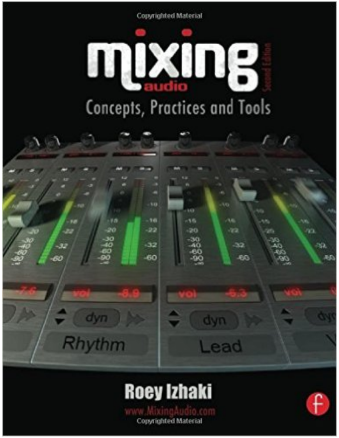


Figure: Recommended textbooks (© Focal Press. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Recommended textbooks



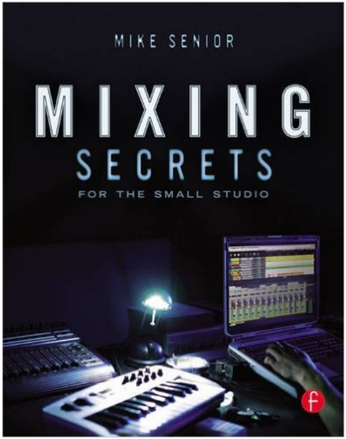


Figure: Recommended textbooks ()

Recommended textbooks

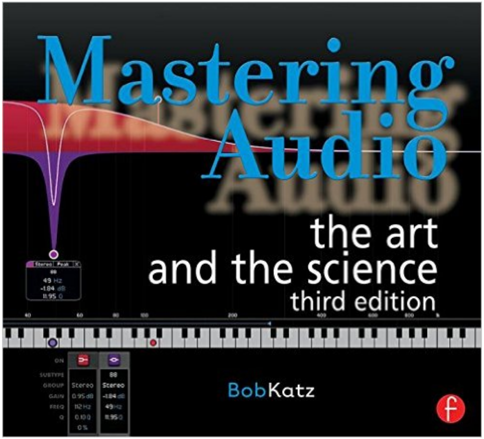


Figure: Recommended textbook (© Focal Press. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

OpenCourseWare archive

Figure: OpenCourseWare archive (spring 2012 course by Chris Ariza)

Assignments, quizzes, and grading

	Description	Code	$\sum$
3	In-class quizzes	QZ1–QZ3	20%
15	Reading assignments	RD01–RD15	10%
2	Production analyses	PA1+PA2	10%
2	Written assignments	WR1+WR2	10%
4	Sound editing exercises	ED1–ED4	20%
2	Recording session reports	SR1+SR2	5%
3	Mixing assignments	MX1–MX3	25%

Table: Assessment items and final grade contributions

Assignments, quizzes, and grading

Letter grade	Numeric score
A	90%–100%
B	80%–89%
C	70%–79%
D	60%–69%
F	0%–59%

Table: Grading scheme

Attendance

- Any absences have to be communicated to and approved by the instructor ahead of time in order to be excused.
- One unexcused absence without penalty (except for recording sessions for which you act as an engineer or performing musician)

Schedule

Date	Content
Wed, 9/7	The art of sound recording
Mon, 9/12	Physics of sound
Wed, 9/14	Microphones
Mon, 9/19	Perception of sound
Wed, 9/21	Workshop: MOSS intro & mic handling
Mon, 9/26	Basic sound editing techniques
Wed, 9/28	Workshop: Cables, preamps, patchbays
Mon, 10/3	Filters & EQs
Wed, 10/5	Stereo recording techniques
Mon, 10/10	**No class (Columbus Day)**
Wed, 10/12	Dynamics & compression
Mon, 10/17	Workshop: Stereo recording practice
Wed, 10/19	Workshop: Headphone monitoring

Schedule (cont.)

Date	Content
Mon, 10/24	Digital audio
Wed, 10/26	Mixing consoles
Mon, 10/31	Student presentations: Recording session plans
Wed, 11/2	Mixing strategies
Mon, 11/7	Recording session 1 (piano solo)
Wed, 11/9	Room acoustics & reverberation
Mon, 11/14	Recording session 2 (Love and a Sandwich)
Wed, 11/16	Recording session 3 (Pscience Phiction)
Mon, 11/21	Quiz, review, preview
Wed, 11/23	Sound quality & critical listening
Mon, 11/28	Recording session 4 (piano trio)
Wed, 11/30	Recording session 5 (violin & piano duet)
Mon, 12/5	Mastering techniques
Wed, 12/7	Workshop: Command-line sound editing

Schedule (cont.)

Date	Content
Mon, 12/12	Guest speaker Al Kooper
Wed, 12/14	Workshop: 5.1 surround sound

What qualifies as music technology?

Figure: Studer Vista digital mixing console ()

What qualifies as music technology?

Figure: AKG C 414 XL II dual-large-diaphragm condenser microphone with switchable directivity ()

What qualifies as music technology?

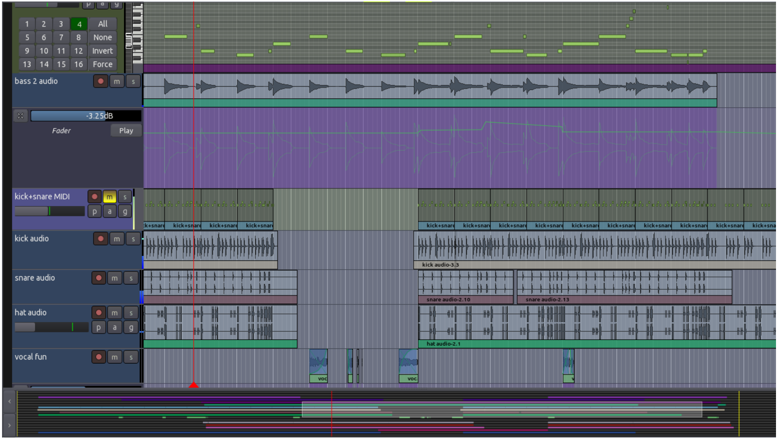


Figure: Ardour digital audio workstation

What qualifies as music technology?

Figure: RME Multiface II audio interface ()

What qualifies as music technology?

Figure: A violin (Ⓟ Public domain image. Public domain, CC0 1.0 license)

What qualifies as music technology?

```
(
play{x=165;b=SinOsc;p=Trig.ar(Saw.ar(x),1);
     y=b.ar(p*x);z=b.ar(p);
     (GVerb.ar(GrainIn.ar(2,y,y/2,z,p*z,-1),9))/9}
//basso gettato #SuperCollider
)
```

Listing 1: *Not* a tweet by Donald Trump ()

What qualifies as music technology?

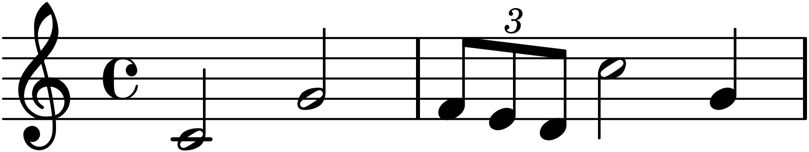


Figure: Some music notation (which piece?)

What do we need to record music?

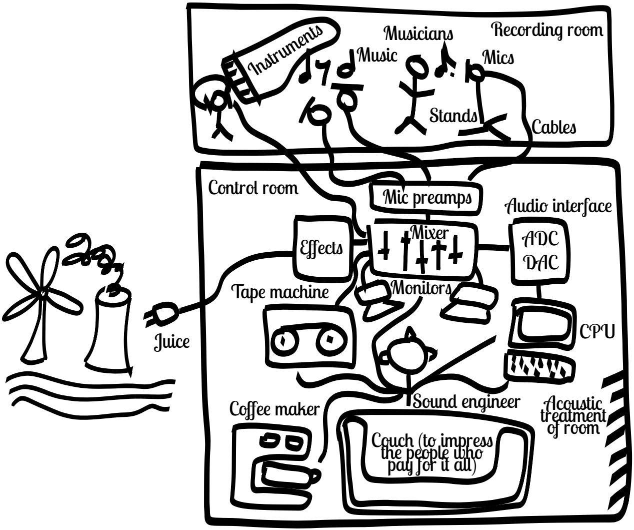


Figure: A few things required to record music

The music production process

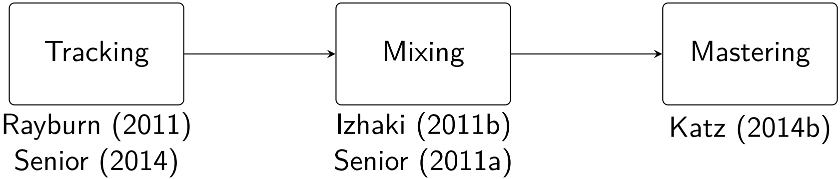


Figure: The music production process (after Eargle 2003a, p. 326)

Words, words, words...

Studio jargon can be pretty intimidating, but the sooner you get a grip on it, the quicker you'll improve your mixing. (Senior 2011a, p. x)

Music technology glossaries

- Bohn (2017)
- Los Senderos Studio (2017)
- Recording Institute Of Detroit (2014)
- Sound on Sound (2014)

Tympanic principle

The vibrating diaphragm that allowed telephones and phonographs to function was itself an artifact of changing understandings of human hearing. (Sterne 2003, p. 7)

Electroacoustic principle

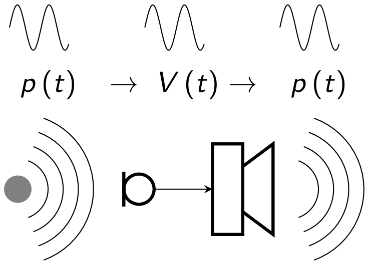


Figure: Electroacoustic reproduction chain

Digital principle

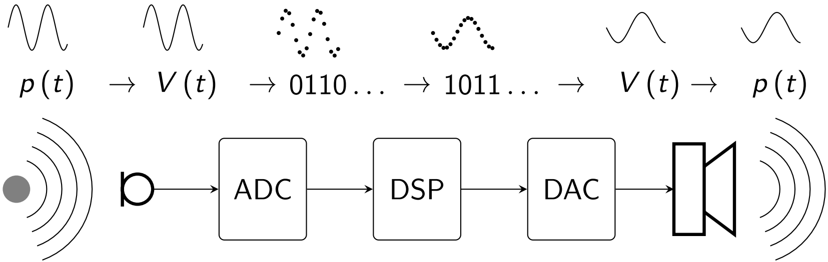


Figure: Digital reproduction chain

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 2: Physics of sound

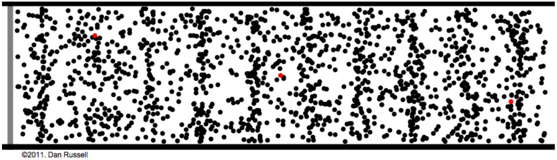
Massachusetts Institute of Technology
Music and Theater Arts

Monday, September 12, 2016

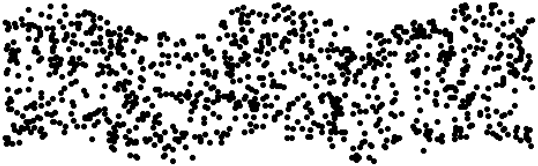
What is sound?

Figure: Fallen tree in a forest (Courtesy of ChenYen.Lai on Flickr.)

Longitudinal vs. transverse waves



(a) Longitudinal plane wave



(b) Transverse wave

Figure: Wave snapshots (© Daniel A. Russell. Grad. Prog. Acoustics, Penn State.)

Longitudinal vs. transverse waves

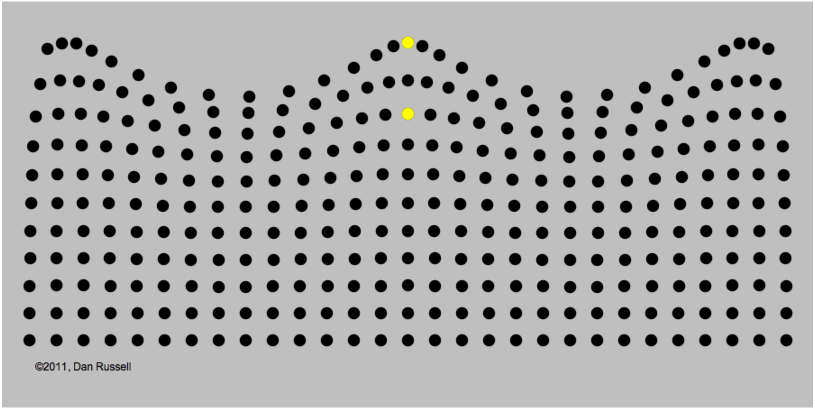
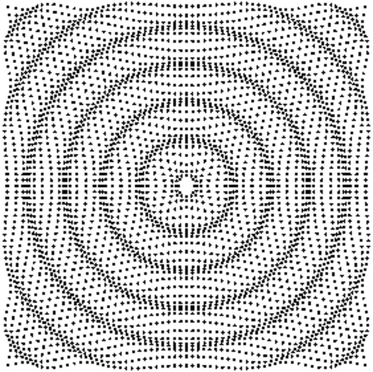
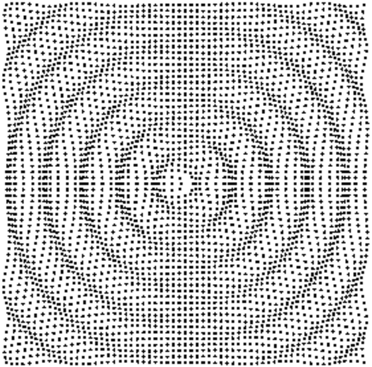


Figure: Water wave (© Daniel A. Russell. Grad. Prog. Acoustics, Penn State.

Radiation patterns



(a) Monopole



(b) Dipole

Figure: Monopole and dipole (© Daniel A. Russell. Grad. Prog. Acoustics, Penn State. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Spherical vs. plane waves

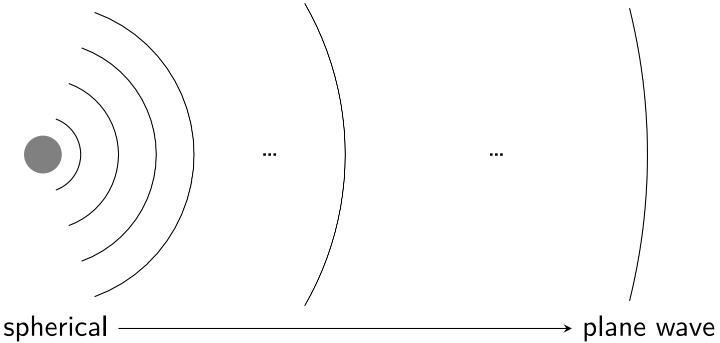


Figure: Spherical vs. plane wavefronts

Visualization as a waveform

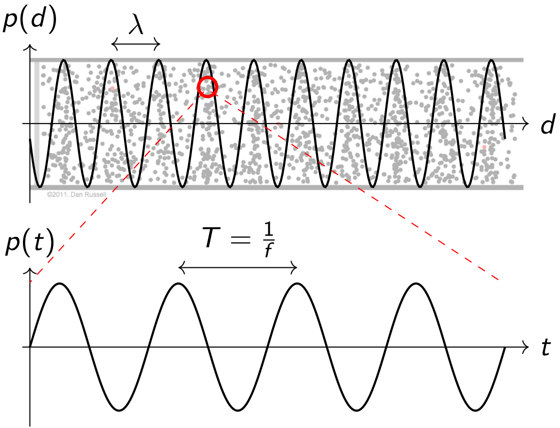


Figure: Sound as a spatial (top) and temporal (bottom) phenomenon (Background image (top) © Daniel A. Russell, Grad. Prog. Acoustics, Penn State, CC BY-NC-ND, This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Visualization as a waveform

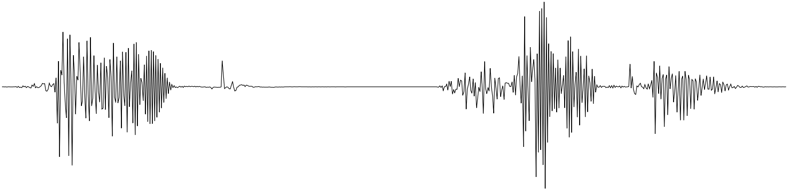


Figure: A more complex example of an audio waveform

Wave properties

Property	Symbol	Unit
Amplitude	A	μPa, mV, …
Period	T	s
Frequency	f	Hz
Wavelength	λ	m
Speed of sound	c	$\mathrm{m\,s^{-1}}$
Phase	φ	° or rad

Table: Wave properties

Amplitude

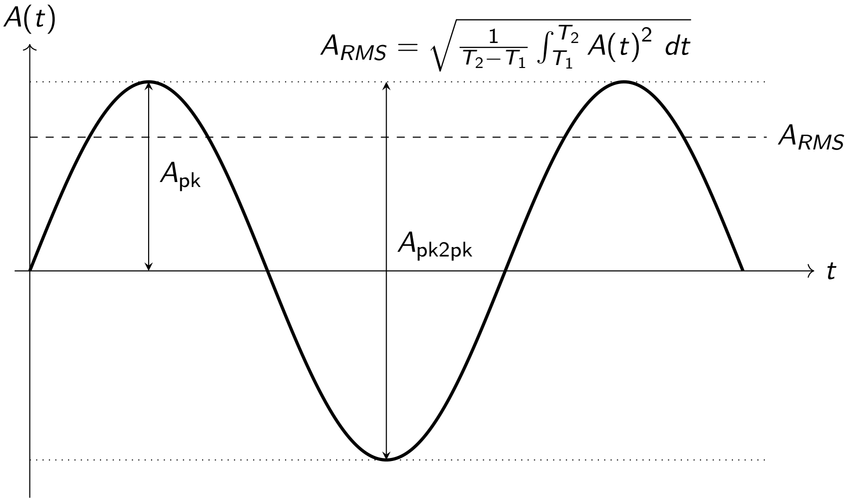


Figure: Peak, peak-to-peak, and RMS amplitudes of a sine wave

Amplitude

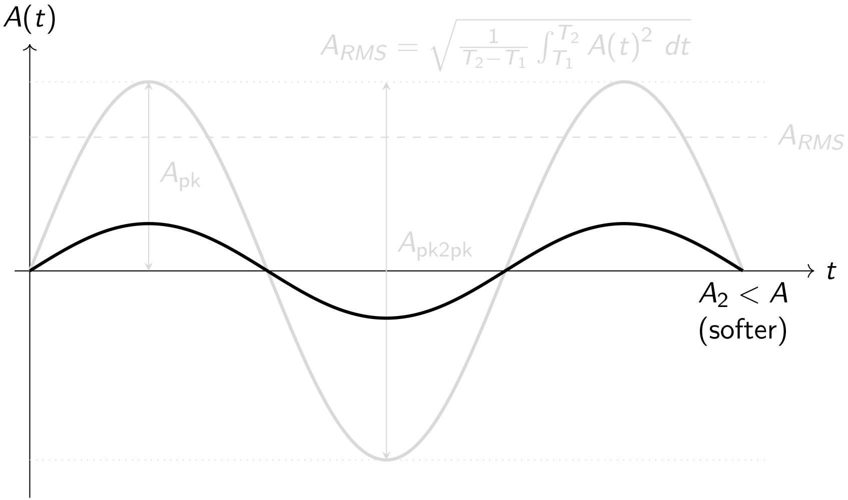


Figure: Amplitude vs. perceived loudness

RMS amplitude

Root mean square

$$A_{RMS} = \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} A(t)^2 \, dt}$$

Signal type	A_{RMS}
DC	A_{pk}
Square wave	A_{pk}
Sine wave	$\frac{A_{pk}}{\sqrt{2}}$
Sawtooth	$\frac{A_{pk}}{\sqrt{3}}$

Table: Relationship between RMS amplitude A_{RMS} and peak amplitude A_{pk} for different signals

Frequency & period

Temporal wave properties

$$f = \frac{1}{T}$$

- T ... period (s)
- f ... frequency ($\mathrm{Hz} = \mathrm{s}^{-1}$)

Frequency & period

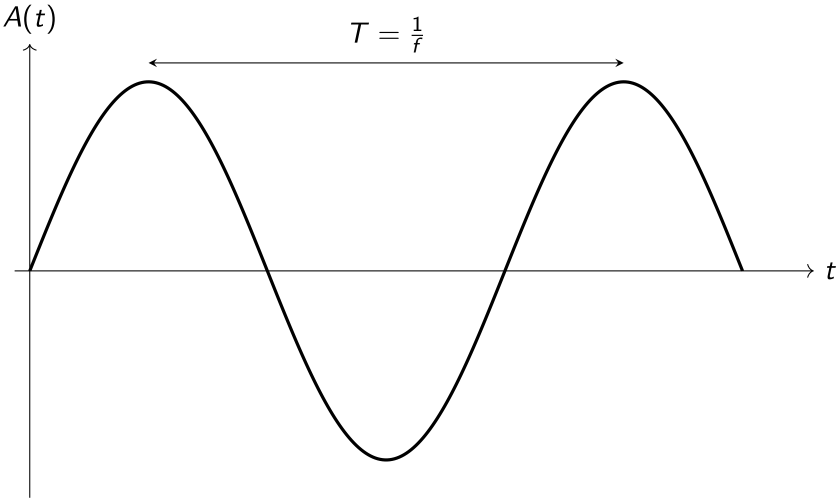


Figure: Period T and frequency f of a sine wave

Frequency & period

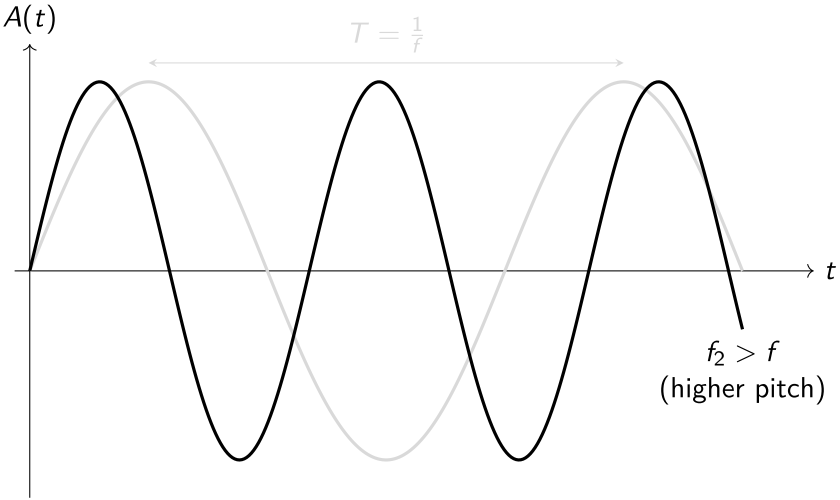


Figure: Frequency vs. perceived pitch

Frequency & period

f_1/f_2	Interval	Acronym
1:1	Perfect unison	P1
2:1	Perfect octave	P8
3:2	Perfect fifth	P5
4:3	Perfect fourth	P4

Table: Frequency ratios vs. (justly tuned) musical intervals

Wavelength

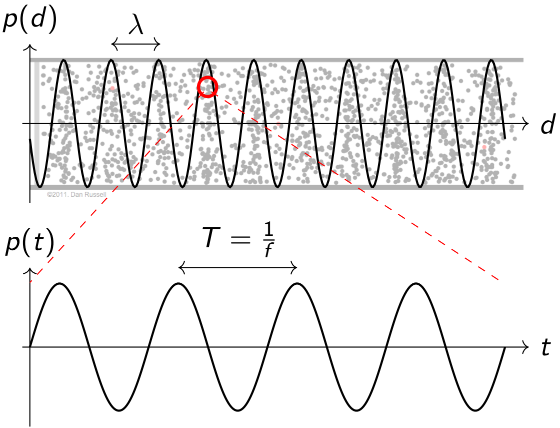


Figure: Sound as a spatial (top) and temporal (bottom) phenomenon

Speed of sound

Wave math

$$c = \lambda \cdot f$$

Depends on temperature in air

$$c_{\text{air}} \approx 331.3 + 0.606 \cdot \vartheta$$

Value to remember (👍×π)

$$c_{\text{air, 15 C}} \approx 340\,\text{m s}^{-1}$$

Medium	$c/\text{m s}^{-1}$
Air (20 °C; 0 % hum.)	343.2
Water (fresh; 25 °C)	1497
Steel	4597

Table: c increases with density ρ

- c … speed of sound (m s^{-1})
- λ … wavelength (m)
- f … frequency ($\text{Hz} = \text{s}^{-1}$)
- ϑ … temperature (°C)
- ρ … density (kg m^{-3})

Speed of sound

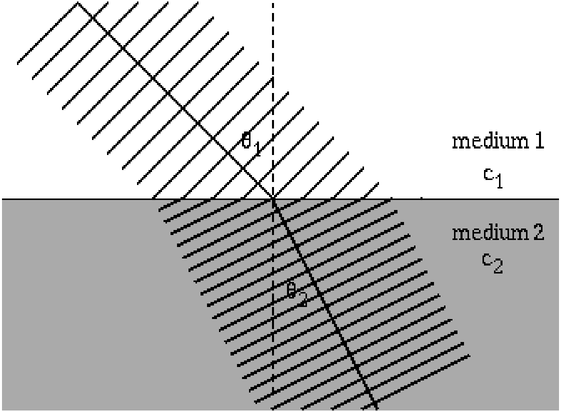


Figure: Change of c and λ across media of different density (

Phase

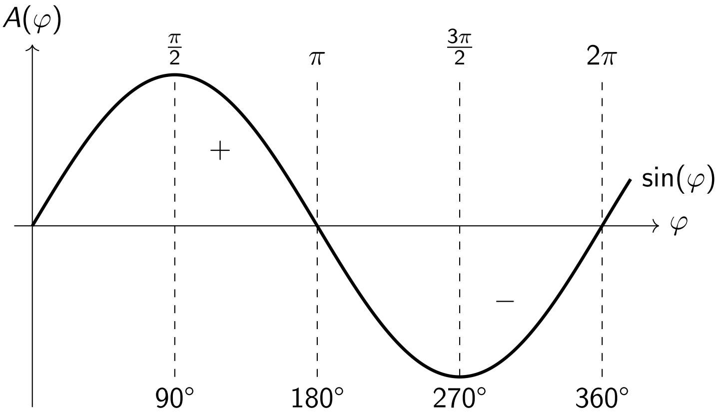


Figure: Phase cycle of a sine wave

Interference & phase cancellation

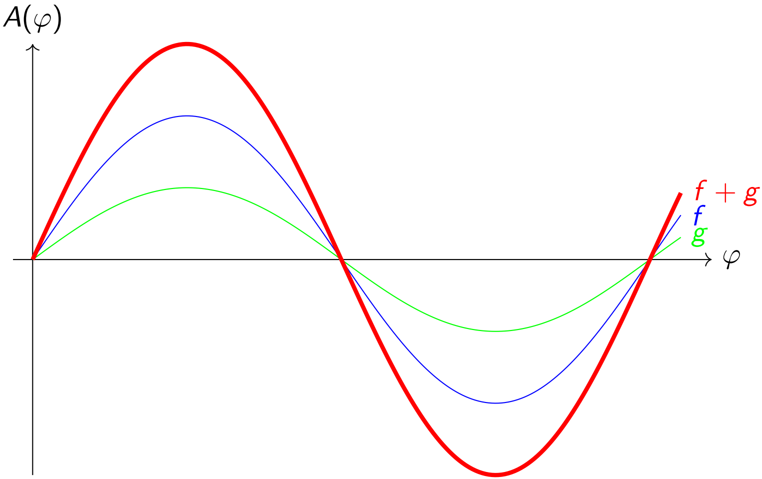


Figure: Constructive interference between two in-phase waves f (blue) and g (green), resulting in a higher-amplitude signal (red, thick)

Interference & phase cancellation

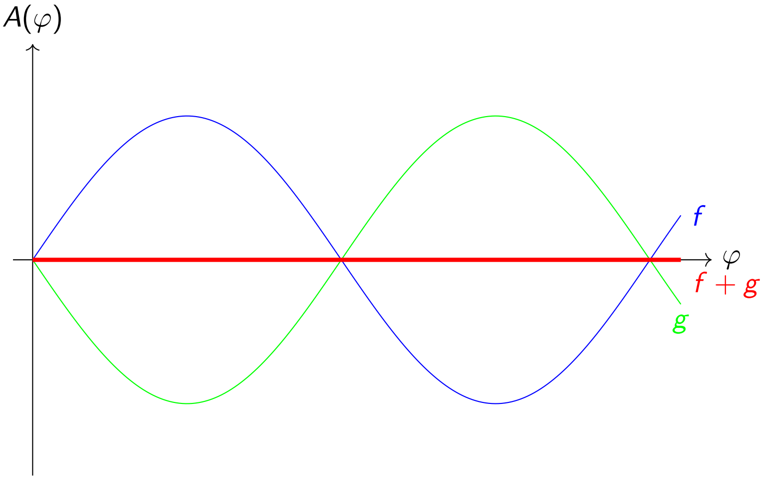


Figure: Destructive interference (phase cancellation) between two anti-phase waves f (blue) and g (green), resulting in a zero signal (red, thick), i.e., silence

Interference & phase cancellation

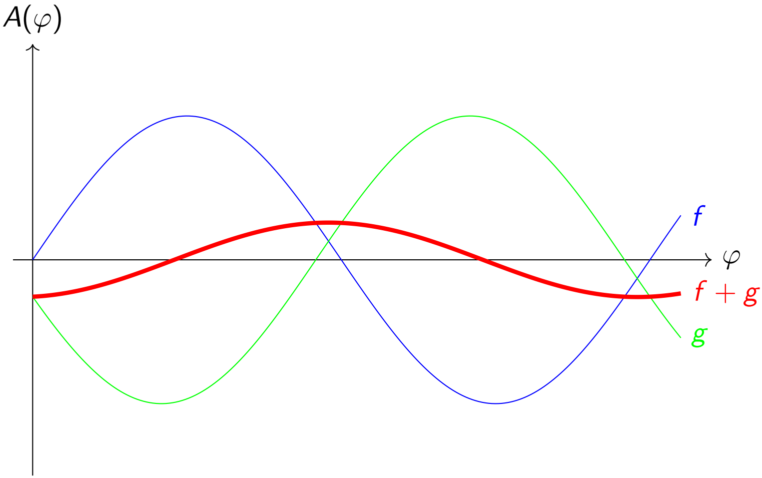


Figure: Mixed interference (mostly destructive) between two out-of-phase waves f (blue) and g (green), resulting in a lower-amplitude signal (red, thick)

Interference & phase cancellation

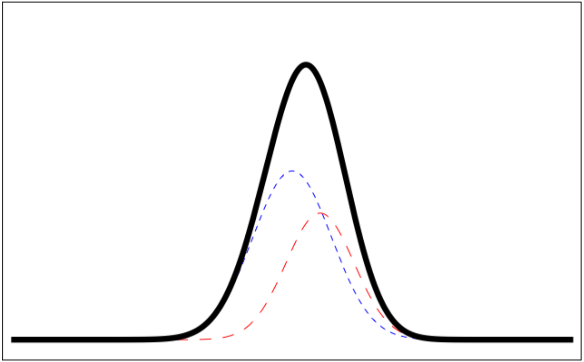


Figure: Superposition of two opposite direction wave pulses ()

Interference & phase cancellation

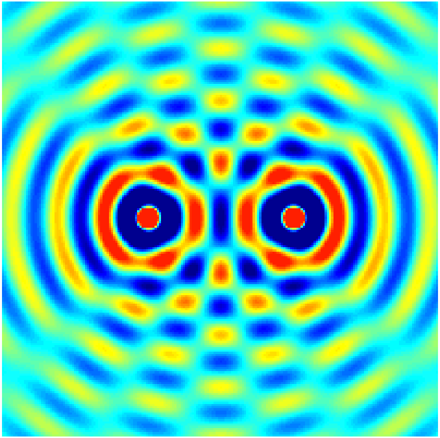


Figure: Interference between two spherical waves (Public domain image. Source: https://en.wikipedia.org/wiki/File:Two_sources_interference.gif)

Field quantities vs. energy quantities

Quantity	Symbol	Unit	Nature
Sound pressure	p	Pa	
Particle displacement	ξ	m	Field quantities
Particle velocity	v	$\mathrm{m\,s^{-1}}$	
Sound power	P_{ac}	W	Energy quantities
Sound intensity	I	$\mathrm{W\,m^{-2}}$	

Table: Acoustic quantities

Inverse square law & inverse distance law

$$I(r) = \frac{P_{ac}}{A} = \frac{P_{ac}}{4\pi r^2} \propto \frac{1}{r^2}$$

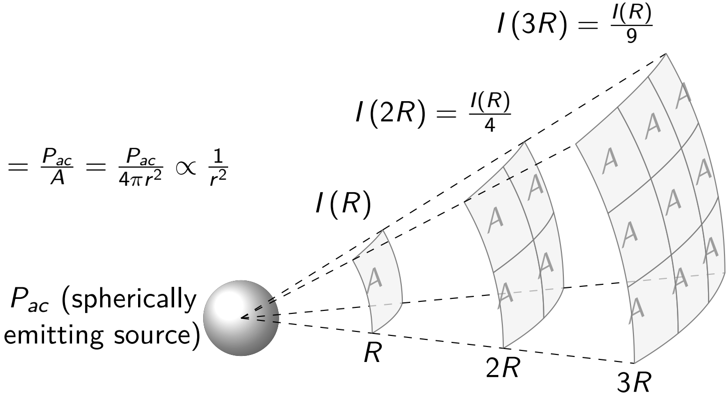


Figure: Inverse square law

Inverse square law & inverse distance law

Inverse square law

The sound intensity I of a spherical wavefront in a free field decreases with the square of the distance r from the source.

$$I \propto \frac{1}{r^2}$$

Inverse distance law

The sound pressure p of a spherical wavefront in a free field decreases with the distance r from the source.

$$p \propto \frac{1}{r}$$

The decibel (dB)

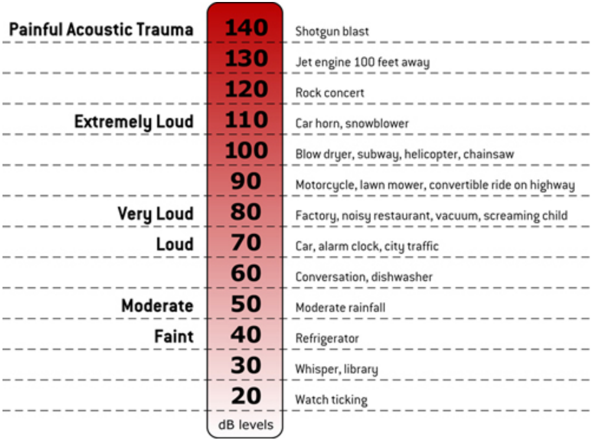


Figure: Decibel comparison chart ()

The decibel (dB)

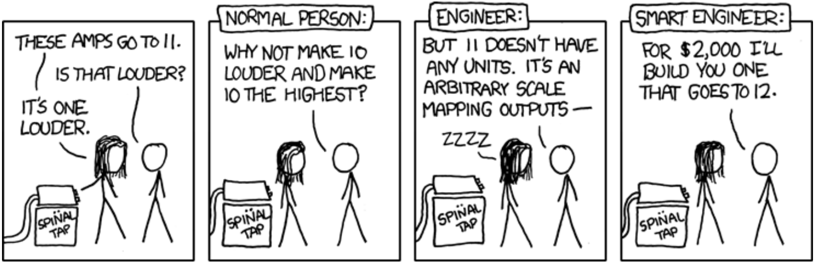


Figure: Spinal Tap Amps (Courtesy of Randall Munroe.)

Mathematical definition

Decibel

$$L = 20 \cdot \log_{10}\left(\frac{A}{A_0}\right) = 10 \cdot \log_{10}\left(\frac{A^2}{A_0^2}\right)$$

- L ... level (dB)
- A ... field quantity
- A^2 ... energy quantity
- A_0 ... reference field quantity
- A_0^2 ... reference energy qty.

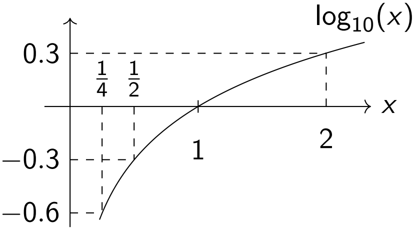


Figure: Logarithm to the base of 10

Sound pressure level (SPL)

Definition

$$L_p = 20 \cdot \log_{10}\left(\frac{p}{p_0}\right)$$

- L_p ... sound pressure level (dB_{SPL})
- p ... measured RMS sound pressure (μPa)
- p_0 ... reference sound pressure (μPa)

Common reference

$p_0 = 20\,\mu Pa \equiv 0\,dB_{SPL}$ (threshold of hearing)

Example

Sound pressure level measured by a reference microphone

Sound pressure level (SPL)

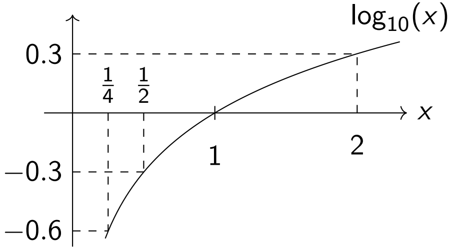
Problem (SPL drop at double distance)

dB_{SPL} drop at double distance according to inverse distance law $p \propto \frac{1}{r}$?

$$L = 20 \cdot \log_{10}\left(\frac{A}{A_0}\right) = 10 \cdot \log_{10}\left(\frac{A^2}{A_0^2}\right)$$

Field quantity A? Energy quantity A^2? Field quantity!

$$\begin{aligned} L_{2r} &= 20 \cdot \log_{10}\left(\frac{p}{p_0}\right) \\ &= 20 \cdot \log_{10}\left(\frac{\frac{1}{2r}}{\frac{1}{r}}\right) \\ &= 20 \cdot \log_{10}\left(\frac{1}{2}\right) \approx -6\,\text{dB} \quad \square \end{aligned}$$



Sound intensity level (SIL)

Definition

$$L_I = 10 \cdot \log_{10}\left(\frac{I}{I_0}\right)$$

- L_I ... sound intensity level (dB_{SIL})
- I ... sound intensity to be compared to reference (W m^{-2})
- I_0 ... reference sound intensity (W m^{-2})

Common reference

$I_0 = 10^{-12}\,\text{W m}^{-2} \equiv 0\,\text{dB}_{\text{SIL}}$ (threshold of hearing at 1 kHz)

Example

Sound intensity level at the human eardrum

Sound intensity level (SIL)

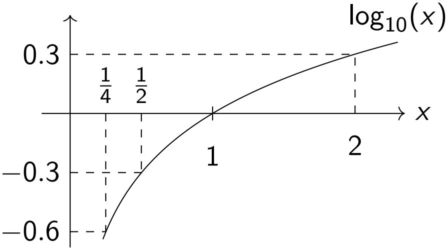
Problem (SIL drop at double distance)

dB_{SIL} drop at double distance according to inverse square law $I \propto \frac{1}{r^2}$?

$$L = 20 \cdot \log_{10}\left(\frac{A}{A_0}\right) = 10 \cdot \log_{10}\left(\frac{A^2}{A_0^2}\right)$$

Field quantity A? Energy quantity A^2? Energy quantity!

$$\begin{aligned} L_{2r} &= 10 \cdot \log_{10}\left(\frac{I}{I_0}\right) \\ &= 10 \cdot \log_{10}\left(\frac{\frac{1}{(2r)^2}}{\frac{1}{r^2}}\right) \\ &= 10 \cdot \log_{10}\left(\frac{1}{4}\right) \approx -6\,\text{dB} \quad \square \end{aligned}$$



Sound power level (SWL)

Definition

$$L_W = 10 \cdot \log_{10}\left(\frac{P_{ac}}{P_0}\right)$$

- L_W ... sound power level ($\mathrm{dB_{SWL}}$)
- P_{ac} ... sound power to be compared to reference (W)
- P_0 ... reference sound power (W)

Common reference

$P_0 = 10^{-12}\,\mathrm{W} = 1\,\mathrm{pW} \equiv 0\,\mathrm{dB_{SWL}}$

Example

Sound power level of a loudspeaker

Visualization as a spectrum

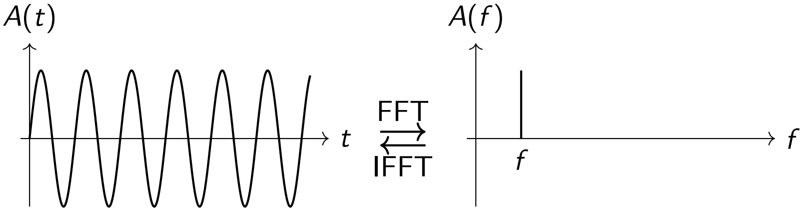


Figure: A sine wave's spectrum consists of a single frequency

Visualization as a spectrum

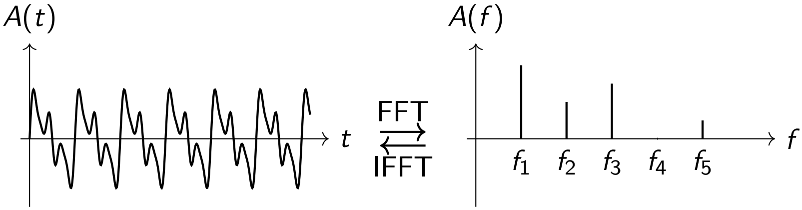


Figure: A periodic wave has a harmonic spectrum

Visualization as a spectrum

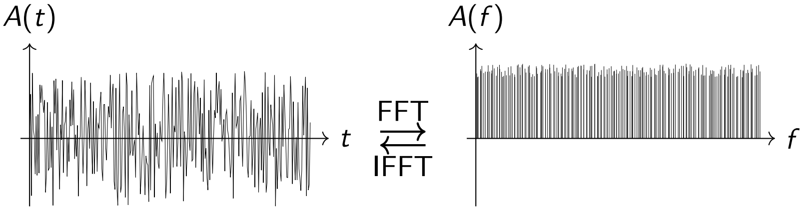


Figure: An aperiodic wave has an inharmonic spectrum

Harmonic sounds

Harmonic spectrum

The frequency components f_N of a harmonic spectrum are integer multiples of its fundamental frequency f_1.

$$f_N = N \cdot f_1$$

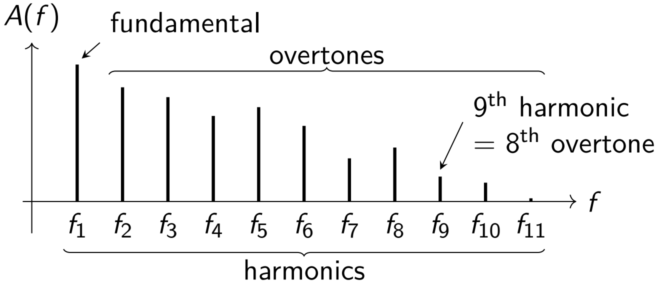


Figure: Harmonic spectrum

Harmonic sounds

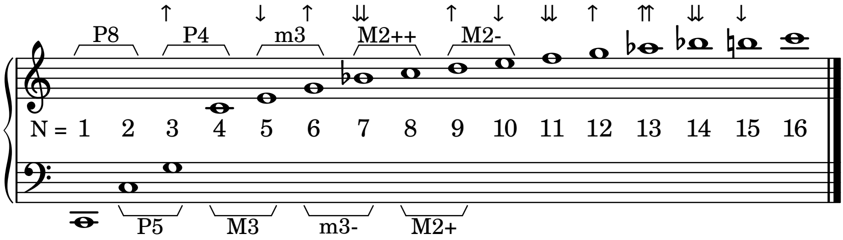


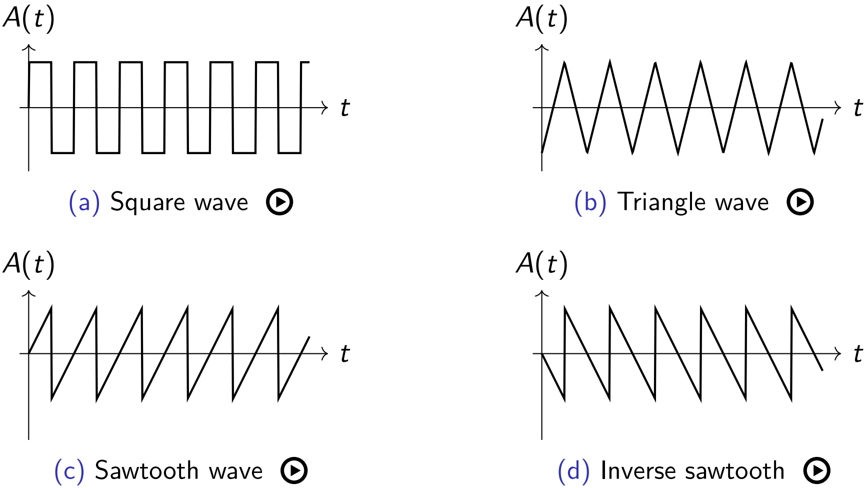
Figure: Musical pitches corresponding to the harmonic series starting from C2. Single arrow indicates mild difference of resulting pitch with regards to 12-tone equal temperament. Double arrow indicates significant difference.

Harmonic sounds

Physical property	Perceptual effect
Amplitude	Loudness
Fundamental frequency	Pitch
Spectral composition	Timbre

Table: Relationships between physical poperties and perception of sound

Harmonic sounds



(a) Square wave

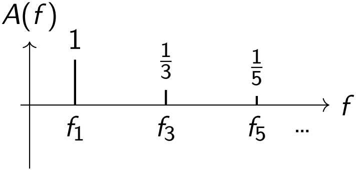
(b) Triangle wave

(c) Sawtooth wave

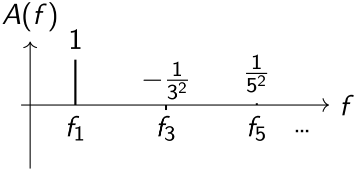
(d) Inverse sawtooth

Figure: Waveform archetypes

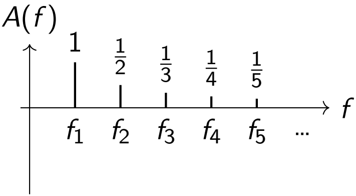
Harmonic sounds



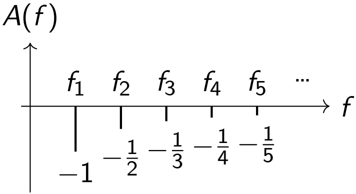
(a) Square wave



(b) Triangle wave



(c) Sawtooth wave



(d) Inverse sawtooth

Figure: Spectra of waveform archetypes

Inharmonic sounds

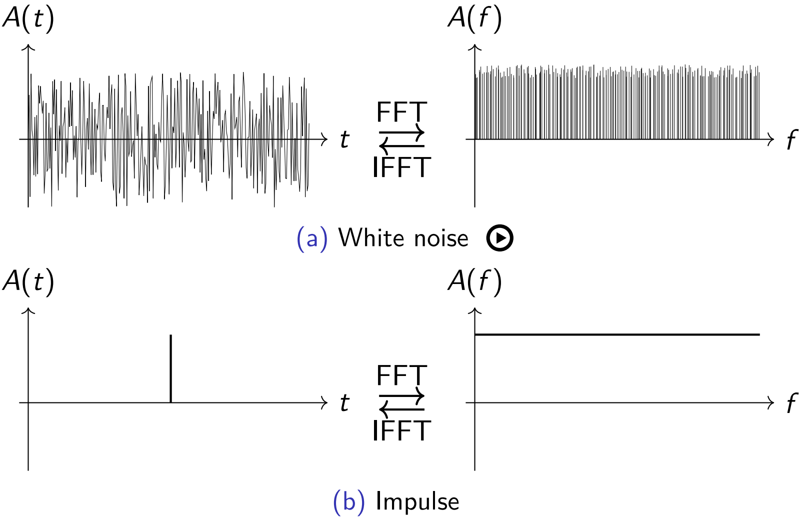
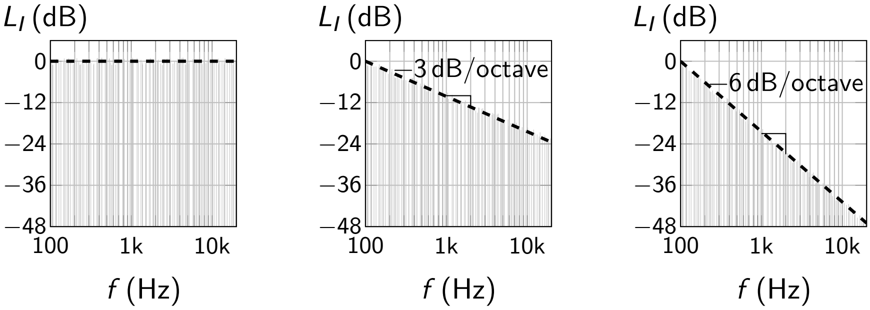


Figure: Waveform and spectrum of two archetypal inharmonic sounds

Inharmonic sounds



(a) White noise (b) Pink noise (c) Brown(ian) noise

Figure: Power spectra of different noise colors (cf., Roads 2015, p. 103)

Inharmonic sounds

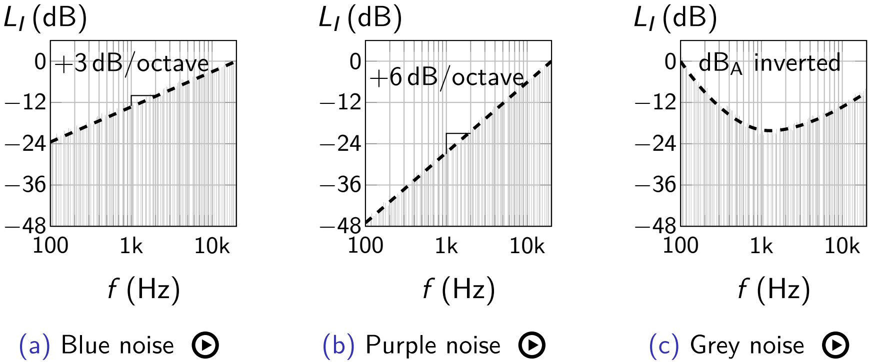


Figure: Power spectra of different noise colors (cf., Roads 2015, p. 103)

Envelopes

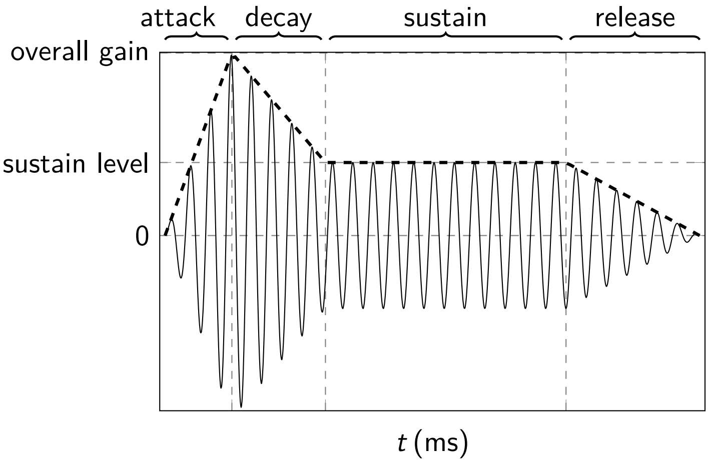


Figure: Linear ADSR envelope

Visualization as a spectrogram

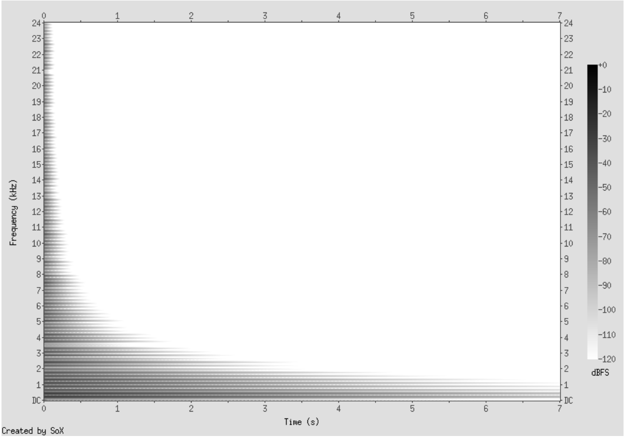


Figure: Spectrogram of a synthesized plucked guitar string

Visualization as a spectrogram

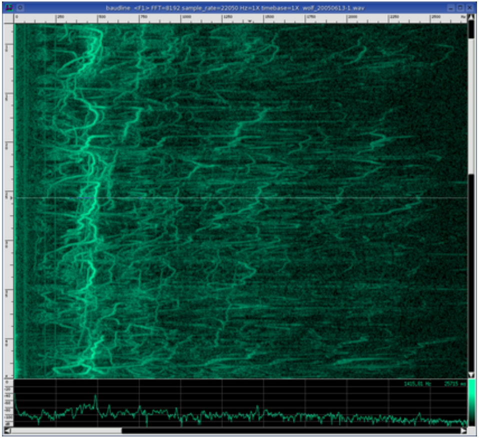


Figure: Spectrogram of howling wolves in Baudline (Courtesy of SigBlips. Used with permission)

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 3: Microphones

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, September 14, 2016

Microphones

Many seasoned audio professionals have a talent for achieving excellent results with a microphone despite not truly understanding the finer details of how it actually functions. (Klepko 2004, p. 115)

Electric quantities

Quantity	Symbol	Unit	Nature
Voltage	V	V	Field quantity
Electric power	P	W	Energy quantity

Table: Electric quantities

Voltage V and voltage level L_V

Voltage level

$$L_V = 20 \cdot \log_{10}\left(\frac{V}{V_0}\right)$$

- L_V ... voltage level ($\mathrm{dB_V}$ or $\mathrm{dB_u}$)
- V ... measured voltage (V)
- V_0 ... reference voltage (V)

Common references V_0:

- $1\,\mathrm{V} \equiv 0\,\mathrm{dB_V}$ (electronics)
- $0.7746\,\mathrm{V} \equiv 0\,\mathrm{dB_u}$ (audio equipment)

Electric power P and electric power level L_W

Electric power level

$$L_W = 10 \cdot \log_{10}\left(\frac{P}{P_0}\right)$$

- L_W ... voltage level (dB or dB_m)
- P ... measured electric power (W)
- P_0 ... reference power (W)

Common references P_0:

- $1\,W \equiv 0\,dB$ (loudspeakers)
- $1\,mW \equiv 0\,dB_m$ (telephone)

Doubling field quantities

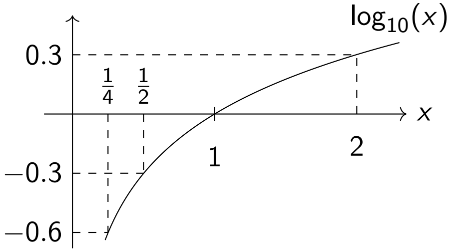
Problem (Double voltage from a microphone)

Two mics record same signal at 2 mV *vs.* 1 mV *RMS. Difference in dB?*

$$L = 20 \cdot \log_{10}\left(\frac{A}{A_0}\right) = 10 \cdot \log_{10}\left(\frac{A^2}{A_0^2}\right)$$

Field quantity A? Energy quantity A^2? Field quantity!

$$\begin{aligned} L &= 20 \cdot \log_{10}\left(\frac{2\,\text{mV}}{1\,\text{mV}}\right) \\ &= 20 \cdot \log_{10}(2) \approx +6\,\text{dB} \quad \square \end{aligned}$$



Doubling energy quantities

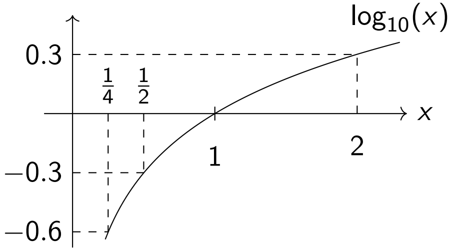
Problem (Double loudspeaker wattage)

Two speakers play same signal, driven at 50 W *vs.* 100 W. *Difference in dB?*

$$L = 20 \cdot \log_{10}\left(\frac{A}{A_0}\right) = 10 \cdot \log_{10}\left(\frac{A^2}{A_0^2}\right)$$

Field quantity A? Energy quantity A^2? Energy quantity!

$$\begin{aligned} L &= 10 \cdot \log_{10}\left(\frac{50\,\mathrm{W}}{100\,\mathrm{W}}\right) \\ &= 10 \cdot \log_{10}(0.5) \approx -3\,\mathrm{dB} \quad \square \end{aligned}$$



Electroacoustic transducer principles

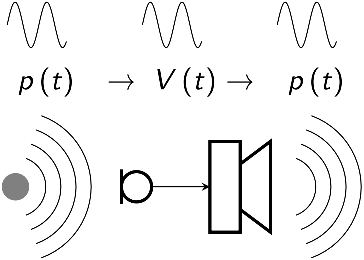


Figure: Electroacoustic transduction process

Electroacoustic transducer principles

Microphone type	Power needed?	Sound quality	Robustness
Dynamic microphones (electromagnetic induction)			
Moving coil	no	medium/good	robust
Ribbon	no	(very) good	fragile
Condenser microphones (capacitance)			
Regular condenser	yes	excellent	fragile
Electret condenser	yes	(very) good	less fragile
Piezo microphones (piezoelectric effect)			
Contact (pickup) mic	no	low	robust

Table: Comparison of different microphones by transducer principle

Electromagnetic induction

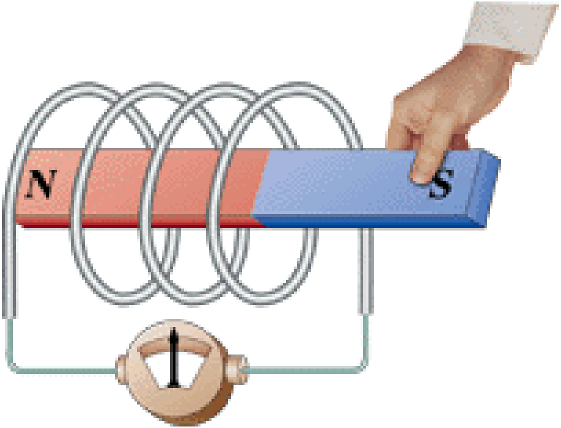


Figure: Principle of electromagnetic induction ()

Moving coil microphones

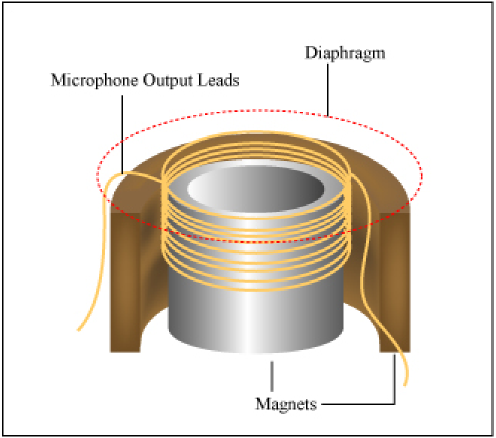


Figure: Electromagnetic induction in a dynamic moving coil microphone (Image by MIT OpenCourseWare)

Moving coil microphones

(a) SM58 ▶ (b) Beta 58A (c) SM57 ▶

Figure: Shure dynamic moving coil microphones ()

Moving coil microphones

Figure: "Test, 1, 2, … is this on?"

Moving coil microphones

(a) MD 421-II

(b) e 604

Figure: Sennheiser dynamic moving coil microphones ()

Moving coil microphones

Figure: Audix D6 dynamic moving coil microphone ()

Moving coil microphones

Figure: Blue Microphones enCORE 200 active dynamic moving coil microphone

Moving coil microphones

Figure: The dual-element Audio-Technica ATM250DE includes a dynamic moving coil capsule ()

Ribbon microphones

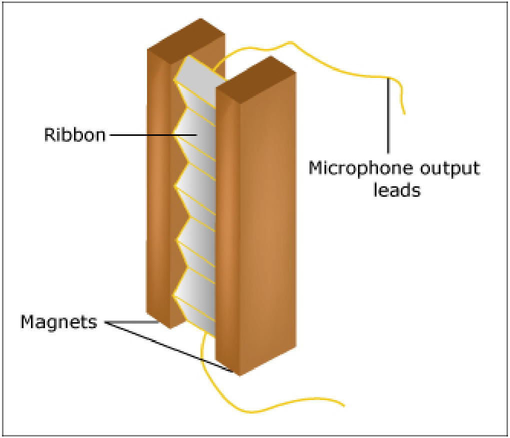


Figure: Principle of a dynamic ribbon microphone (Image by MIT OpenCourseWare)

Ribbon microphones

Figure: Royer R-101 dynamic ribbon figure-eight ()

Ribbon microphones

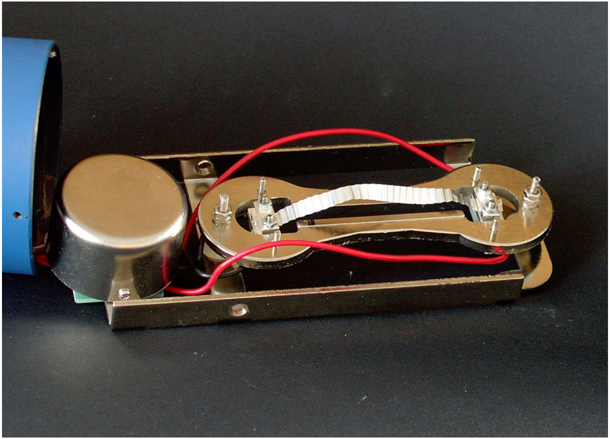


Figure: An unhappy ribbon (© Michael Joly. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Capacitance

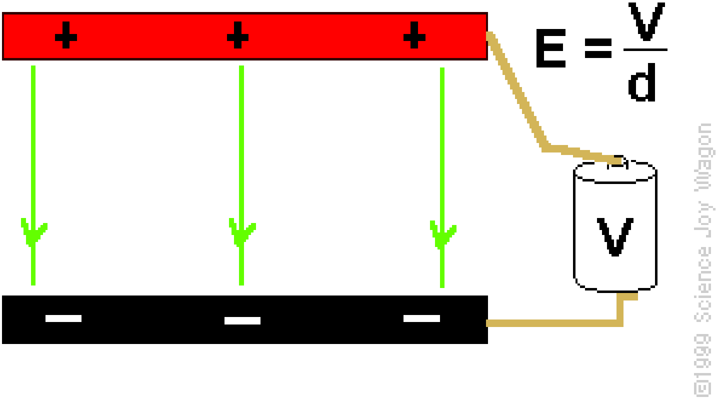


Figure: Principle of capacitance (© Joy Wagon. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Capacitance

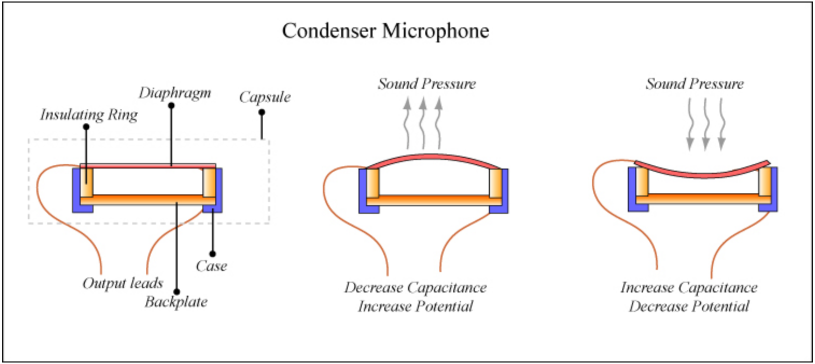


Figure: Capacitance in a condenser microphone (Image by MIT OpenCourseWare)

Large vs. small diaphragm condensers

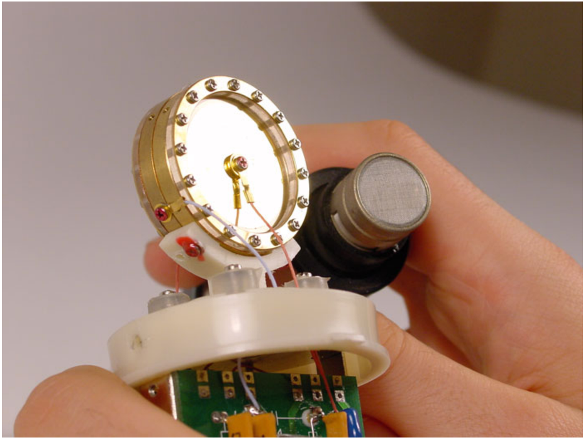


Figure: Large diaphragm (left) vs. small diaphragm (right) ()

Large vs. small diaphragm condensers

Figure: AKG C 414 XL II dual-large-diaphragm condenser ()

Large vs. small diaphragm condensers

Figure: Mojave Audio MA-200 large-diaphragm condenser ()

Large vs. small diaphragm condensers

Figure: Audio-Technica AT4041 small-diaphragm condenser ()

Large vs. small diaphragm condensers

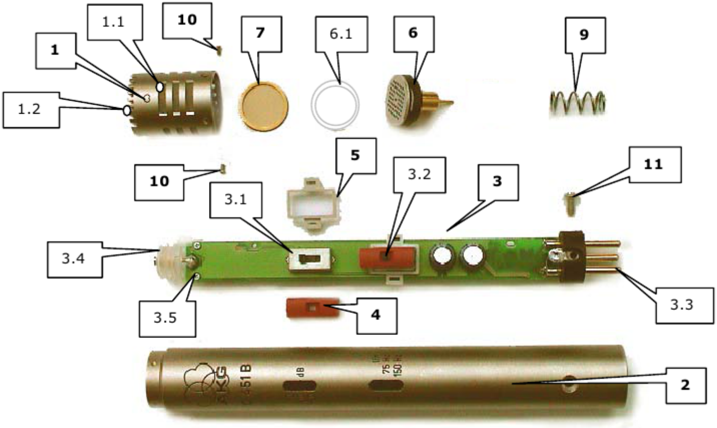


Figure: AKG C451 small-diaphragm condenser parts (© AKG Acoustics. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Large vs. small diaphragm condensers

Figure: Earthworks TC20 small-diaphragm condenser ()

Large vs. small diaphragm condensers

Figure: The dual-element Audio-Technica ATM250DE includes a small-diaphragm condenser capsule ()

Large vs. small diaphragm condensers

Property	Large diaphragm	Small diaphragm
Diaphragm diameter	$\geq$ 1"	$<$ 1"
Output voltage	Higher	Lower
Self noise	Lower	Higher
Signal-to-noise ratio	Higher	Lower
Sensitivity	Higher	Lower
Soundfield disturbance	Larger	Smaller
Polar pattern	Varies w/ f	More neutral
Frequency range	Narrower	Wider
High-frequency response	Colored	Neutral
Dynamic range	Lower	Higher
Maximum SPL	Lower	Higher

Table: Large vs. small diaphragm condenser microphones (DPA 2015b)

Large vs. small diaphragm condensers

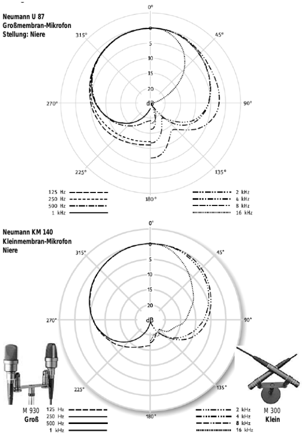
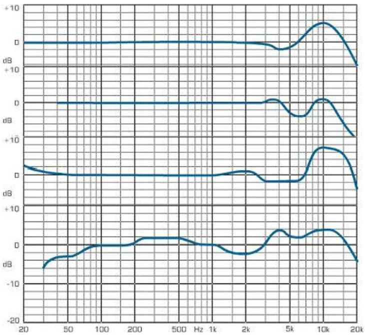
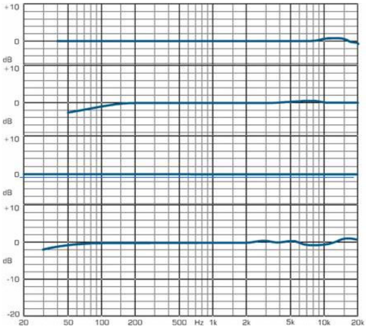


Figure: Typical polar patterns for a large diaphragm (top) and a small diaphragm (bottom) condenser microphone (Sengpiel 2006.)

Large vs. small diaphragm condensers



(a) Large diaphragm



(b) Small diaphragm

Figure: Frequency responses of eight different condenser microphones (Wuttke 2006.)

Large vs. small diaphragm condensers

Figure: Neumann M50 (left) vs. M49 (right) (© Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Large vs. small diaphragm condensers

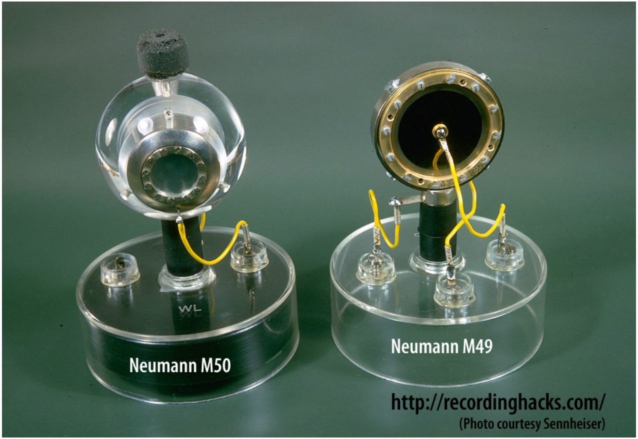


Figure: Neumann M50 (left) vs. M49 (right) diaphragms ()

Tube condensers

Figure: Frank Sinatra and a Neumann U47 ()

Tube condensers

(a) Microphone (© Mojave Audio)

(b) Power supply (© Audiofanzine)

Figure: Mojave Audio MA-200 vacuum tube condenser ()

Electret condensers

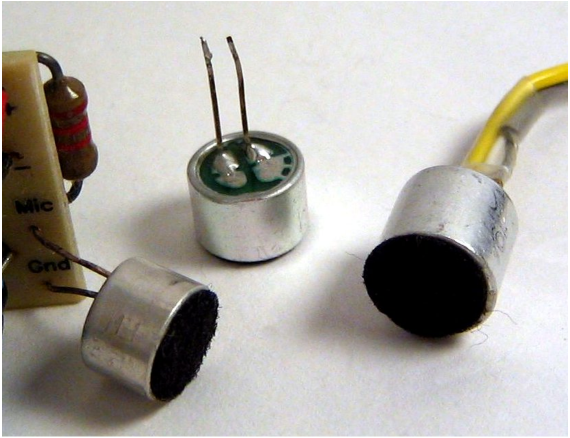


Figure: Electret condenser mic capsules (© Wikipedia user: Omegatron. CC BY-SA. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Electret condensers

Figure: Soundman OKM binaural in-ear electret condenser mics (
)

Electret condensers

Figure: Shure Countryman B2D lavalier microphone ()

Electret condensers

Figure: The dual-element Audio-Technica ATM250DE includes an electret condenser capsule ()

Phantom (and other kinds of) power

Rule of 👍

Condenser microphones require phantom power, dynamic mics don't.

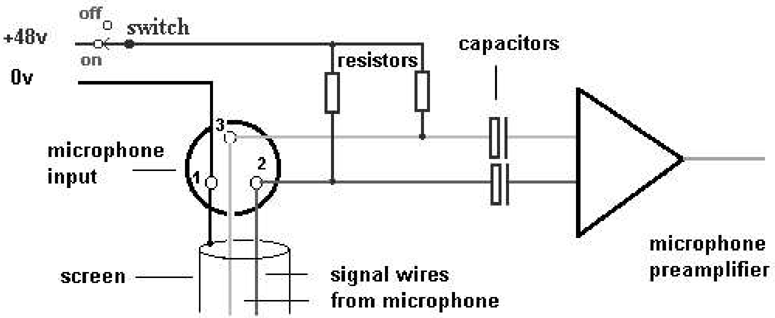


Figure: Phantom power ()

Phantom (and other kinds of) power

(a) A condenser mic that does *not* require phantom power from preamp (© Mojave Audio)

(b) A dynamic mic that *does* require phantom power from preamp (© Blue Microphones, with edits)

Figure: Exceptions to confirm the rule.

Piezoelectric effect

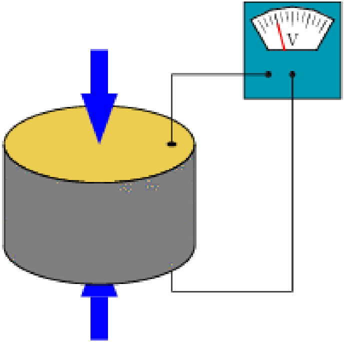


Figure: Principle of the piezoelectric effect (© Wikipedia user: Tizeff. CC BY-SA. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

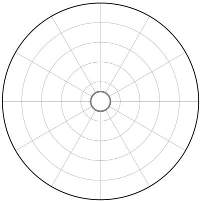
Contact microphones

Figure: Contact microphone ()

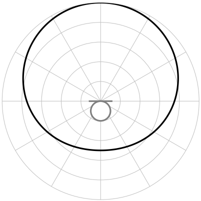
Hydrophones

Figure: DolphinEAR PRO hydrophone ()

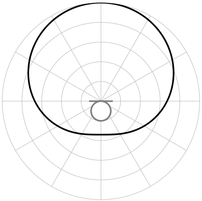
How to read polar diagrams



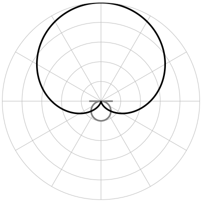
(a) Omni



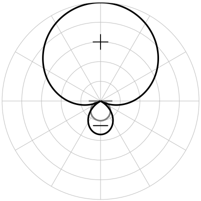
(b) Wide cardioid



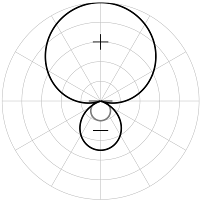
(c) Open cardioid



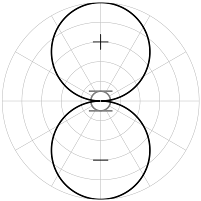
(d) Cardioid



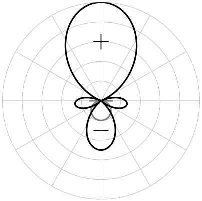
(e) Supercardioid



(f) Hypercardioid



(g) Figure-eight



(h) Shotgun

Figure: Microphone directivity patterns

Stage plan notation

Directivity pattern	Symbol
Omnidirectional	
Unidirectional	
Bidirectional	

Table: Notation of microphones with different directivity in a stage plan

Comparison

Property	Omnidirectional	Directional
Gain to feedback ratio	Lower	Higher
Feedback build-up	Slow	Fast
Off-axis coloration	Smooth and even	Less smooth
Proximity effect	No	Yes
Wind, handling, pop noises	Less sensitive	More sensitive
Distortion	Lower	Higher
Channel separation	Only in direct field	Good

Table: Characteristics of omnidirectional vs. directional microphones (Nymand 2005, p. 7)

Figure-eights

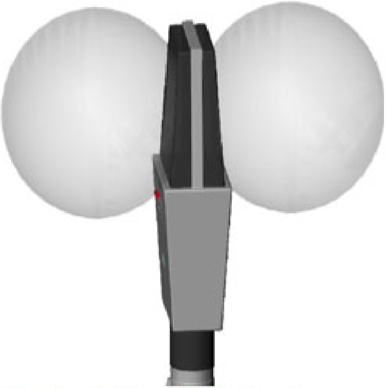


Figure: 3D directivity pattern of a large-diaphragm figure-eight (© Shure. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Figure-eights

Figure: Royer R-101 figure-eight ()

Figure-eights

Figure: AKG C 414 XL II with switchable directivity, including figure-eight

Omnis

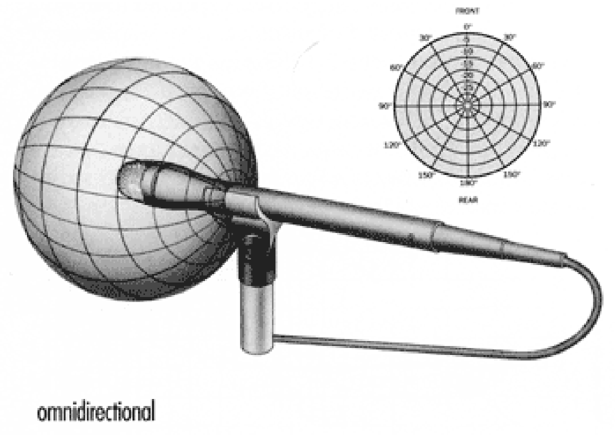


Figure: 3D and 2D directivity pattern of an omni ()

Omnis

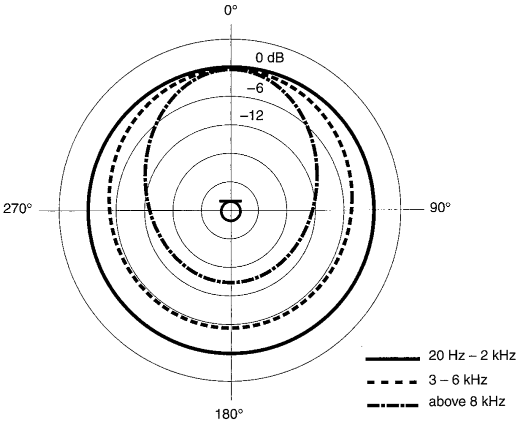


Figure: Typical polar diagram of an omnidirectional microphone at different frequencies (Rumsey and McCormick 2009, p. 54.)

Omnis

Figure: Earthworks TC20 omni ()

Omnis

Figure: AKG C 414 XL II with switchable directivity, including omni ()

Cardioids

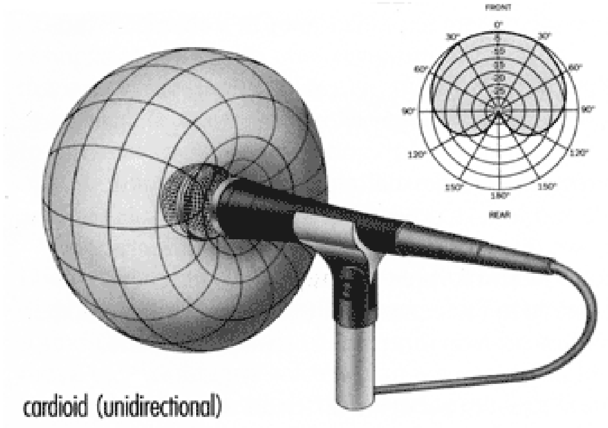


Figure: 3D and 2D directivity pattern of a cardiod mic ()

Cardioids

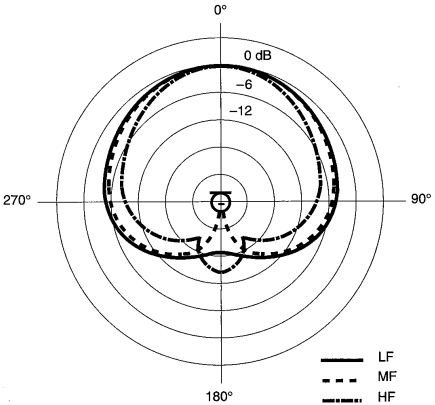


Figure: Typical polar diagram of a cardioid microphone at different frequencies (Rumsey and McCormick 2009, p. 58. © F. Rumsey & T. McCormick. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Cardioids

(a) SM58

(b) SM57

Figure: Shure cardioid microphones ()

Cardioids

(a) MD 421-II

(b) e 604

Figure: Sennheiser cardioids ()

Cardioids

Figure: Audix D6 cardioid ()

Cardioids

Figure: Blue Microphones enCORE 200 cardioid ()

Cardioids

Figure: Audio-Technica AT4041 cardioid (© Audio-Technica. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

Cardioids

Figure: Mojave Audio MA-200 cardioid (© Mojave Audio. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Cardioids

Figure: AKG C 414 XL II with switchable directivity, including cardioid (© AKG Acoustics. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Cardioids

Figure: The condenser capsule in the dual-element Audio-Technica ATM250DE has a cardioid pattern (© Audio-Technica. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Wide & open cardioids

(a) MK 21 (wide cardioid)

(b) MK 22 (open cardioid)

Figure: Schoeps microphone capsules (© Schalltechnik Dr.-Ing. Schoeps GmbH. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Wide & open cardioids

Figure: AKG C 414 XL II with switchable directivity, including wide and open cardioid configurations ()

Supercardioids & hypercardioids

(a) MK 41 (supercardioid)

(b) MK 41V (supercardioid)

Figure: Schoeps microphone capsules ()

Supercardioids & hypercardioids

Figure: Shure Beta 58A supercardioid (© Shure. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Supercardioids & hypercardioids

Figure: The dynamic capsule in the dual-element Audio-Technica ATM250DE has a hypercardioid pattern ()

Supercardioids & hypercardioids

Figure: AKG C 414 XL II with switchable directivity, including hyper- and supercardioid configurations ()

Pressure vs. pressure gradient

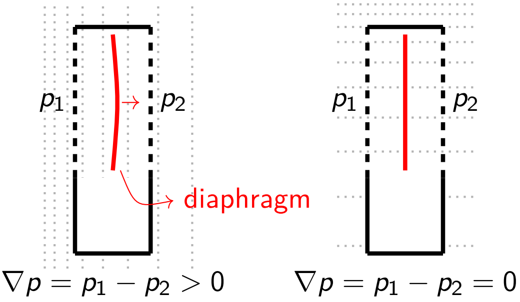


Figure: Principle of a pressure gradient (bidirectional) microphone

Pressure vs. pressure gradient

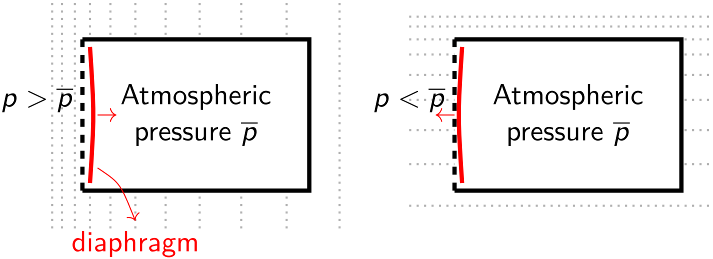


Figure: Principle of a pressure (omnidirectional) microphone

Pressure vs. pressure gradient

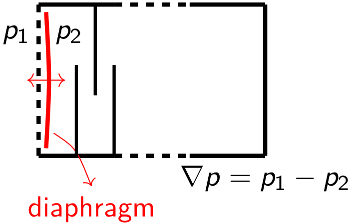


Figure: Principle of a mixed pressure & pressure gradient (unidirectional) microphone

Pressure vs. pressure gradient

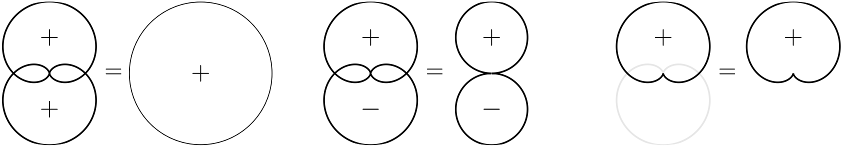
(a) MK 8 (figure-eight) (b) MK 2 (omni) (c) MK 4 (cardioid)

Figure: Schoeps microphone capsules ()

Dual-diaphragm microphones with switchable directivity

Figure: AKG C 414 XL II dual-diaphragm microphone ()

Dual-diaphragm microphones with switchable directivity



(a) Omni (b) Figure-eight (c) Cardioid

Figure: Principle of a dual-diaphragm microphone with switchable directivity

Mathematical description

Microphone directivity

$$A(\phi) = A_p + A_{\nabla p} \cdot \cos\phi$$

- ϕ … sound source direction
- A_p … pressure component
- $A_{\nabla p}$ … pressure gradient component
- $A_p + A_{\nabla p} = 1$
- $A(\phi) < 0$ … negative polarity

Polar pattern		A_p	$A_{\nabla p}$
Omni		1	0
Wide cardioid	↕	$3/4$	$1/4$
Open cardioid		$2/3$	$1/3$
Cardioid		$1/2$	$1/2$
Supercardioid	↕	$1/3$	$2/3$
Hypercardioid		$1/4$	$3/4$
Figure-eight		0	1

Table: Pressure and pressure gradient components for different microphone directivity patterns

Mathematical description

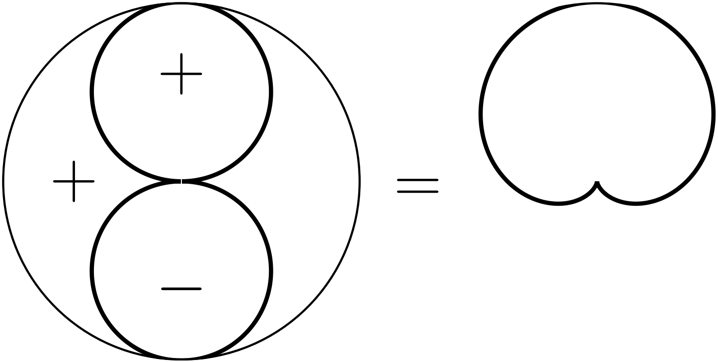


Figure: Cardioid = omni + figure-of-eight

Proximity effect

Proximity effect

Directional microphones exhibit an boost of bass frequencies for close, on-axis sound sources.

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 4: Perception of sound

Massachusetts Institute of Technology
Music and Theater Arts

Monday, September 19, 2016

Physics vs. perception of sound

Physical property	Perceptual effect
Amplitude	Loudness
Fundamental frequency	Pitch
Spectral composition	Timbre
Sound source position	Perceived direction

Table: Some psychoacoustic relationships

Just noticeable difference (JND)

Definition

The smallest change of a physical quantity that results in a perceptual effect

Examples

- JND for amplitude ($\approx 1\,\text{dB}$)
- JND for frequency (depends on range)
- JND of source position ($\approx 1^\circ$ for front direction)

Auditory scene analysis

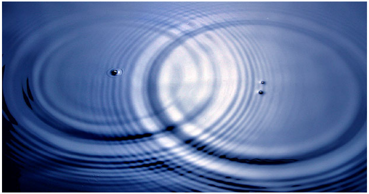
The control of [the principles described by auditory scene analysis] is the core of the music mixing process where sound sources are electronically reshaped to promote either blend or separation, or both. (Bregman and Woszczyk 2004, p. 46)

First 'law' of music mixing

Balance = Transparency + Coherence

Auditory scene analysis

(a) Sailboats (Courtesy of Ron Lute on Flickr. Used with permission.)



(b) Water ripples (Courtesy of Andrew Davidhazy. Used with permission)

Figure: A visual analogy of auditory scene analysis

Auditory scene analysis

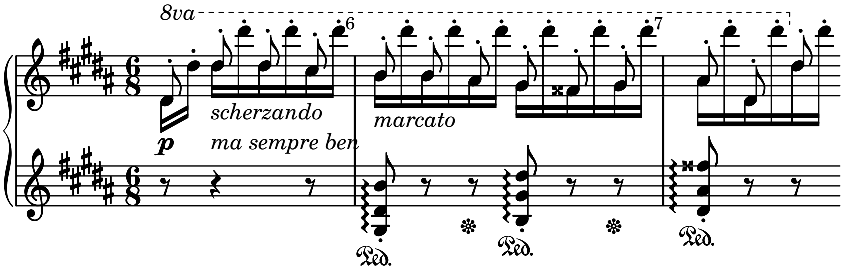


Figure: Auditory stream segregation as a compositional principle in Franz Liszt's *Etude III: La Campanella* (mm. 5–7)

Sequential grouping (stream segregation)

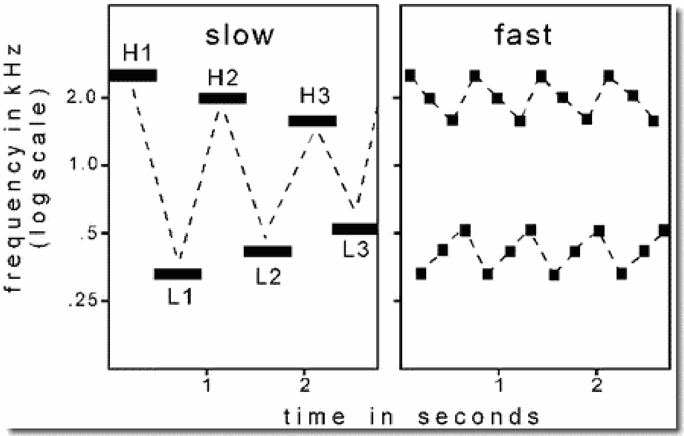


Figure: Stream segregation in a cycle of six tones (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Sequential grouping (stream segregation)

Figure: Segregation of high notes from low ones in a sonata by Telemann (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Sequential grouping (stream segregation)

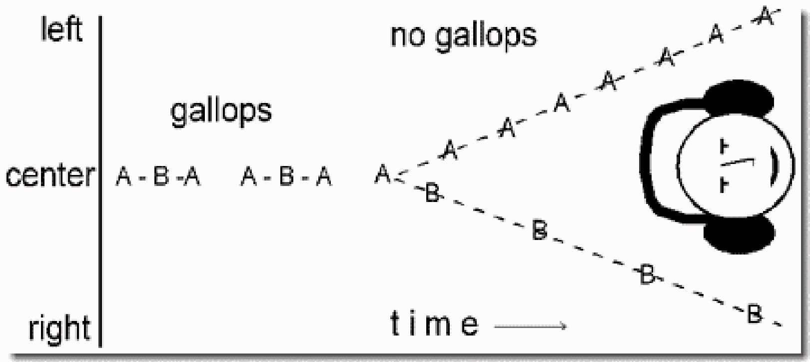


Figure: Streaming by spatial location (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Simultaneous grouping (spectral integration or fusion)

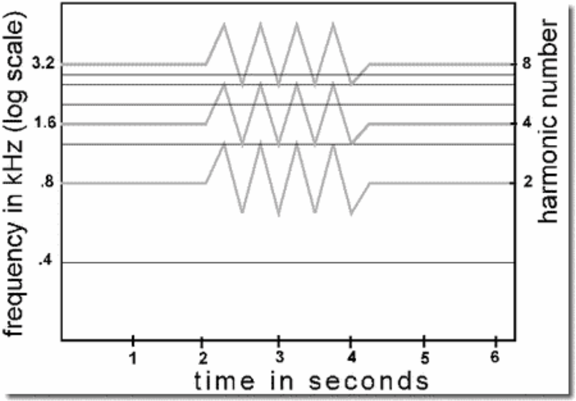


Figure: Fusion by common frequency change (principle of harmonicity) (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Simultaneous grouping (spectral integration or fusion)

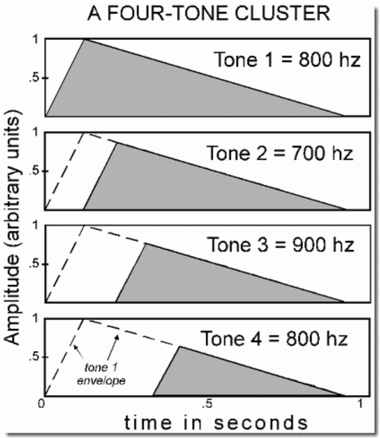


Figure: Effects of rate of onset on segregation (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Competition sequential vs. simultaneous grouping

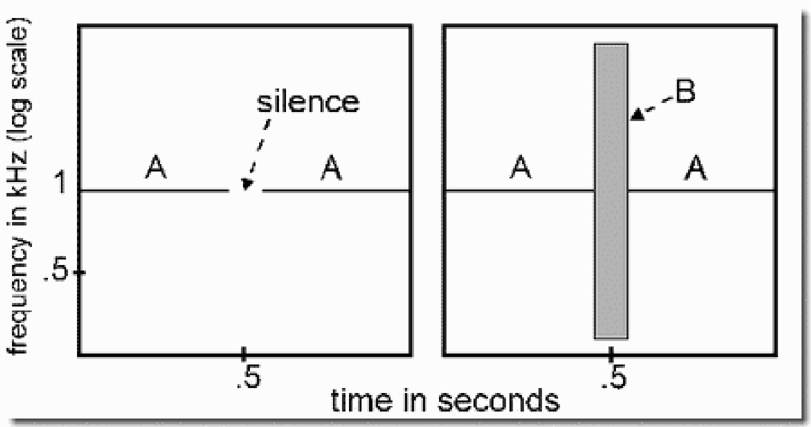


Figure: Apparent continuity (old-plus-new heuristic) (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Competition sequential vs. simultaneous grouping

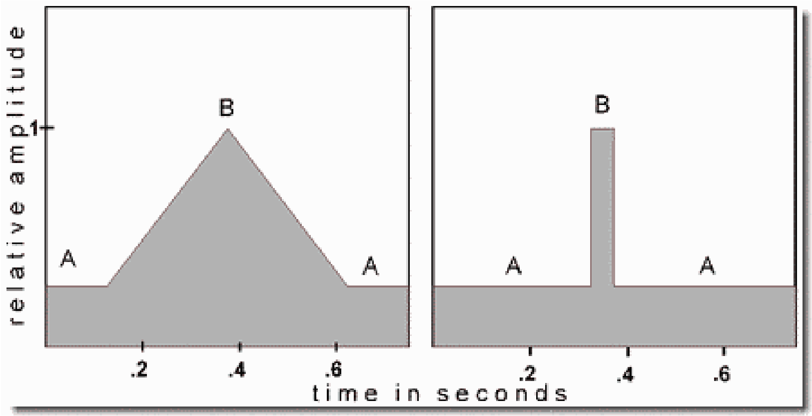


Figure: Homophonic continuity and rise time (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Competition sequential vs. simultaneous grouping

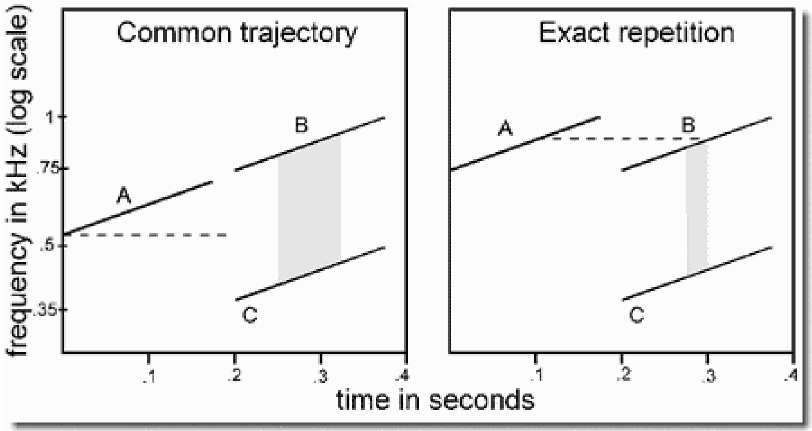


Figure: Capturing a component glide in a mixture of glides (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Competition sequential vs. simultaneous grouping

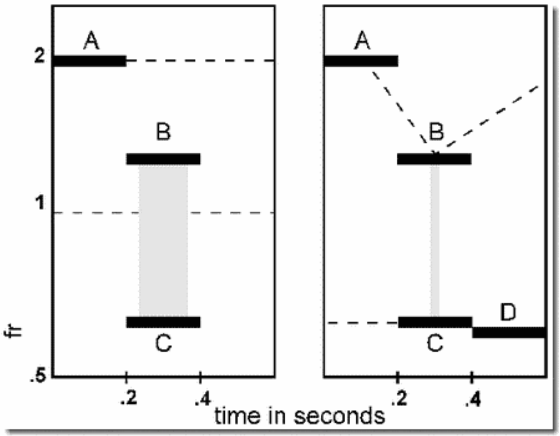


Figure: Competition of sequential and simultaneous grouping (Bregman and Ahad (1996). Demonstrations of Auditory Scene Analysis: The Perceptual Organization of Sound. Audio compact disk. Montréal, Canada: Auditory Perception laboratory, Psychology Department, McGill University. Distributed by MIT Press)

Anatomy of the human ear

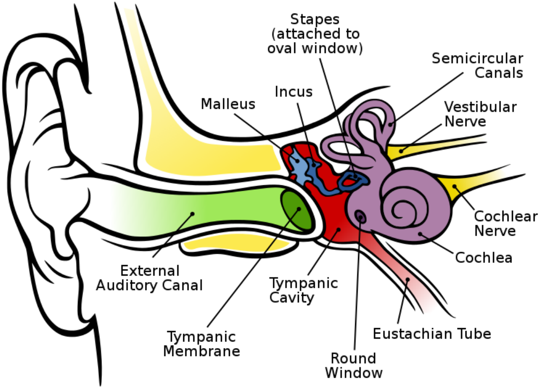


Figure: Anatomy of the human ear (Courtesy of Lars Chittka and Axel Brockmann. Used with permission.)

Anatomy of the human ear

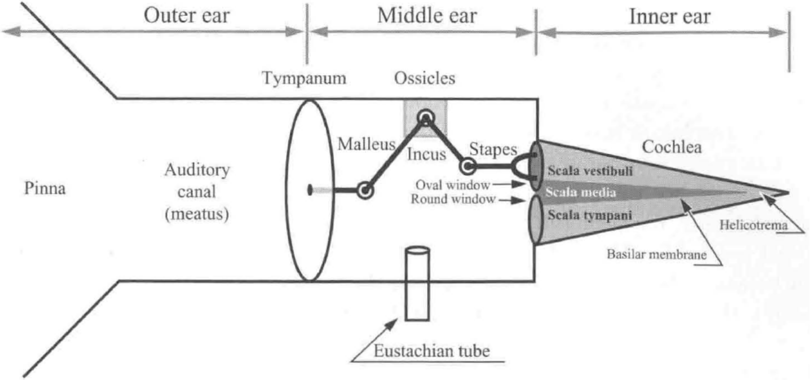


Figure: Schematic diagram of the human ear (Loy 2007, p. 151. Courtesy of MIT Press. Used with permission. https://mitpress.mit.edu/books/musimathics)

Limits of human hearing

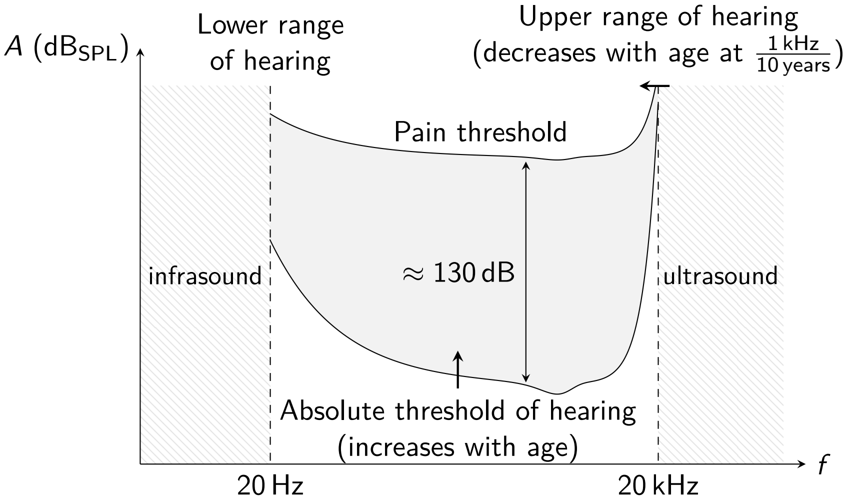


Figure: Amplitude and frequency limits of human hearing

Limits of human hearing

Problem

What is the dynamic range ΔL of the human ear between the pain threshold I_{pain} and the lower threshold of hearing I_0?

Solution

$$
\begin{aligned}
\Delta L &= 10 \cdot \log_{10} \frac{I_{pain}}{I_0} \\
&= 10 \cdot \log_{10} \frac{10^1\,\mathrm{W\,m^{-2}}}{10^{-12}\,\mathrm{W\,m^{-2}}} \\
&= 10 \cdot \log_{10} \left(10^{13}\right) \\
&= 10 \cdot 13 = 130\,\mathrm{dB} \quad \square
\end{aligned}
$$

Equal-loudness contours

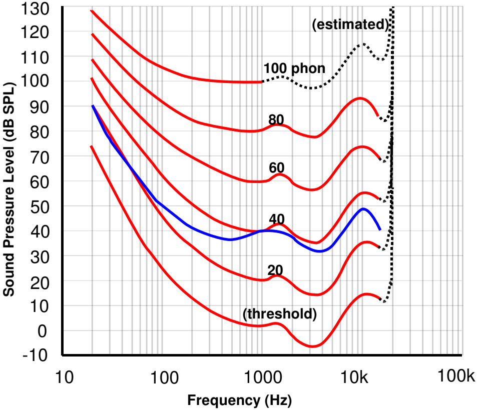


Figure: Equal-loudness contours. Red: ISO226:2003 revision. Blue: Original ISO standard for 40 phon (Public domain image. With edits. Source: `https://en.wikipedia.org/wiki/File:Lindos1.svg`)

Decibels weightings

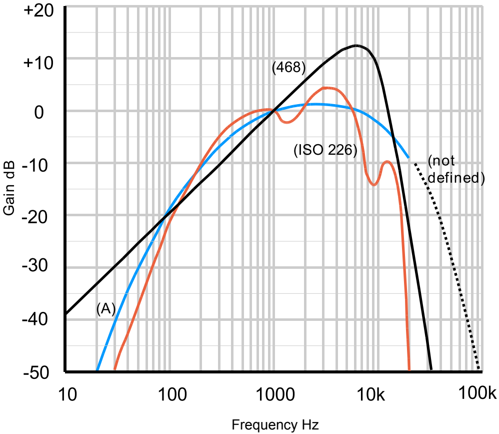


Figure: Red: inverted 40-phon curve. Blue: dB_A. Black: dB_{ITU} (Ⓟ Public domain image. With edits. Source: `https://en.wikipedia.org/wiki/File:Lindos3.svg`)

Decibels weightings

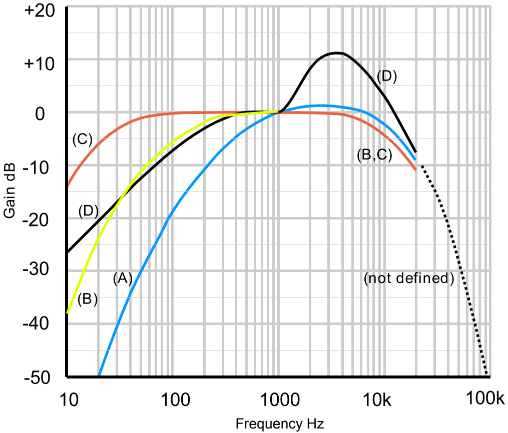


Figure: dB_A, dB_B, dB_C, dB_D weightings (Public domain image. With edits. Source: https://en.wikipedia.org/wiki/File:Acoustic_weighting_curves_(1).svg)

Masking

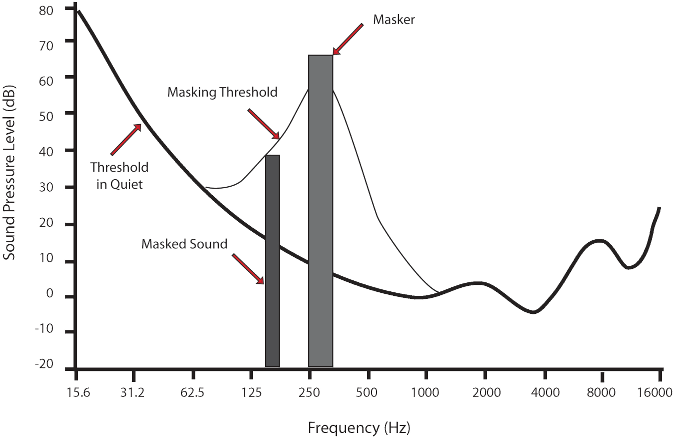


Figure: Spectral masking (Public domain image. Source: `https://en.wikipedia.org/wiki/File:Audio_Mask_Graph.png`)

Masking

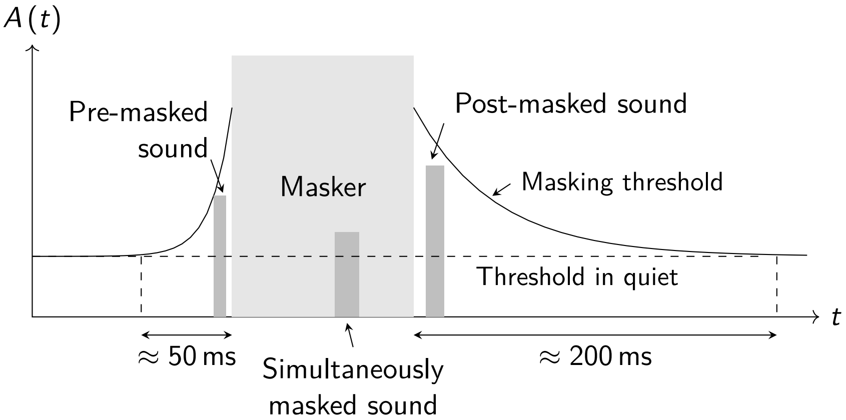


Figure: Temporal masking

Combination tones

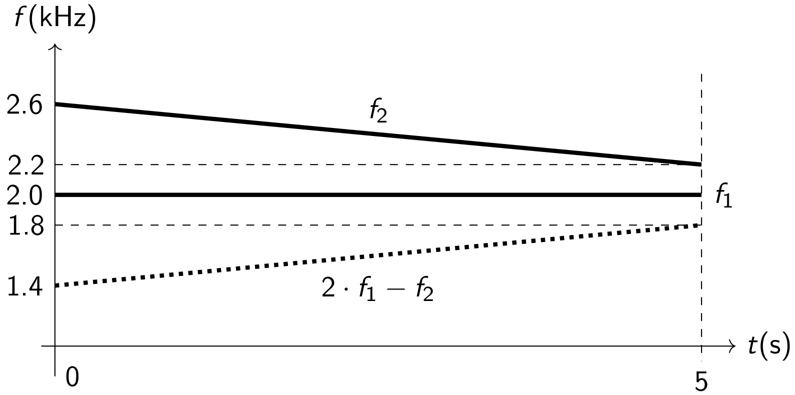
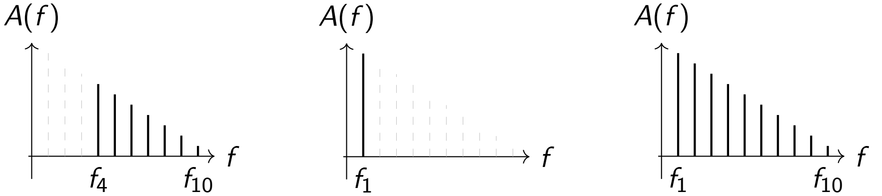


Figure: Difference tone $2 \cdot f_1 - f_2$

Missing fundamental



(a) Harmonics 4–10 (b) Fundamental (c) Harmonics 1–10

Figure: Missing fundamental

Examples

- Some woodwind instruments (e.g., oboe)
- *MaxxBass*™ plug-in (© Waves Inc.)
- Extending the perceived range of subwoofers or organ pipes

Sound localization

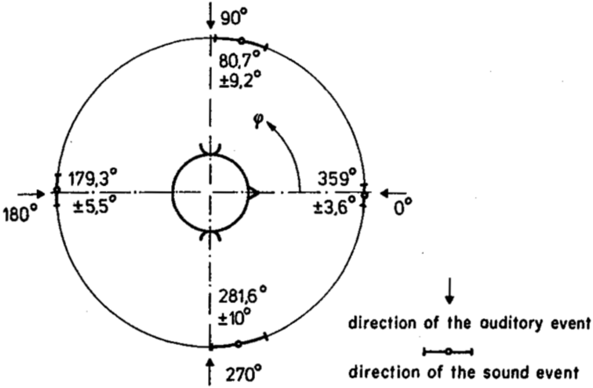


Figure: Localization blur in the horizontal plane. Experimental setup: 100 ms white noise pulses, head immobilized (Blauert 1996, p. 41.)

Interaural time differences (ITD)

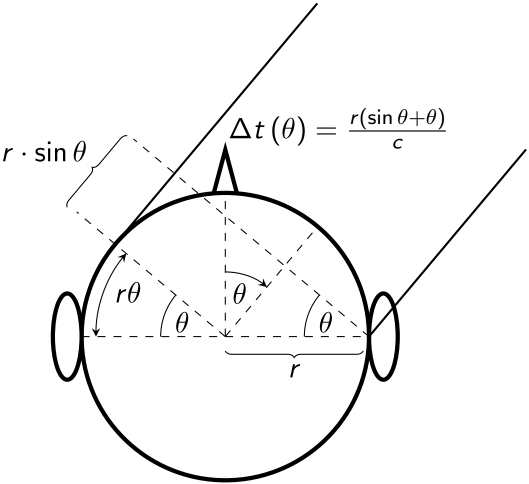


Figure: Simple model of interaural time differences

Interaural level differences (ILD)

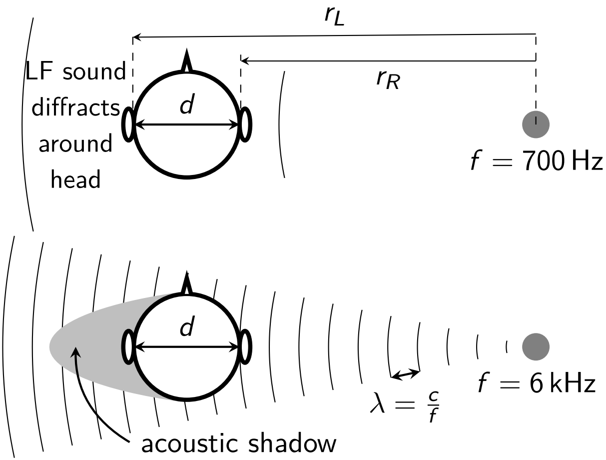


Figure: Interaural level differences

ITD and ILD over the frequency range

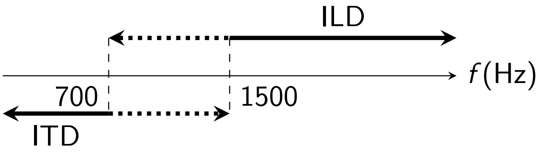


Figure: Interaural time and level differences complement each other over the audible frequency range.

Cone of confusion

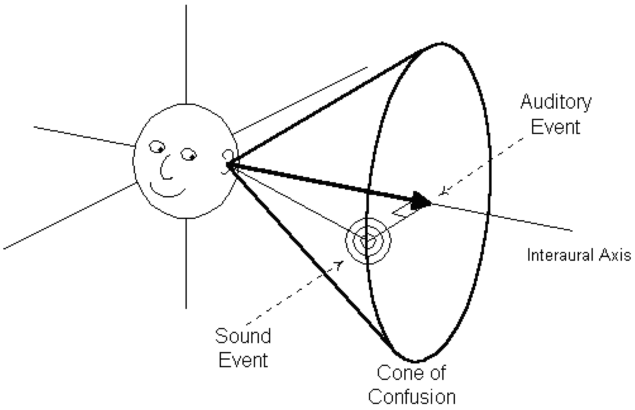


Figure: Cone of confusion ()

Head rotations resolve front-back ambiguities

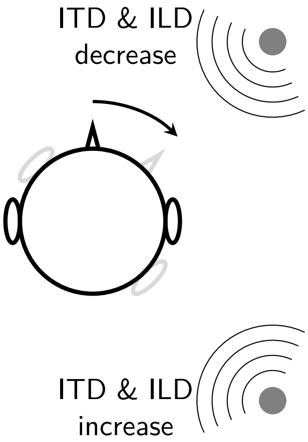


Figure: Head rotations resolve front-back ambiguities in sound localization (cf., Blauert 1996, p. 180)

Elevation cues

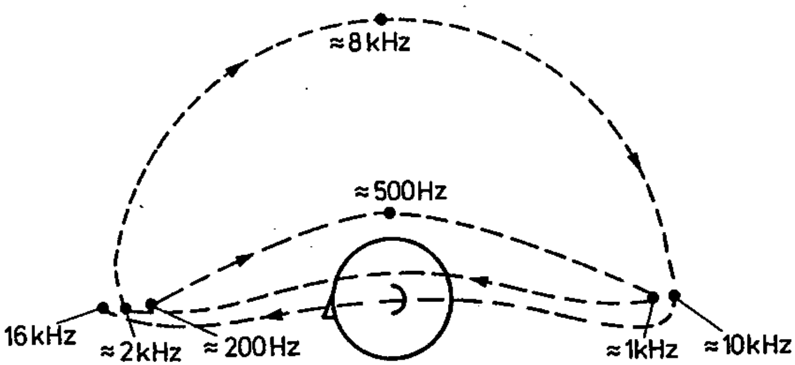


Figure: Localization in the median plane depending on frequency of a static source signal. Experimental setup: narrow-band noise, 1 subject, imobilized head (Blauert 1996, p. 45.

Precedence effect

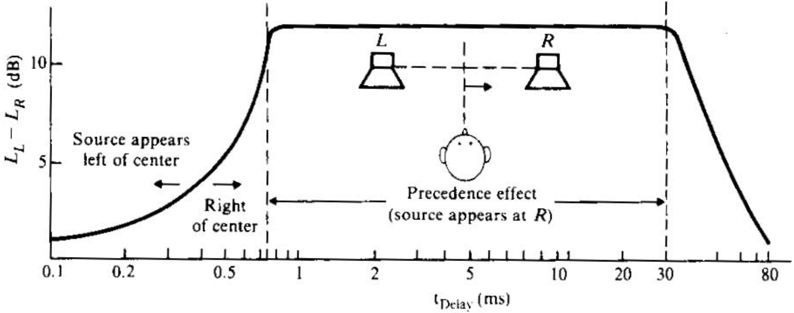


Figure: Haas effect (Rossing 1990.)

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 5: Workshop: MOSS intro & mic handling

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, September 21, 2016

Large MOSS road case overview

Figure: The MObile Sound System (MOSS), designed by Chris Ariza (Image by MIT OpenCourseWare)

Galaxy CM-140 SPL

Figure: Galaxy CM-140 SPL meter ()

Galaxy CM-140 SPL

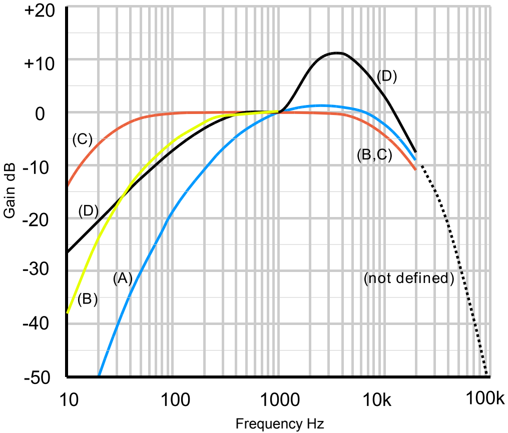


Figure: dB_A, dB_B, dB_C, dB_D weightings (Ⓟ Public domain image. With edits. Source: `https://en.wikipedia.org/wiki/File:Acoustic_weighting_curves_(1).svg`)

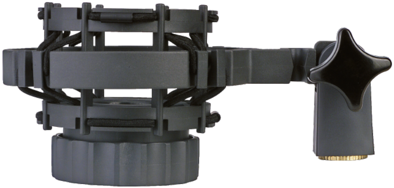
Cable coiling

Figure: First method demonstrated in this video corresponds to the one shown in class ()

Cable coiling

Figure: Alternative cable coiling methods ()

Clips & shock mounts



(a) H85 (side-addressed mics)

(b) H30 (front-addressed mics)

Figure: AKG microphone shock mounts (also known as 'cradles') ()

Wind screens & pop filters

(a) W90 wind screen

(b) PF80 pop filter

Figure: AKG wind screen and pop filter ()

Mic stand handling

Figure: The eight deadly points of failure on a microphone stand (© Ric Wallace.

Discussion: SPL measurement results

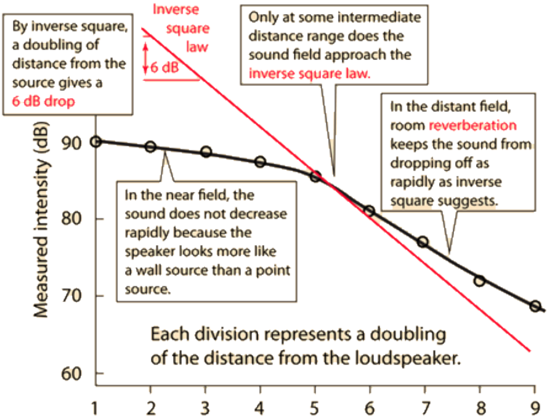


Figure: Inverse square law in a free field vs. measured intensity in a room (© R. Nave. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 6: Basic sound editing techniques

Massachusetts Institute of Technology
Music and Theater Arts

Monday, September 26, 2016

Digital audio basics

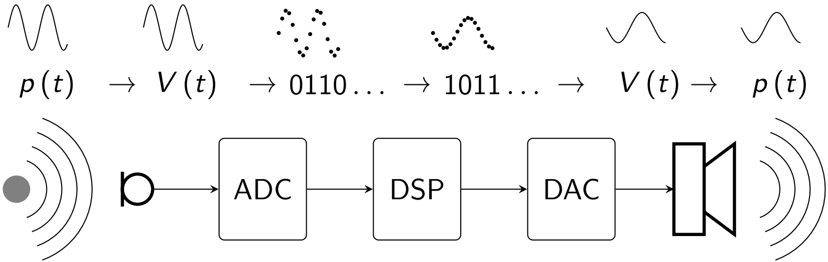


Figure: Digital reproduction chain

Audio file formats

Data compression	Coding format	Container formats
Uncompressed	PCM	.wav, .aif, .aiff
Lossless (reversible)	FLAC	.flac
	ALAC	.m4a
Lossy (irreversible)	MPEG layer III	.mp3
	AAC	.m4a, .m4b, .aac
	Vorbis	.ogg
	Opus	.opus

Table: Audio coding and container formats

Sample rate & bit depth

Value	Unit	Refers to	Application
44.1	kHz	Sample rate	Audio CD
48 000	Hz		Digital audio tape (DAT)
96	kHz		SACD, production
192	kHz		Production
16	bit	Bit depth	Audio CD
24	bit		SACD, production
32	bit		DAWs
64	bit		DAWs
128	$\mathrm{kbit\,s^{-1}}$	Bit rate	Common `.mp3` bit rate
192	$\mathrm{kbit\,s^{-1}}$		Common `.mp3` bit rate
256	$\mathrm{kbit\,s^{-1}}$		High-quality `.mp3`

Table: Magic numbers in digital audio

Sample rate & bit depth

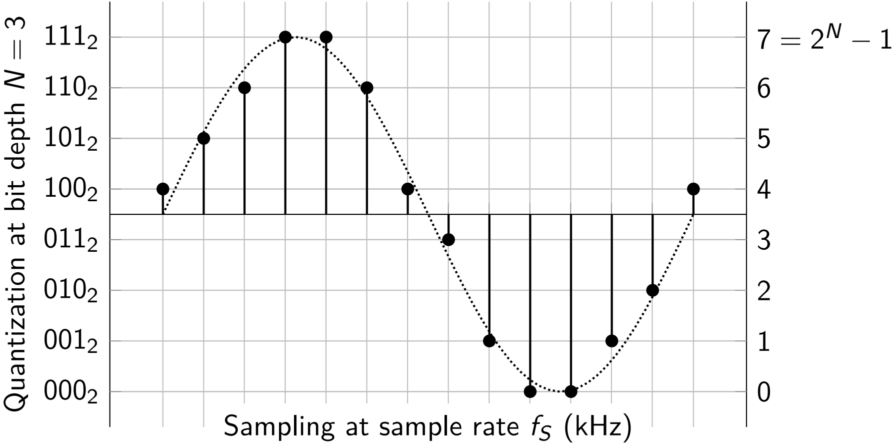


Figure: Sample rate and bit depth in digital audio

Avoiding clicks through crossfades

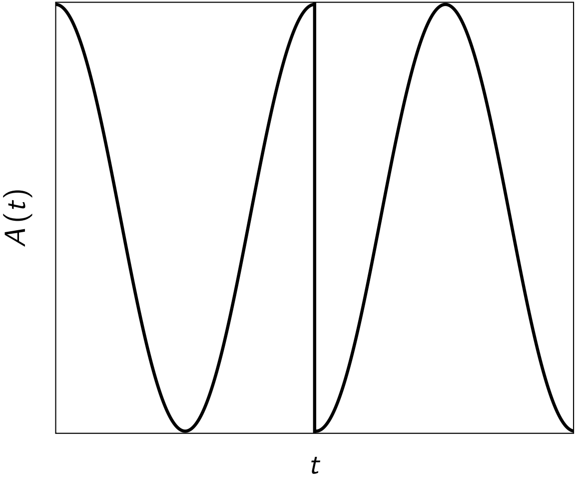
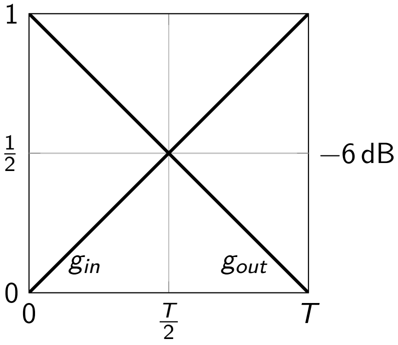
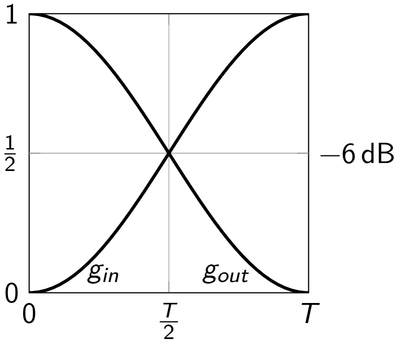


Figure: Signal discontinuity resulting in an audible click

Avoiding clicks through crossfades



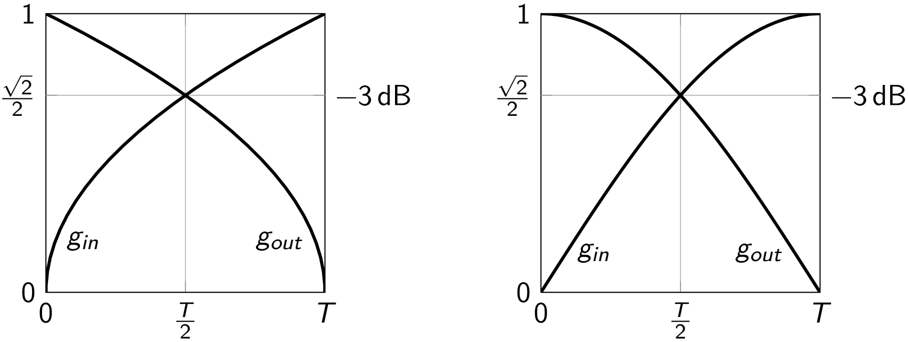
(a) Linear



(b) Half cosine

Figure: Symmetrical constant-gain crossfades ($g_{in} + g_{out} = 1$)

Avoiding clicks through crossfades



(a) Square-root (b) Quarter cosine

Figure: Symmetrical constant-power crossfades ($g_{in}^2 + g_{out}^2 = 1$)

Setting appropriate output levels to avoid clipping

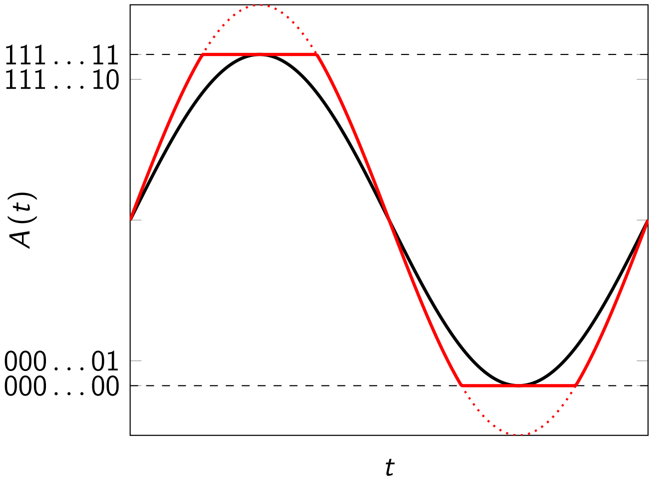


Figure: Full-scale (black) and clipped (red) digital signal

Normalization

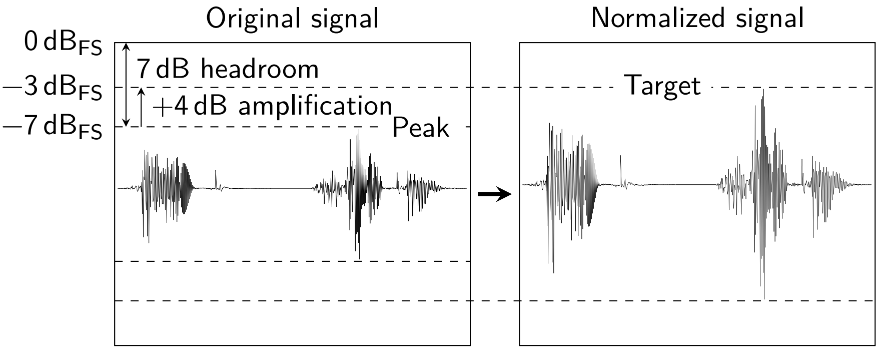
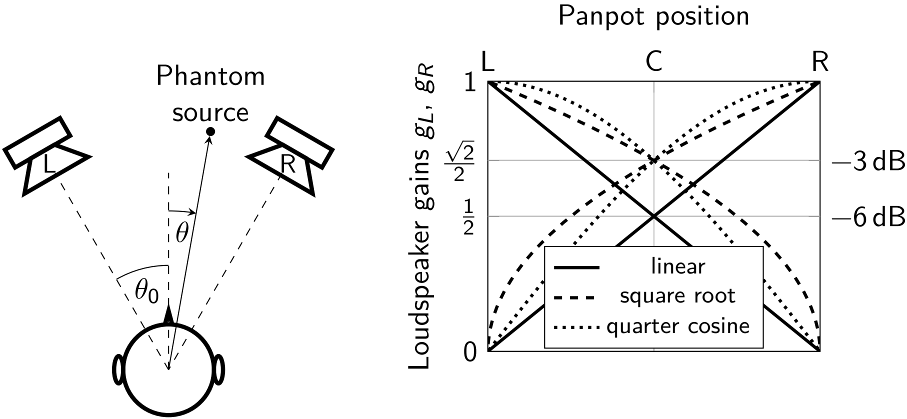


Figure: Principle of peak normalization

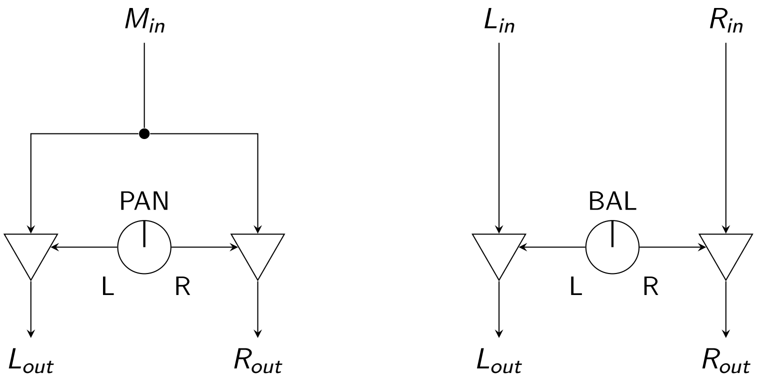
Basic mixing: Panning & level balance



(a) Stereo loudspeaker setup (b) Stereo panpot laws

Figure: Stereo panning

Basic mixing: Panning & level balance



(a) Panpot (mono input) (b) Balance control (stereo input)

Figure: Panpot vs. balance control

Basic sound editing in Reaper

Figure: Overview of Reaper window ()

Splicing, fades & crossfades

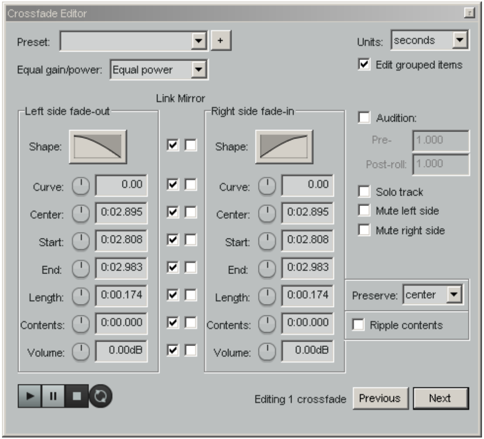


Figure: Reaper's View › Crossfade Editor dialogue (© Cockos. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Rendering a completed project to a new sound file

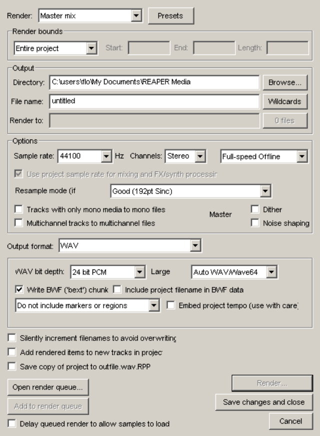


Figure: Reaper's File ⟩ Render... dialogue ()

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 7: Workshop: Cables, preamps, patchbays

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, September 28, 2016

Small MOSS road case overview

Figure: The MObile Sound System (MOSS), designed by Chris Ariza (Image by MIT OpenCourseWare)

Small MOSS road case overview

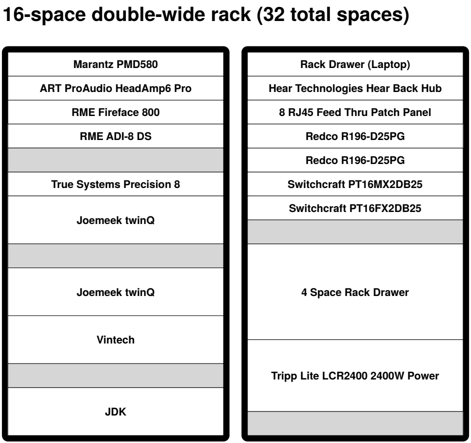


Figure: Small MOSS road case layout (Courtesy of Chris Ariza. Used with permission)

Standard studio gear dimensions

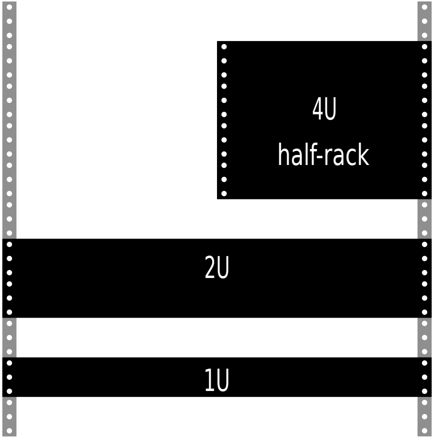


Figure: A 19" rack with devices of different heights (🄍 Public domain image. Source: https://en.wikipedia.org/wiki/File:Rackunit.svg)

Solid state recorder

Figure: Marantz PMD580 solid state digital audio recorder ()

Headphone amplifier

Figure: ART ProAudio HeadAmp6 Pro headphone amplifier (© ART ProAudio. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

Audio interface and AD/DA converter

(a) Front panel

(b) Rear connections

Figure: RME Fireface 800 digital audio interface ()

Audio interface and AD/DA converter

Figure: RME ADI-8 DS A/D and D/A converter ()

Microphone preamps

Figure: True Systems Precision 8 eight-channel mic preamp ()

Microphone preamps

Figure: Joemeek twinQ two-channel mic preamp (discontinued) ()

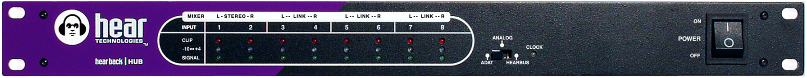
Microphone preamps

Figure: Vintech 1272 (aka Dual 72) two-channel mic preamp (© Vintech Audio. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Microphone preamps

Figure: JDK Audio R20 two-channel mic preamp ()

Headphone monitoring



(a) Hear Technologies Hear Back hub (© Hear Technologies)

(b) RJ45 feed thru patch panel (© markertek)

Figure: Headphone monitor mixing facilities in the MOSS.

Patchbays

(a) Switchcraft PT16MX2DB25

(b) Switchcraft PT16FX2DB25

Figure: XLR patchbays in the MOSS ()

Patchbays

Figure: Redco R196-D25PG Bantam patchbay (front) ()

Patchbays

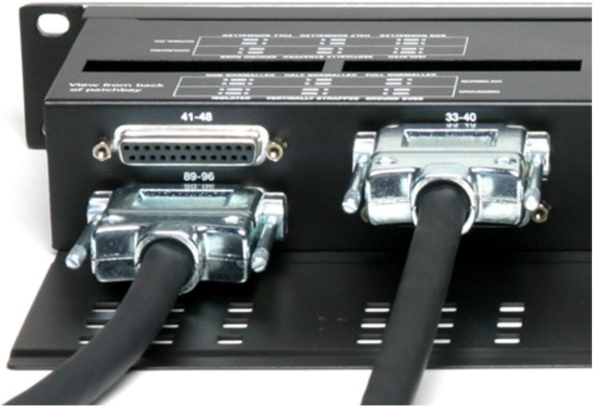


Figure: Redco R196-D25PG Bantam patchbay (rear) (© Redco. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

Voltage regulation & surge protection

Figure: TrippLite LCR2400 power line conditioner ()

Signal flow

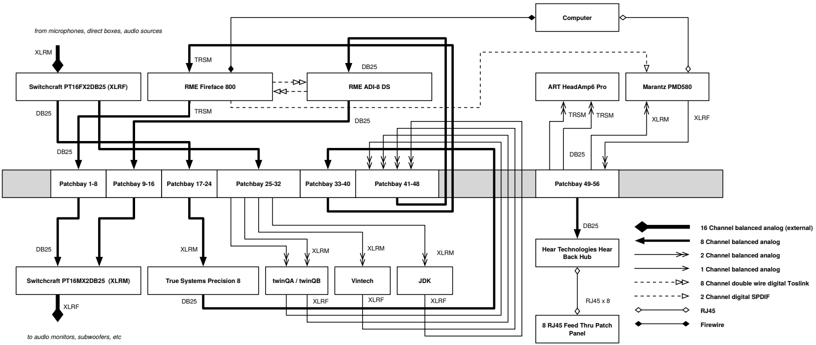


Figure: Internal MOSS rack connections (Courtesy of Chris Ariza. Used with permission)

Microphone patching

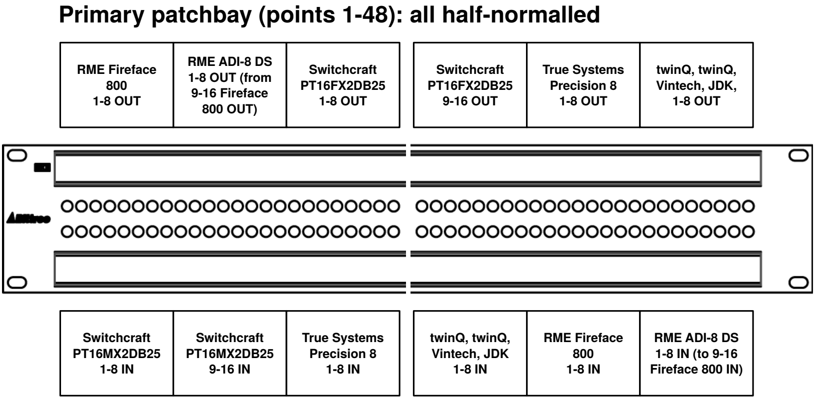


Figure: Primary MOSS Bantam patchbay (Courtesy of Chris Ariza. Used with permission)

Microphone patching

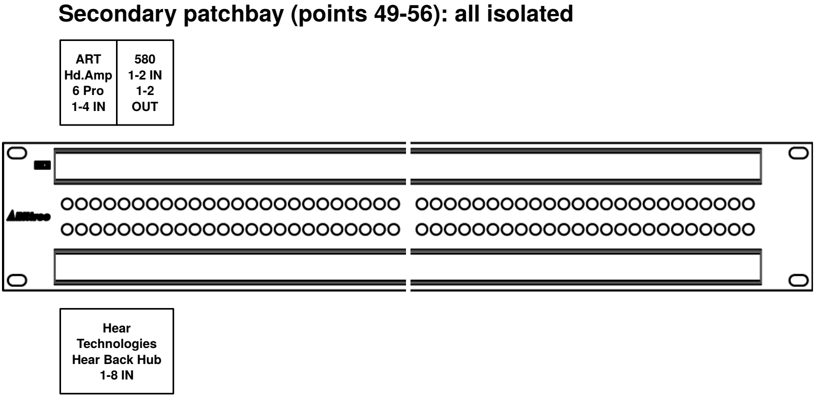


Figure: Secondary MOSS Bantam patchbay (Courtesy of Chris Ariza. Used with permission)

Microphone patching

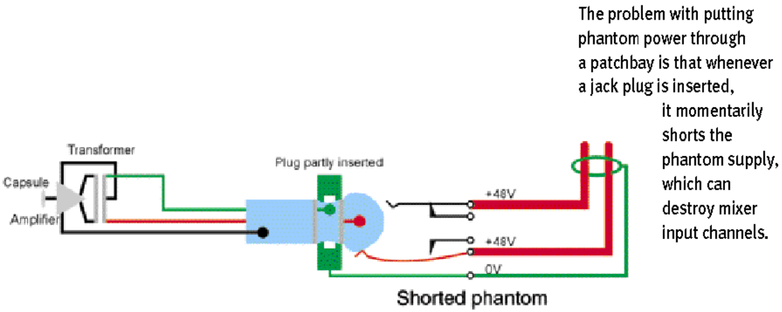


Figure: Why you should not patch under phantom power on a Bantam patchbay ()

Balanced vs. unbalanced lines

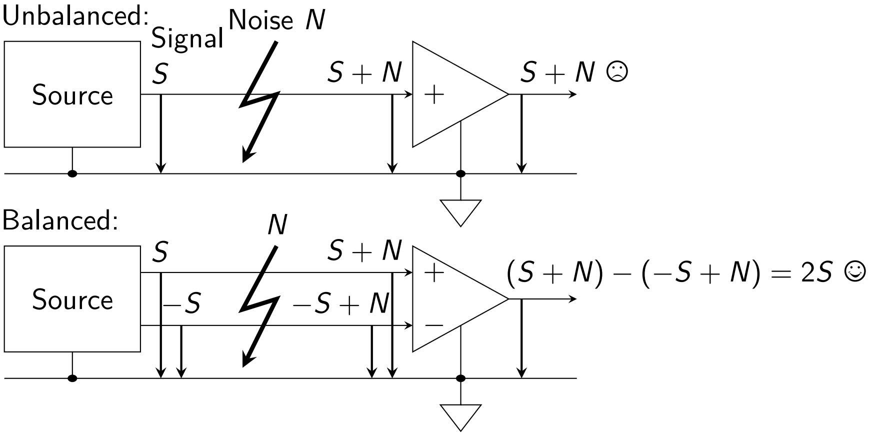


Figure: Common mode rejection typically used in balanced lines

DI boxes

Figure: Radial JPC active stereo DI box ()

DI boxes

Figure: Radial JDI passive mono DI box ()

DI boxes

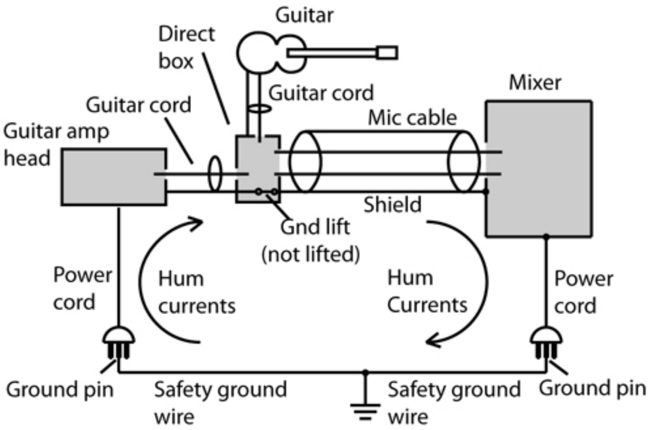


Figure: Principle of a ground loop and an earth lift switch ()

DI boxes

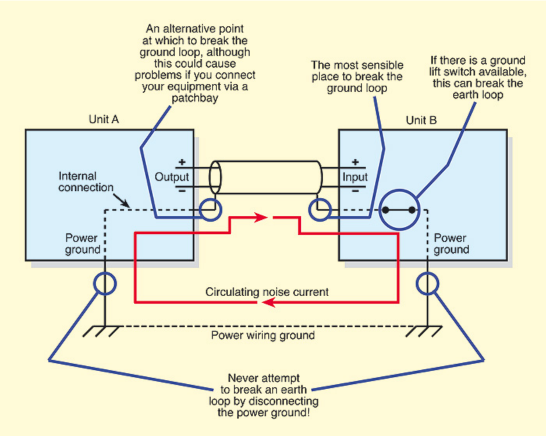


Figure: Where to (not) break a ground loop ()

XLR connector

Figure: XLR-3 socket and plug (© Michael Piotrowski and Wikipedia users: Mxp, Daniel FR, Iainf, Omegatron. With edits. (cc) BY-SA. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

XLR connector

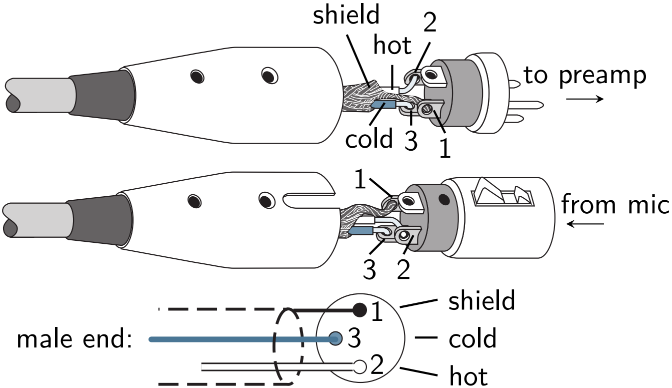


Figure: XLR connector allocation (© LOUD Technologies Inc. With edits.)

TS & TRS connectors

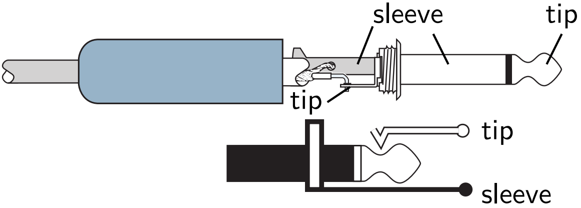


Figure: TS connector allocation ()

TS & TRS connectors

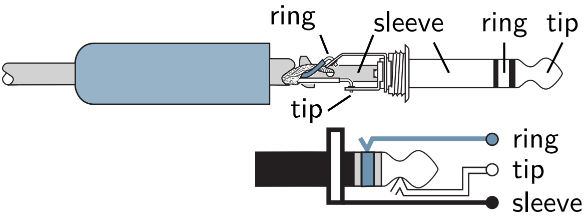


Figure: TRS connector allocation ()

TS & TRS connectors

(a) A-gauge

(b) B-gauge

Figure: ¼" TRS plugs of different shape ()

TS & TRS connectors

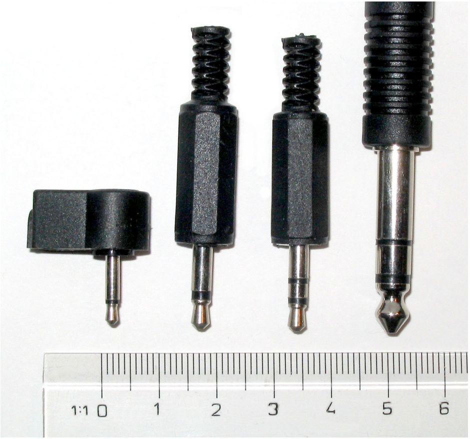


Figure: A-gauge plug sizes from left to right: 2.5 mm; 1/8" = 3.5 mm (TS & TRS); 1/4" = 6.35 mm (Public domain image. Source: https://commons.wikimedia.org/wiki/File:Photo-audiojacks.jpg)

TS & TRS connectors

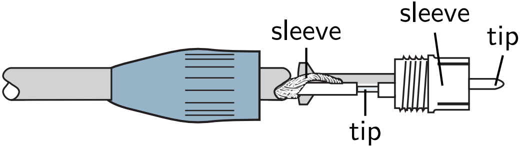
(a) $^1/_4$" = 6.35 mm (PO316)

(b) 0.173" = 4.4 mm (Bantam/TT)

Figure: B-gauge plug sizes (© Neutrik AG. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

RCA connector

(a) RCA stereo plug (white = left; red = right) (© Unknown)



(b) RCA connector allocation (© LOUD Technologies Inc. With edits)

Figure: RCA plugs.

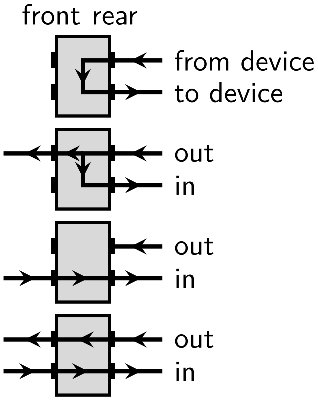
Snakes

Figure: Hosa 8-channel TRSM-to-XLRM snake ()

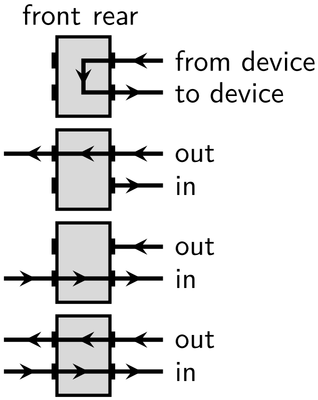
Snakes

Figure: Pro Co StageMASTER XLR snake (16 send, 4 return channels)

Patchbay normaling



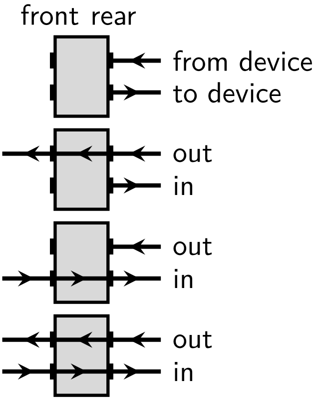
(a) Half-normalled



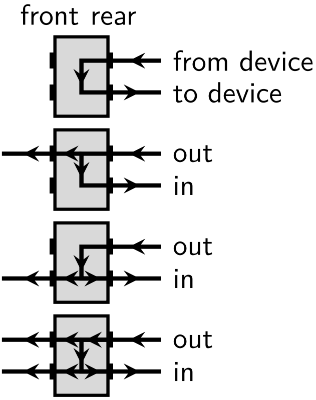
(b) (Fully (or single)) normalled

Figure: Different patchbay standards

Patchbay normaling



(a) Open (or denormalled)



(b) Parallel

Figure: Different patchbay standards

Patchbay normaling

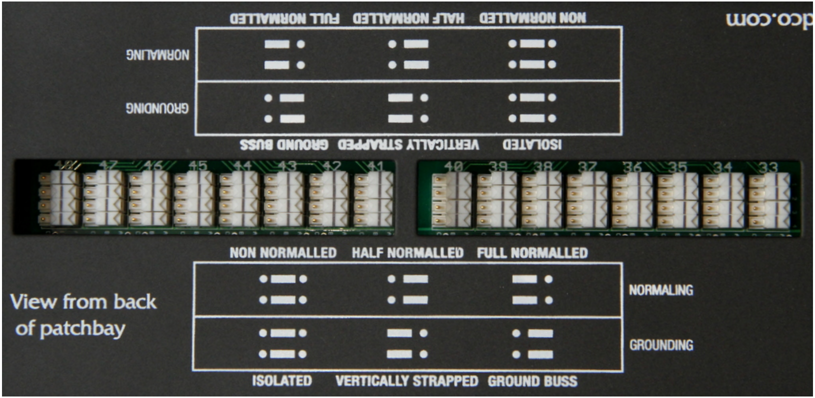


Figure: Redco R196-D25PG audio patchbay, top panel (© Redco. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Patchbay normaling

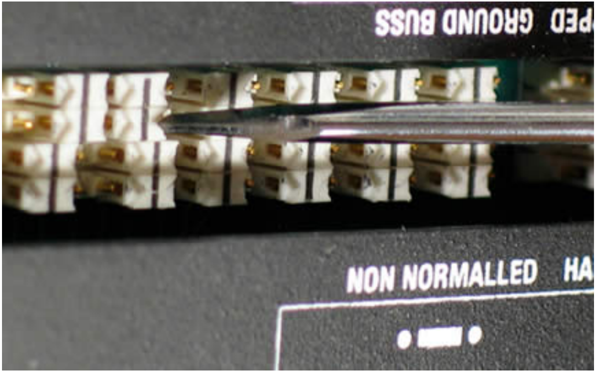


Figure: Redco R196-D25PG audio patchbay, close-up of normaling/grounding slide switches (© Redco. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 8: Filters & EQs

Massachusetts Institute of Technology
Music and Theater Arts

Monday, October 3, 2016

Filtering the frequency spectrum

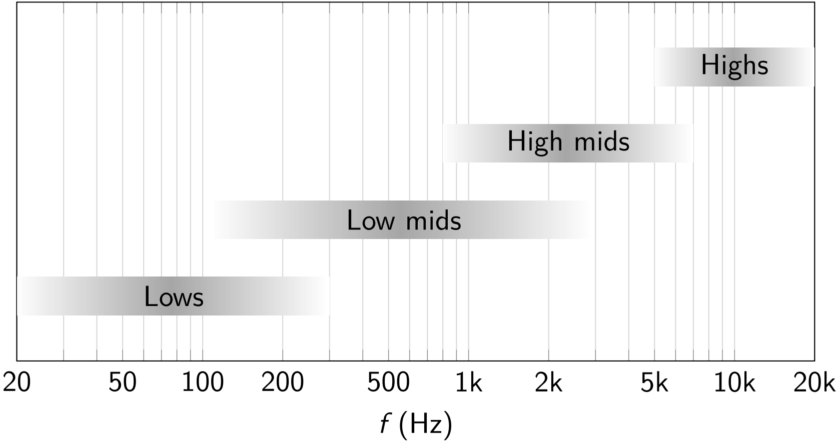


Figure: The basic four-band division of the audible frequency spectrum (after Izhaki 2011a, fig. 14.3)

Filtering the frequency spectrum

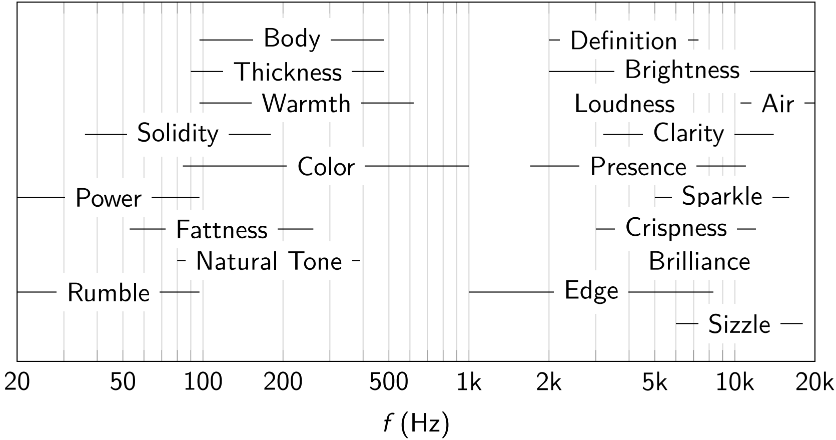


Figure: Qualitative descriptions of various frequency ranges (after Izhaki 2011a, fig. 14.4)

Cut filters

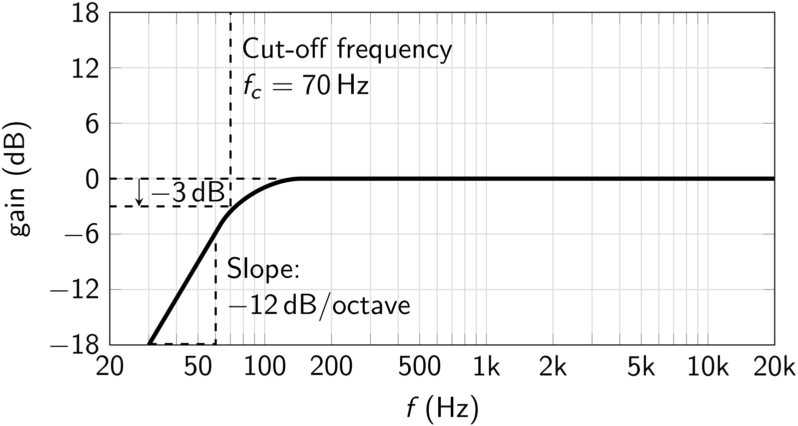


Figure: Frequency response of a low-cut (high-pass) filter

Cut filters

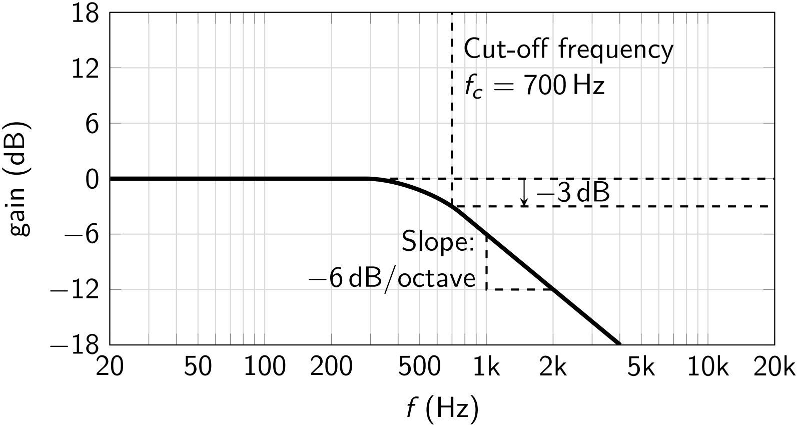


Figure: Frequency response of a high-cut (low-pass) filter

Shelving filters

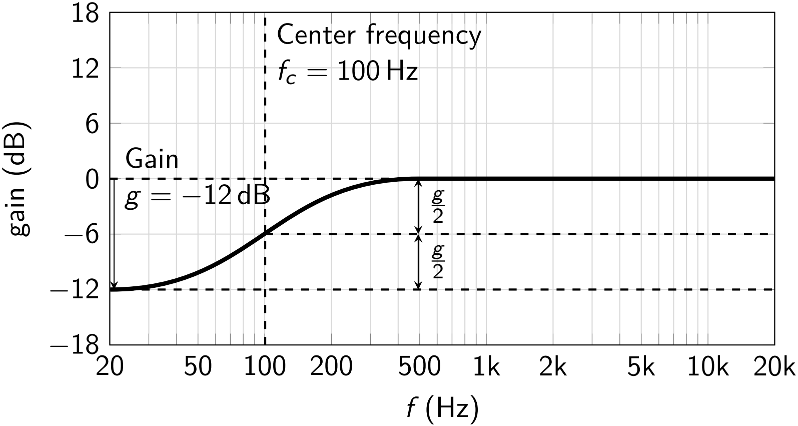


Figure: Frequency response of a low-frequency shelving filter

Shelving filters

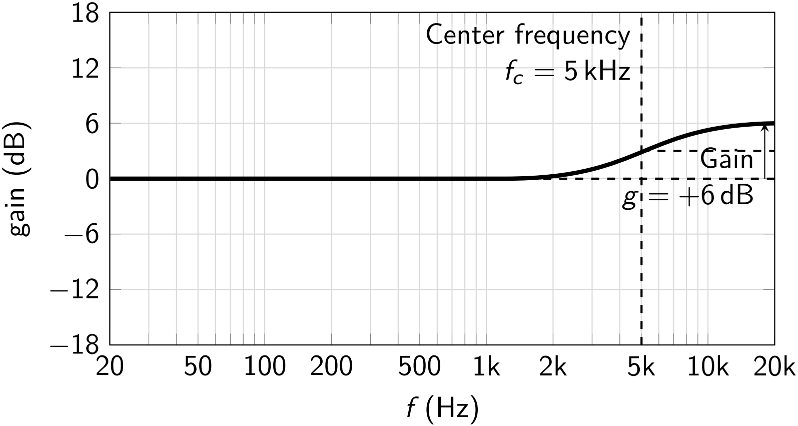


Figure: Frequency response of a high-frequency shelving filter

Peaking filters

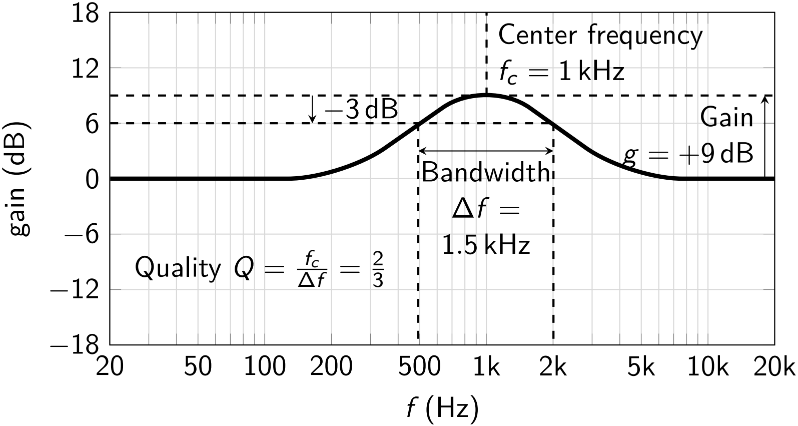


Figure: Frequency response of a peaking filter

Parametric EQs

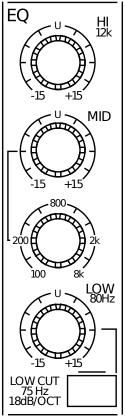


Figure: Parametric EQ in an input channel strip of a Mackie CR1604-VLZ mixing desk (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

Parametric EQs

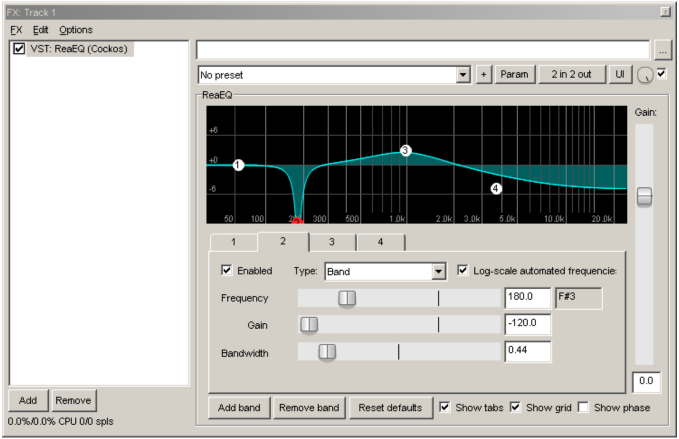


Figure: Cockos *ReaEQ* plugin in a Reaper session ()

Parametric EQs

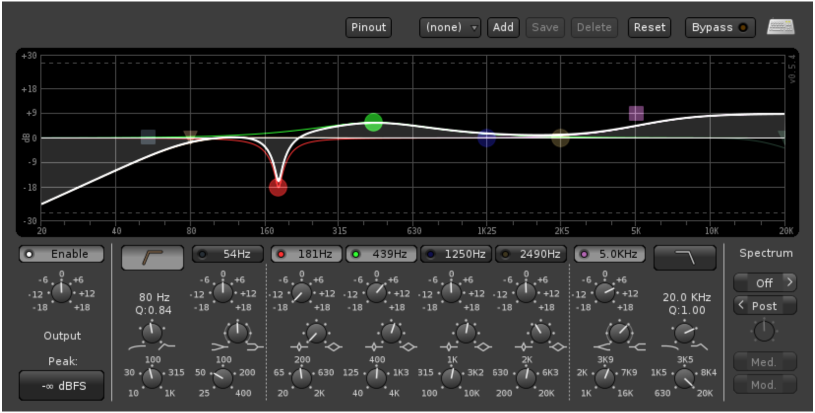


Figure: x42-eq plugin in an Ardour session (© Robin Gareus. GNU General Public License. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Parametric EQs

Figure: EQ section of a Joemeek *twinQ* microphone preamp (© Joemeek. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

Parametric EQs

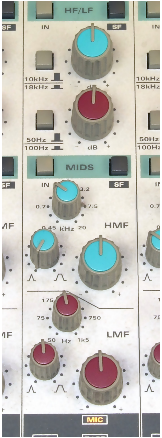


Figure: 4-band parametric EQ on an Audient ASP8024 mixing console (Courtesy of Wikipedia user: lainf. CC BY)

Graphic EQs

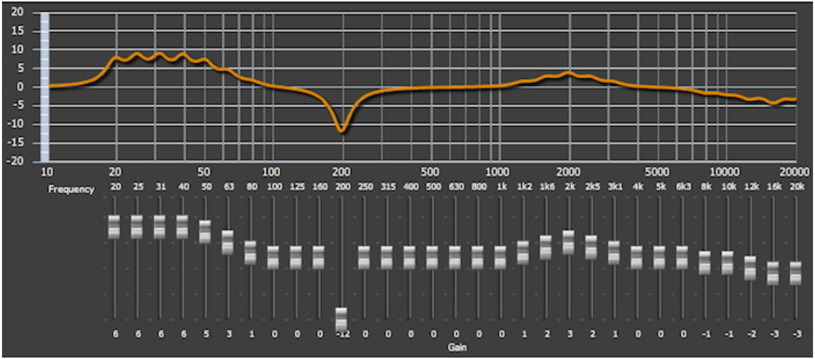


Figure: Graphic EQ and corresponding frequency response in a software plugin by miniDSP ()

Graphic EQs

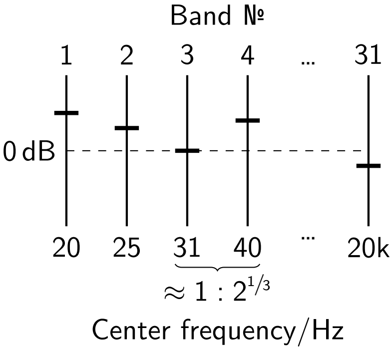


Figure: Principle of a graphic EQ with 31 ⅓-octave bands

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 9: Stereo recording techniques

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, October 5, 2016

Loudspeaker stereophony

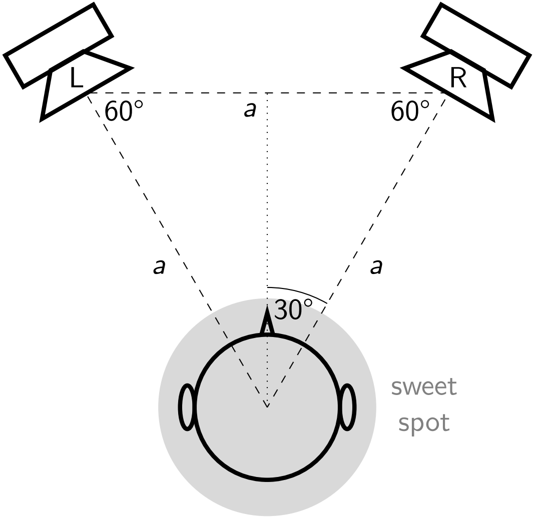


Figure: Standard stereo loudspeaker setup

Loudspeaker stereophony

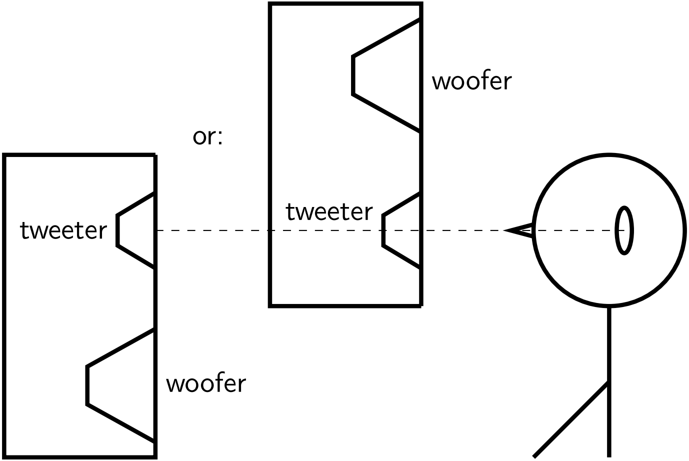


Figure: A nearfield monitor loudspeaker's tweeter should usually be aligned with the listener's ears

Stereophonic recording techniques

	Coincident	Mixed	Spaced	Binaural
Loudspeaker compatible?	✔	✔	✔	✘
Mono compatibility	☺	😐	☹	☹
Spaciousness	☹	😐	☺	☺
Depth	☺	😐	☹	☺
Localization	☺	😐	☹	☺
Omnis an option?	✘	✘	✔	✔

Table: Families of stereophonic recording techniques (cf., Schoeps 2004)

XY

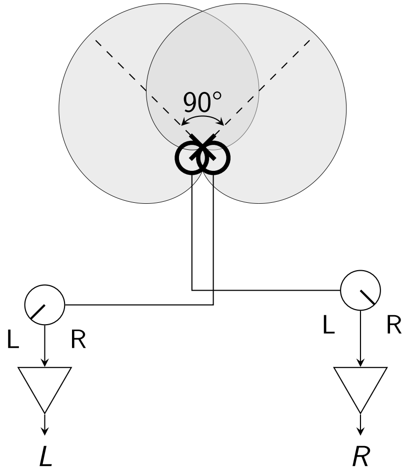


Figure: XY stereo recording technique

XY

(a) M930 large-diaphragms, vertical configuration (view from $\theta = -45°$)

(b) M300 small-diaphragms (top and front views)

Figure: XY configurations (© Microtech Gefell GmbH. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

XY

Figure: Horizontal XY configuration with two large-diaphragm condensers (front view)

XY

Figure: Creative (but wrong!) interpretation of XY (© Unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Blumlein pair

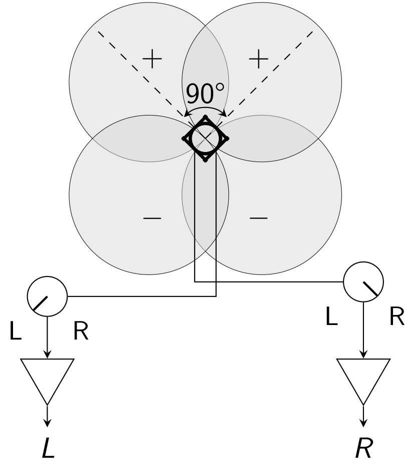
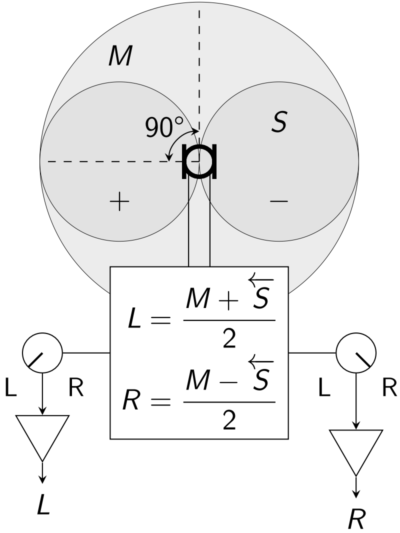


Figure: Blumlein pair

Mid/side (M/S)



M/S decoder

$$L = \frac{M + \overleftarrow{S}}{2}$$
$$R = \frac{M - \overleftarrow{S}}{2}$$

- L ... left loudspeaker signal
- R ... right loudspeaker signal
- M ... omni microphone signal
- $\overleftarrow{S}$ ... figure-eight mic signal (positive polarity left)

Mid/side (M/S)

Figure: M/S configuration with two small-diaphragm condensers (side view) ()

Mid/side (M/S)

Figure: M/S configuration with large- and small-diaphragm condenser (side view)

Mid/side (M/S)

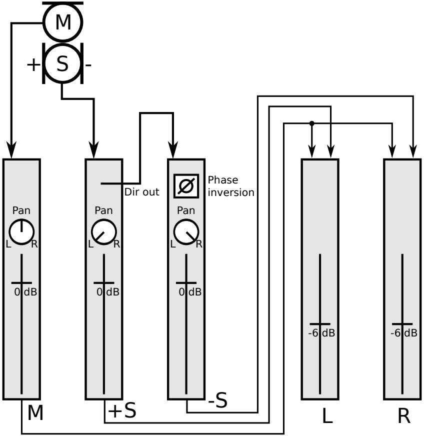


Figure: M/S decoder implemented on a mixing console

Mid/side (M/S)

Figure: True Systems Precision 8 eight-channel mic preamp with optional M/S decoder on channels 1+2 ()

AB

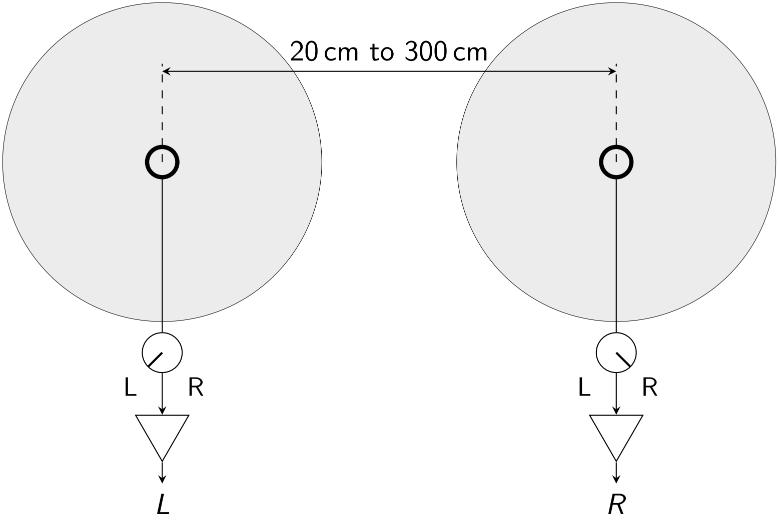


Figure: AB stereo recording technique

Faulkner pair

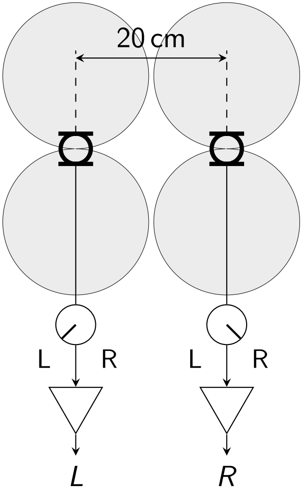


Figure: Faulkner pair

Decca tree

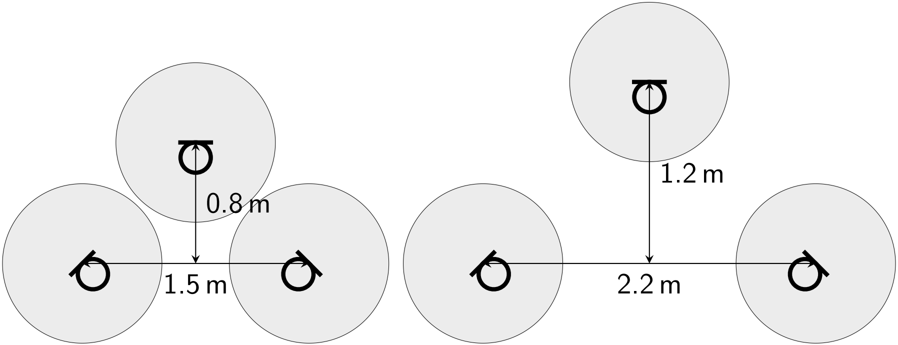


Figure: Two Decca trees of different dimensions (after Sengpiel 1994)

ORTF

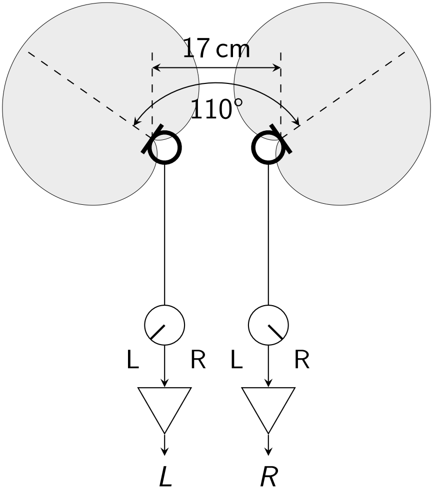


Figure: ORTF stereo recording technique

ORTF

(a) M930 large diaphragms (view from $\theta = +40°$)

(b) M300 small diaphragms (top and front views)

Figure: ORTF configurations ()

ORTF

Figure: Schoeps MSTC 64 U ORTF mic ()

Other mixed stereophonic techniques

Technique	Angle $\beta/°$	Distance d/cm
ORTF	110	17
NOS	90	30
EBS	90	25
RAI	100	21
DIN	90	20
Olson	135	20

Table: Mixed stereophonic recording techniques (all using two cardioids)

Dummy head

Figure: Neumann KU100 dummy head (© Georg Neumann GmbH. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Schoeps KFM 6

Figure: Schoeps KFM 6 spherical microphone ()

Schoeps KFM 6

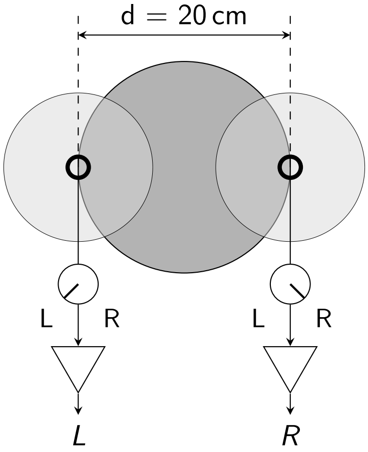


Figure: Schoeps KFM 6 geometry

OSS (Jecklin disk)

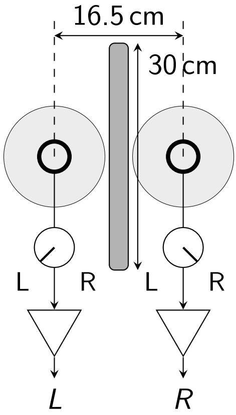


Figure: Original Jecklin disk dimensions

OSS (Jecklin disk)

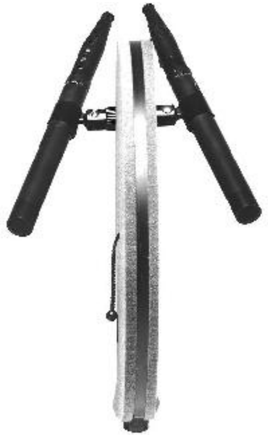


Figure: 'Jecklin disk' with original dimensions ()

OSS (Jecklin disk)

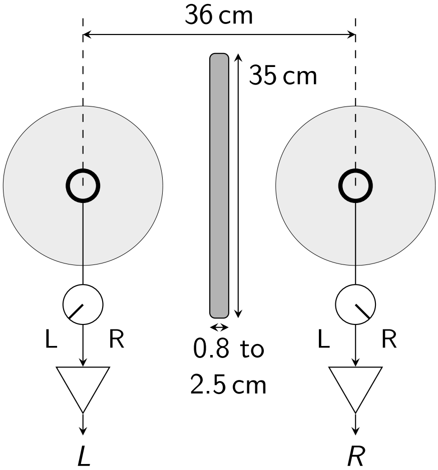


Figure: Revised OSS dimensions by Jürg Jecklin

Interpretation of the recording angle

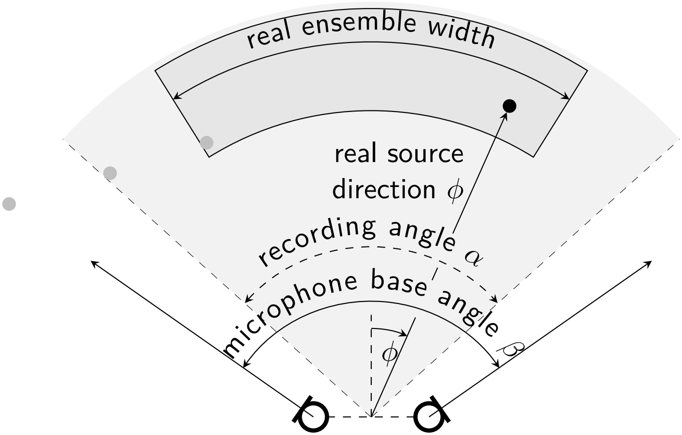


Figure: The invisible recording angle α is different from the visible stereo microphone base angle β.

Interpretation of the recording angle

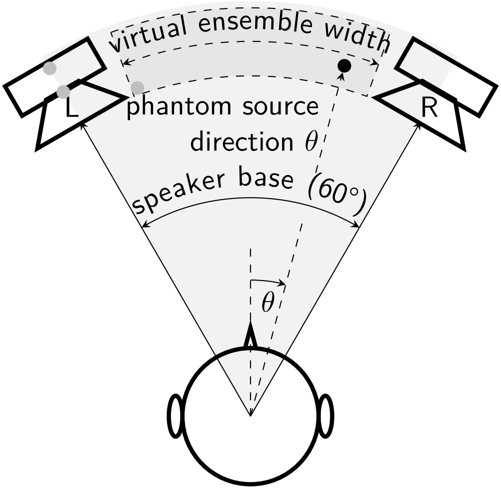


Figure: At playback, the recording angle is mapped to the loudspeaker base.

Determining the recording angle

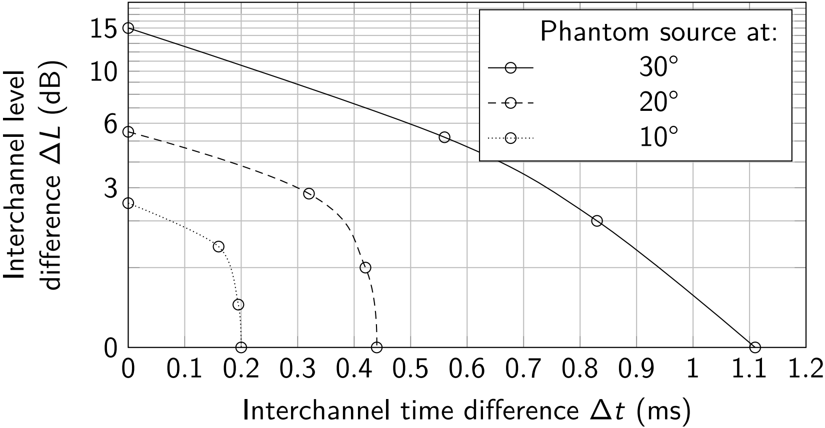


Figure: Phantom source direction in dependence of interchannel time and level differences (after Rumsey and McCormick 2009, p. 481)

Determining the recording angle

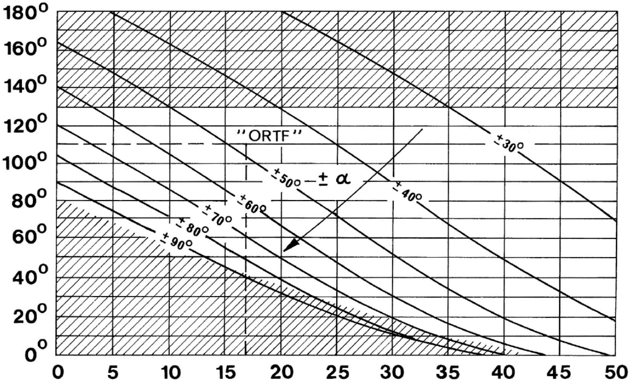


Figure: Williams localization curves, showing the recording angle as a function of the distance d/cm between the microphones and the microphone base angle $\beta/°$ (Wuttke 2000, p. 21.)

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 10: Dynamics & compression

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, October 12, 2016

Dynamic range

Dynamic range ΔL

$$\Delta L = L_{max} - L_{min}$$

- ΔL ... dynamic range (dB)
- L_{max} ... max. signal level (dB)
- L_{min} ... min. signal level (dB)

Signal or system	ΔL/dB
Symphony orchestra	70
Pop music	6
Human ear	130
AKG C414 XLS	134
Digital audio (16 bit)	96
Digital audio (24 bit)	144

Table: Dynamic range ΔL of different audio systems

Dynamic range processors

Figure: Joemeek twinQ mic preamp with built-in compressor and EQ ()

Dynamic range processors

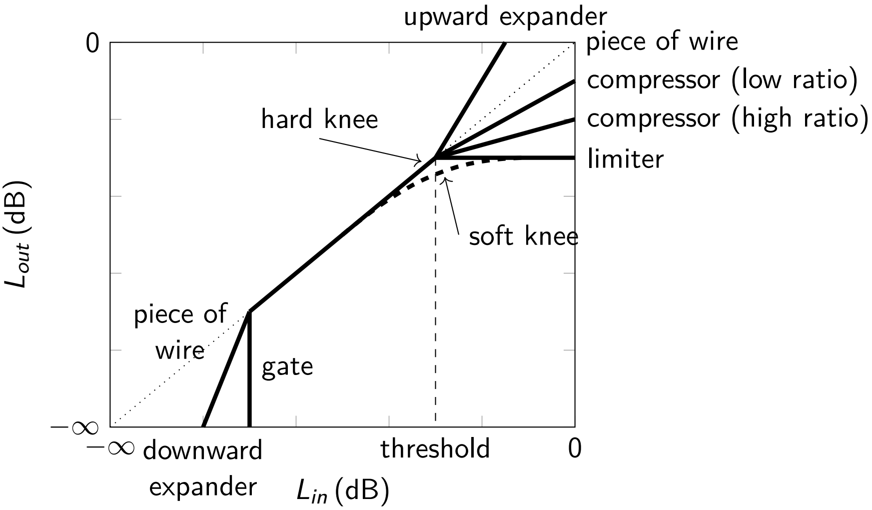


Figure: Transfer functions of different dynamic range processors

Compressor

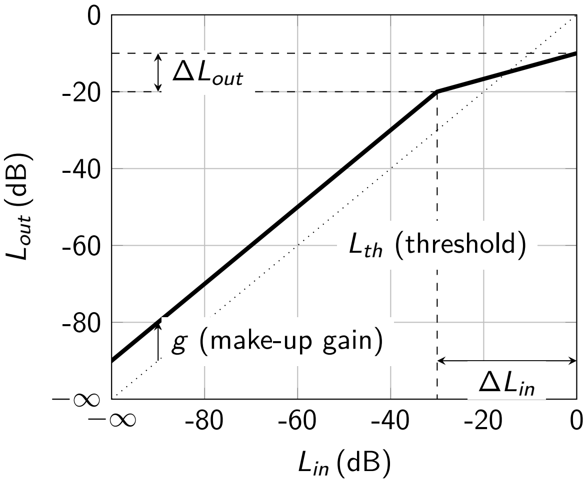


Figure: Transfer function of a compressor

Limiter

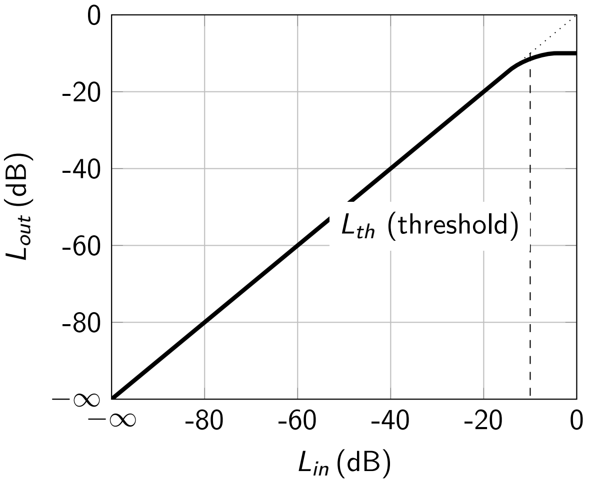


Figure: Transfer function of a limiter

Expander

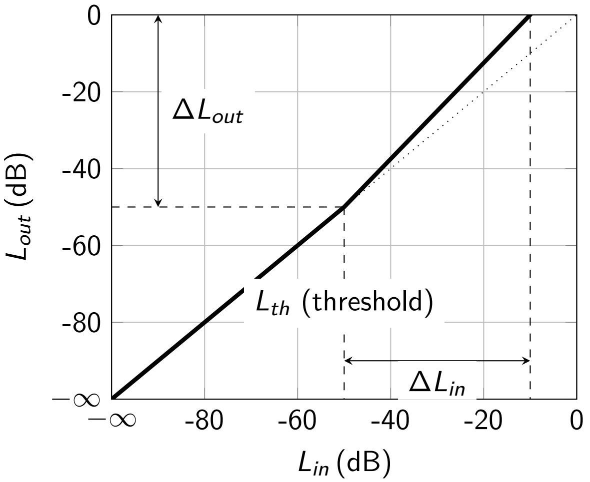


Figure: Transfer function of an upward expander

Gate

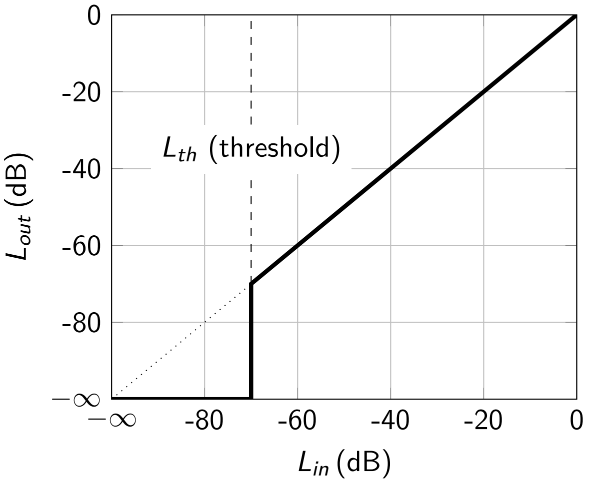


Figure: Transfer function of a gate

Control parameters

Parameter	Symbol	Unit
Threshold	L_{th}	dB
Ratio	R	1
Knee	—	dB
Make-up gain	g	dB
Attack time	T_a	ms
Release time	T_r	ms
Release delay	T_d	ms

Table: Parameters of dynamic range processors

Threshold, ratio, knee, make-up gain

Ratio R of a dynamic range processor

$$R = \frac{\Delta L_{in}}{\Delta L_{out}}$$

Processor	R	Typical values
Compressor	> 1	2:1, 3:1, 4:1, etc.
Limiter	$\to \infty$	
Expander	< 1	1:2, 1:3, 1:4, etc.
Gate	$\to 0$	

Table: Ratio R of dynamic range processors

Attack time, release time, release delay

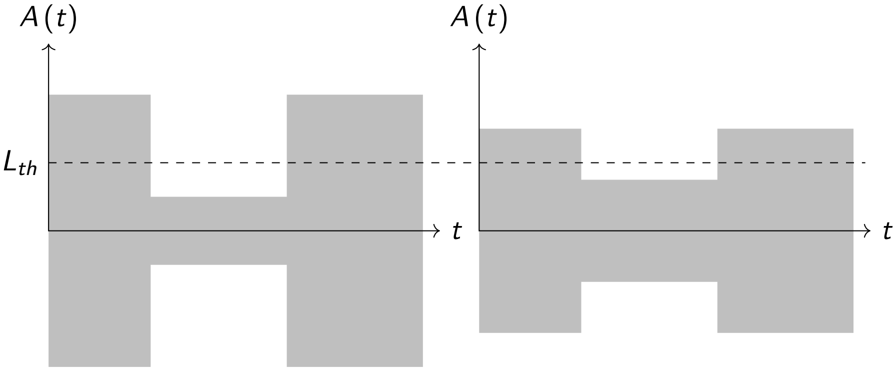


Figure: Input (left) and output (right) of a compressor with attack and release times of zero (after Katz 2014a, figs. A, B)

Attack time, release time, release delay

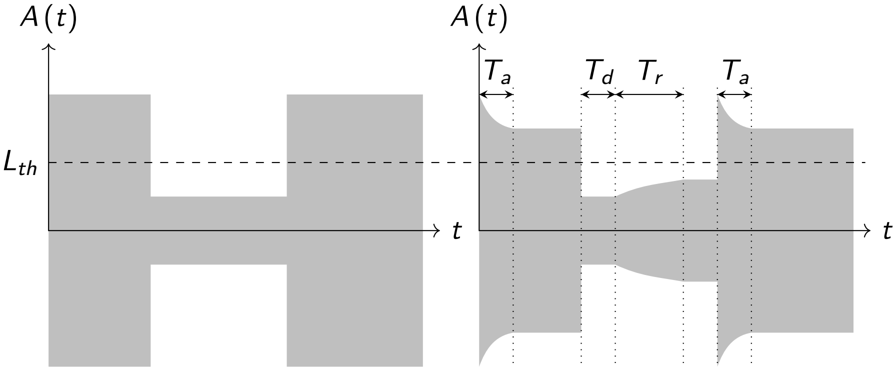


Figure: Input (left) and output (right) of a compressor with attack time T_a, release time T_r, and release delay T_d all $\neq 0$ (after Katz 2014a, fig. C)

Compression techniques

The simplest cue that you need to compress a track is that you keep wanting to reach over and adjust its fader. (Senior 2011a, p. 146)

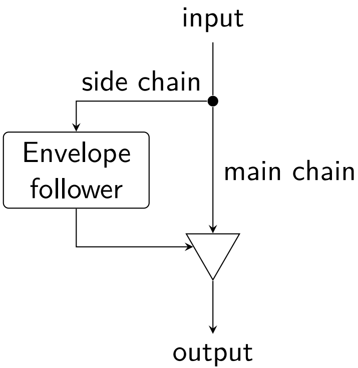
General compression recipe

> *[I]t's probably better to remove all the labels on the knob [...] and just listen!* (Katz 2007b, p. 121)

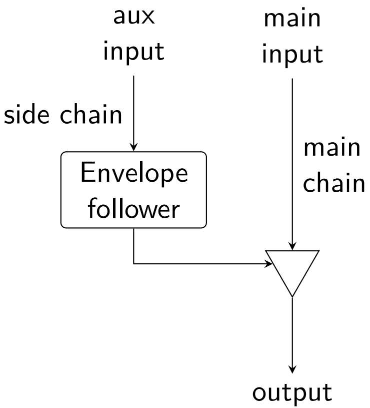
Compression recipe (Katz 2014b, p. 94)

1. Use a high ratio (e.g., $^4/_1$) and fast release time (e.g., 100 ms)
2. Find useful threshold around the music's 'action point'
3. Reduce ratio (e.g., to $^{1.2}/_1$)
4. Increase release time (e.g., to 250 ms)
5. Listen and fine-tune attack time, release time, and ratio

Side chain manipulation

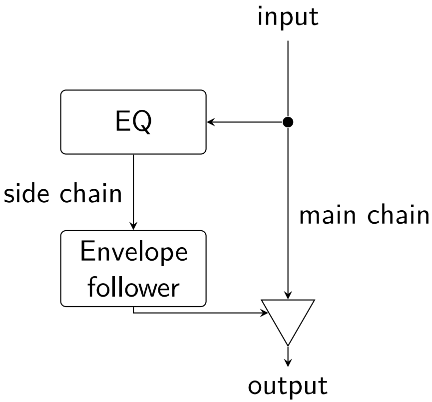


(a) Side chain in a feed-forward compressor

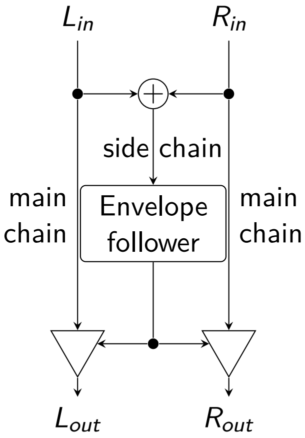


(b) Separate aux input

Side chain manipulation



(a) Side-chain EQing (e.g., de-esser)



(b) Stereo compressor

Figure: Side chain manipulation

Side chain manipulation

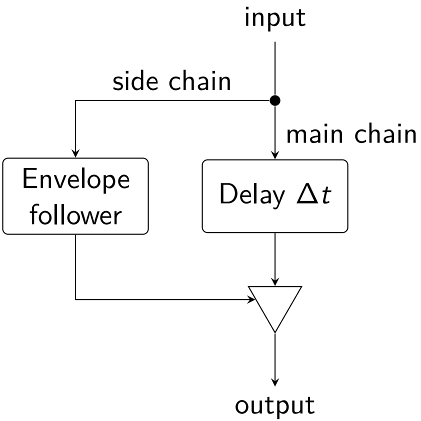


Figure: Look-ahead function (e.g., peak limiting)

Multiband compression

Figure: Calf Multiband Compressor plugin (© Calf Studio Gear. GNU General Public License. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Parallel compression

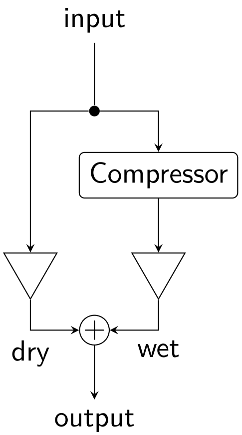


Figure: Parallel compression

Motivation

- Compress, but maintain transients

Recipe (Katz 2014b, p. 103)

- Threshold: −50 dB
- Ratio: $^{2.5}/_{1}$
- Attack time: very short
- Release time: 250 ms to 350 ms

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 11: Workshop: Stereo recording practice

Massachusetts Institute of Technology
Music and Theater Arts

Monday, October 17, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 12: Workshop: Headphone monitoring

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, October 19, 2016

Mic task

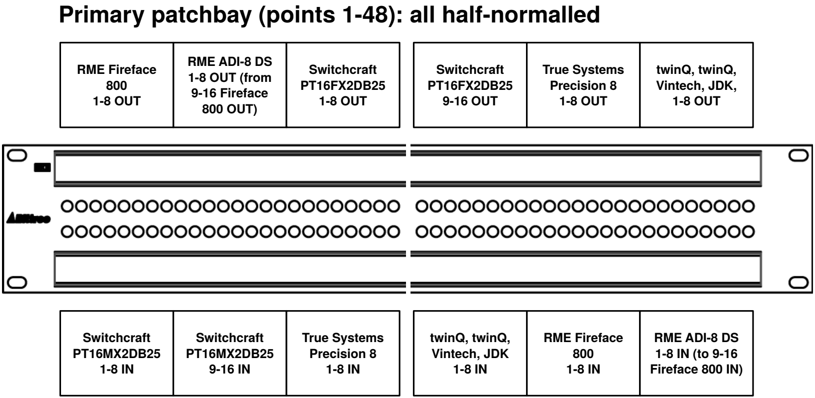
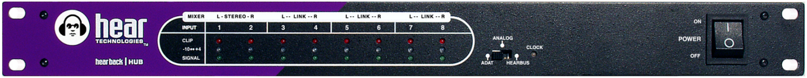


Figure: Primary MOSS Bantam patchbay (Courtesy of Chris Ariza. Used with permission)

Monitor task



(a) Hear Technologies Hear Back hub (© Hear Technologies)

(b) RJ45 feed thru patch panel (© markertek)

Figure: Headphone monitor mixing facilities in the MOSS.

Monitor task

Figure: Hear Technologies Hear Back mixer ()

DAW task

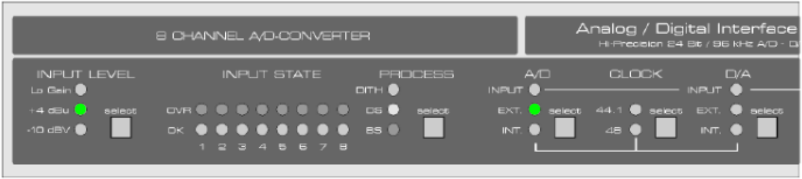


Figure: RME ADI-8 DS settings to be used for recording sessions (D/A clock settings irrelevant) (© RME Audio. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

DAW task

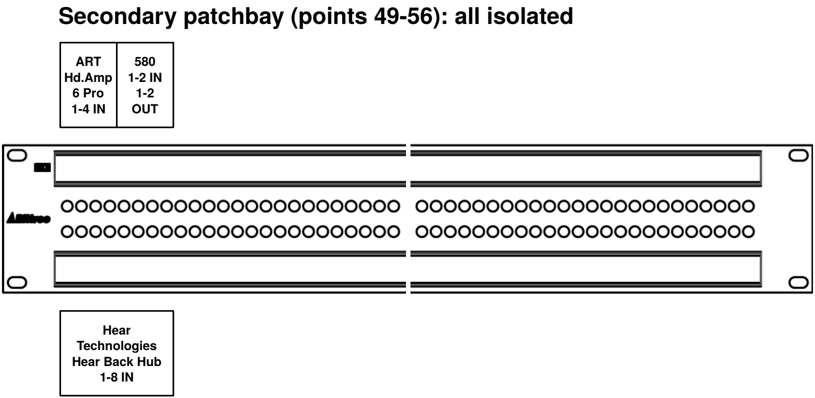


Figure: Secondary MOSS Bantam patchbay (Courtesy of Chris Ariza. Used with permission)

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 13: Digital audio

Massachusetts Institute of Technology
Music and Theater Arts

Monday, October 24, 2016

Digital audio

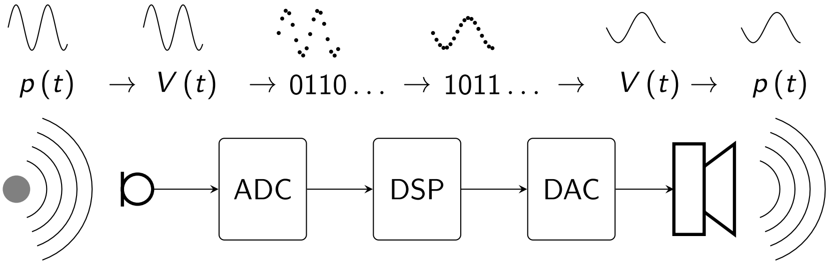


Figure: Digital reproduction chain

Why digital?

If you happen to be a sound engineer, [the possibility of lossless copies] is heaven. If you are a record company executive you take another pill for blood pressure and phone your lawyer to see if you can have it stopped. (Watkinson 2001, p. 9)

Analog-digital conversion

Figure: RME ADI-8 DS A/D and D/A converter (© RME Audio. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Analog-digital conversion

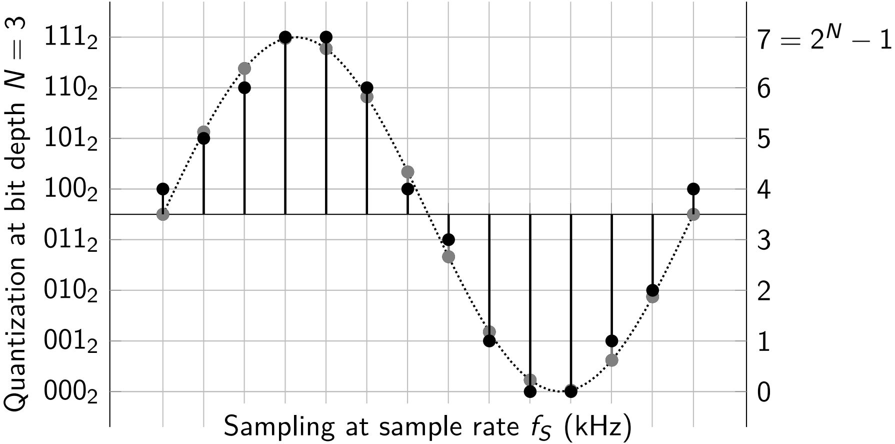


Figure: Analog/digital conversion

Sampling theorem

Sampling theorem

$$f_S \overset{!}{>} 2 \cdot f_{max}$$

Nyquist frequency

$$f_N = \frac{f_S}{2}$$

- f_S ... Sample rate (Hz)
- f_{max} ... Highest frequency to be sampled (Hz)
- f_N ... Nyquist frequency (Hz)

Sampling does not imply a loss of information (but quantization does)

A signal that has been sampled in compliance with the sampling theorem (but not quantized) can be truthfully restored.

Sampling theorem

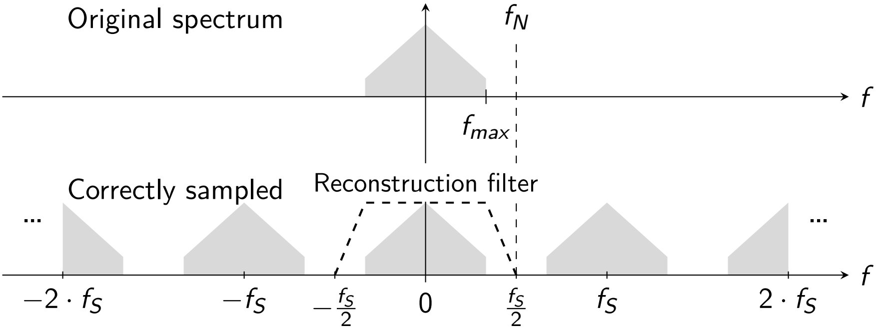


Figure: Sampling creates spectral sidebands of the original spectrum that repeat periodically around multiples of f_S (after Lyons 2004, fig. 2.4)

Sampling theorem

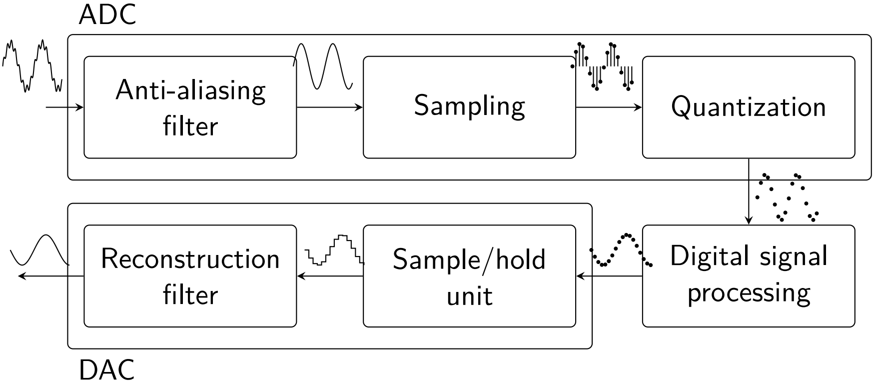


Figure: ADC/DAC conversion chain (after S. W. Smith 1997, fig. 3.7)

Aliasing (undersampling)

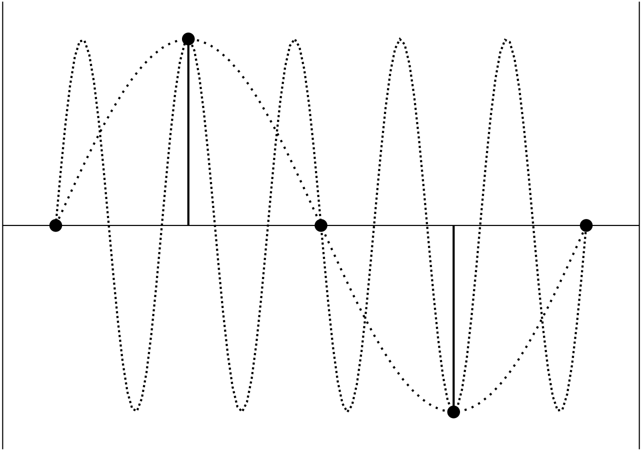


Figure: Violation of the sampling theorem creates an ambiguity

Aliasing (undersampling)

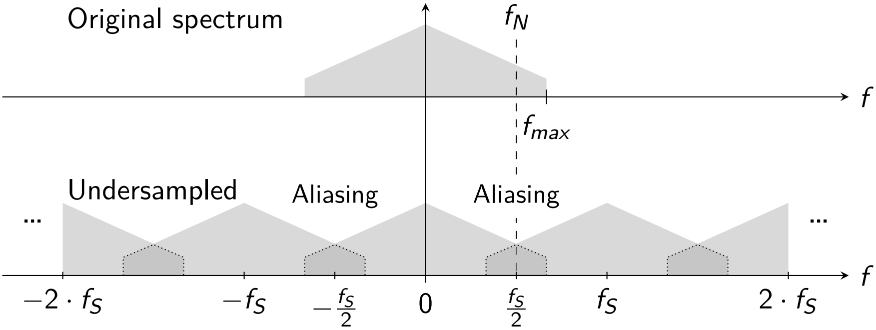


Figure: A violation of the sampling theorem (undersampling) results in aliasing (after Lyons 2004, fig. 2.4)

Signal reconstruction & oversampling

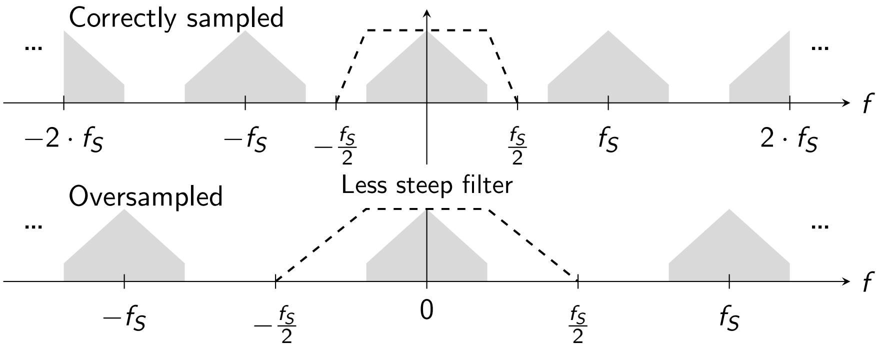


Figure: Deliberate oversampling allows the use of less steep reconstruction filters (after Lyons 2004, fig. 2.4)

Jitter

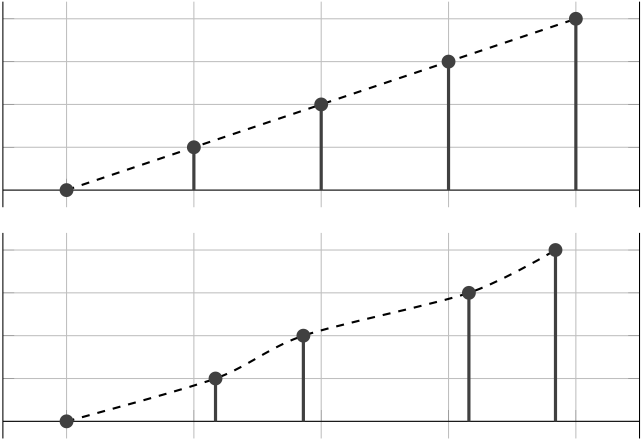


Figure: A signal sampled with a jitter-free sample clock (top) will be distorted when played back through a sample clock with jitter (bottom)

Binary numbers

There are 10 types of people in the world... those who know binary and those who don't. (courtesy of [redacted]*, MIT class of 2014)*

Binary-to-decimal conversion

$$\begin{aligned} 1001_2 &= 1 \cdot 2^3 + 0 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0 \\ &= 8 + 0 + 0 + 1 \\ &= 9_{10} \end{aligned}$$

- 1001 binary equals 9 decimal
- Analogous: $975_{10} = 9 \cdot 10^2 + 7 \cdot 10^1 + 5 \cdot 10^0$

Bit depth

Numeric values that can be expressed by N bit

$$2^N$$

Examples

- 16 bit audio: $2^{16} = 65\,536$
- 24 bit audio: $2^{24} = 16\,777\,216$

Binary	Decimal
000_2	0
001_2	1
010_2	2
011_2	3
100_2	4
101_2	5
110_2	6
111_2	7

Table: Numeric values that can be expressed with a bit depth of $N = 3$

Quantizing error

Dynamic range of digital audio

$$\Delta L_{dig} = 20 \cdot \log_{10}\left(2^N\right) = 20 \cdot N \cdot \log_{10}(2) \approx (6 \cdot N)\,\mathrm{dB}$$

- ΔL_{dig} ... dynamic range (dB)
- N ... bit depth ($N \in \mathbb{N}$)

N	ΔL_{dig}
16	96
24	144

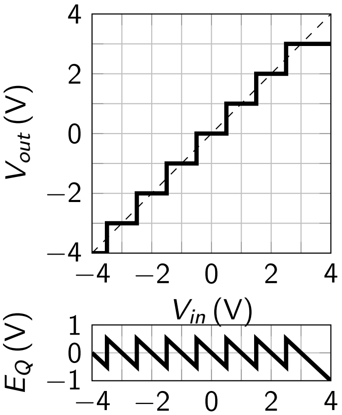


Figure: Quantizing error E_Q of a 3 bit ADC

Dither

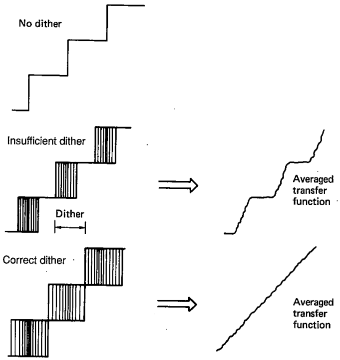


Figure: Dithering 'linearizes' the quantizer's transfer function, i.e. it makes it look more like a straight line. This comes at the cost of introducing a small amount of noise (Watkinson 2001, p. 227.)

Dither

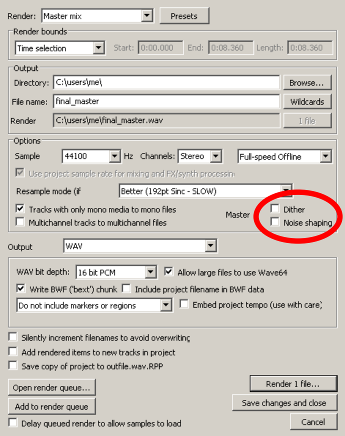


Figure: Dither and noise-shaping options in Reaper's File › Render ... dialog

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 14: Mixing consoles

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, October 26, 2016

What are mixers for?

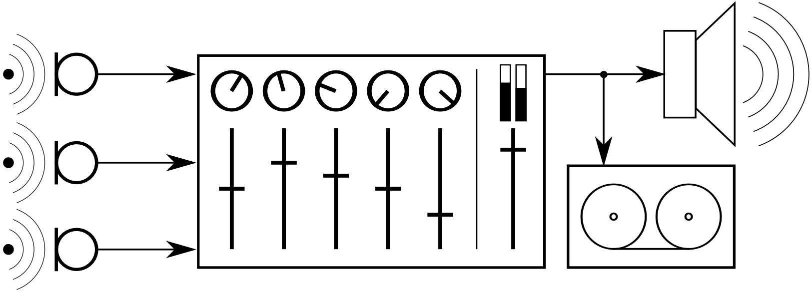


Figure: General concept of a mixing console

What are mixers for?

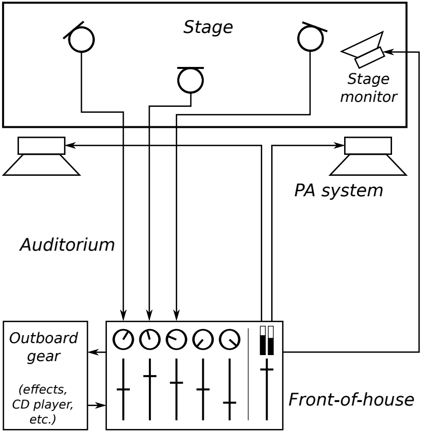


Figure: Typical live sound reinforcement scenario

What are mixers for?

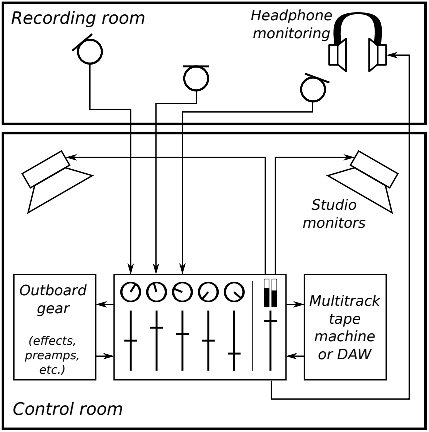


Figure: Typical studio recording scenario

Example models

Figure: Soundcraft M12 mixer ()

Example models

Figure: Yamaha O2R96VCM digital mixer ()

Example models

Figure: Behringer UB502 desktop mixer (© Behringer. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Example models

Figure: Gemini PS2 DJ mixer (© Gemini. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Example models

Figure: Mackie PPM1008 power mixer ()

Example models

Figure: One of the most popular power mixers according to Google ()

Example models

Figure: Midas Venice F live mixer ()

Example models

Figure: SSL studio console ()

Example models

Figure: AMS Neve 88 RS analogue mixer ()

Example models

Figure: Studer Vista digital mixing console (© Studer Professional Audio GmbH.)

Example models

Figure: Vintage mixer from the WDR's (West German Broadcasting) famous electronic music studio in Cologne (with thanks to Volker Müller)

Example models

Figure: Hear Technologies Hear Back mixer ()

Example models

Figure: Software mixer in Reaper ()

Topology

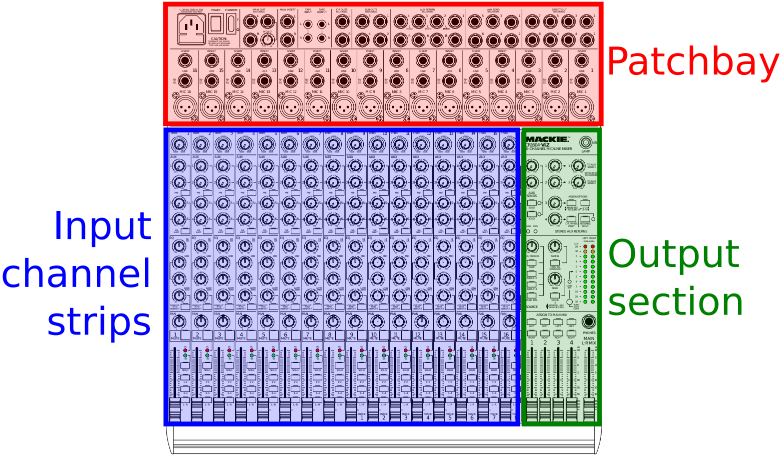


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Topology

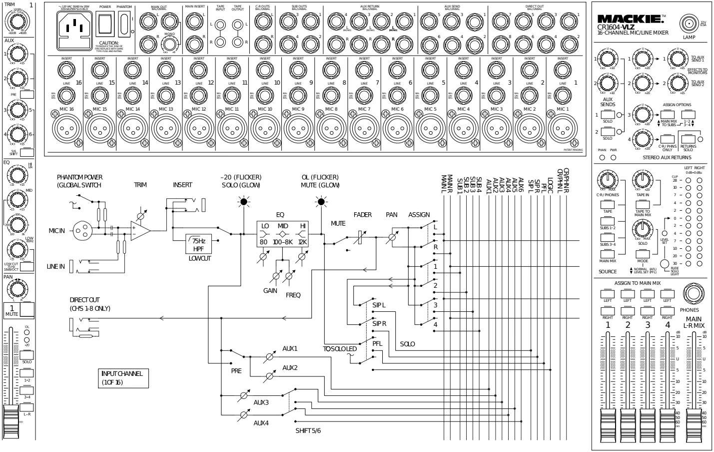


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Physical inputs

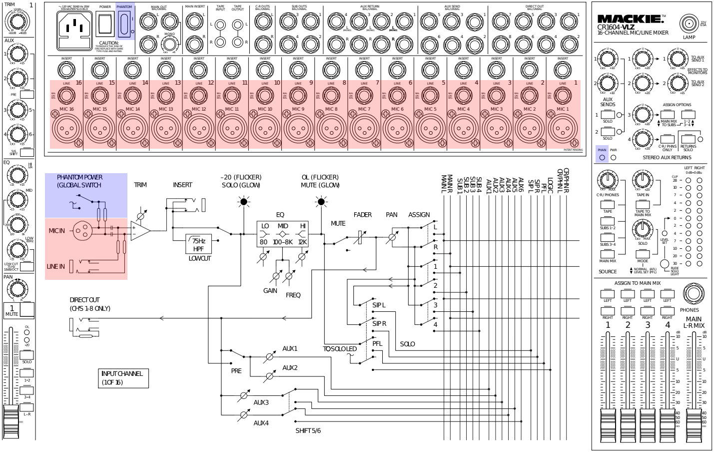


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Preamps & phantom power

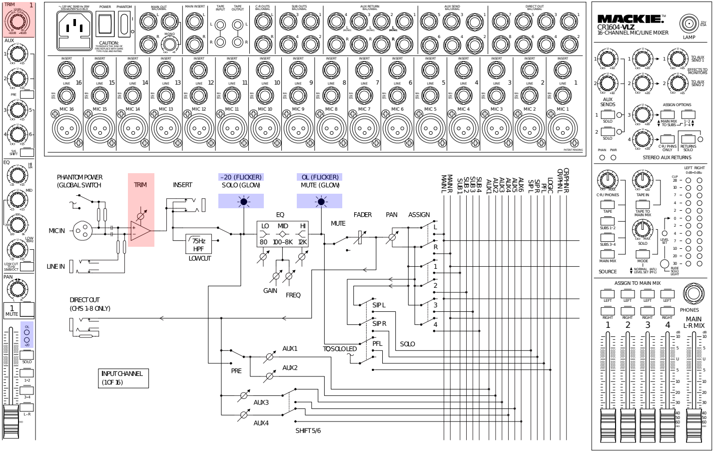


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Inserts

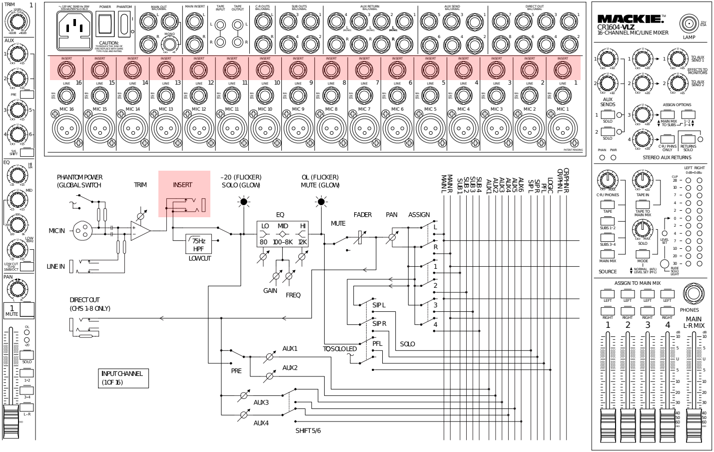
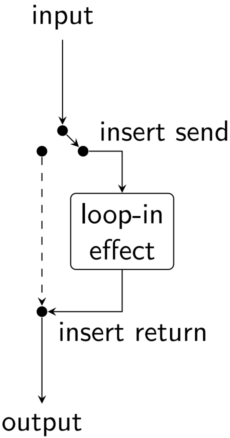
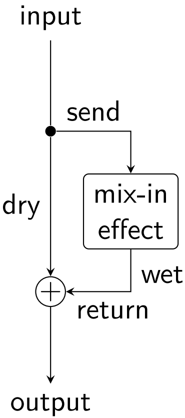


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Inserts



(a) Loop-in effect (e.g., EQ, compressor, distortion), typically implemented as an *insert*



(b) Mix-in effect (e.g., reverb, chorus, flanger), typically implemented as an *auxiliary*

Inserts

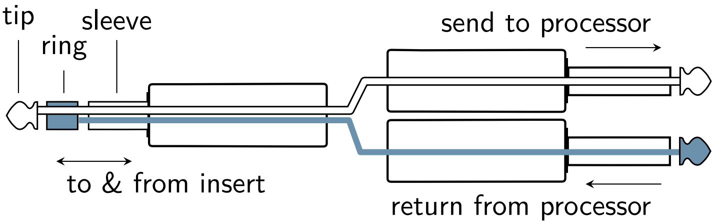


Figure: Typical ¼" insert cable (© LOUD Technologies Inc. With edits.)

EQ section

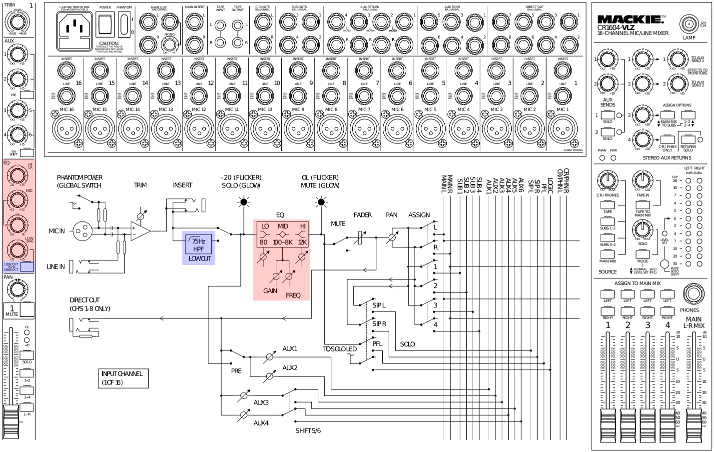


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Mute button

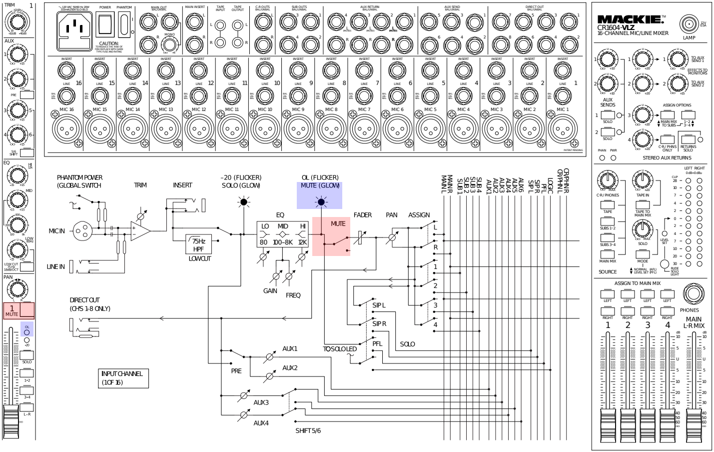


Figure: Mackie CR1604 VLZ mixer ()

Fader

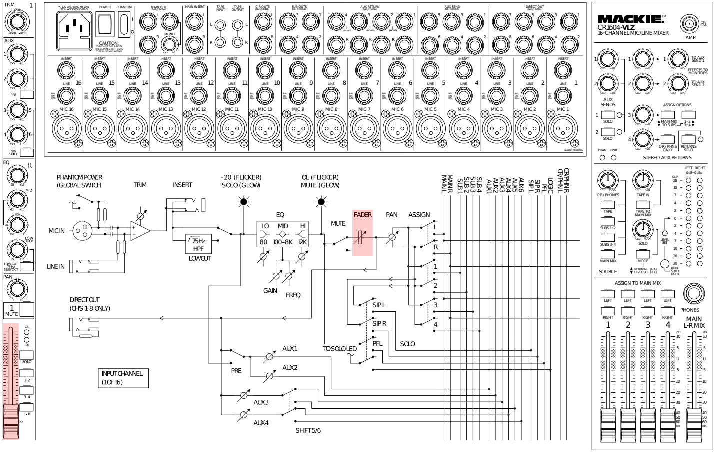


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.

Direct outputs

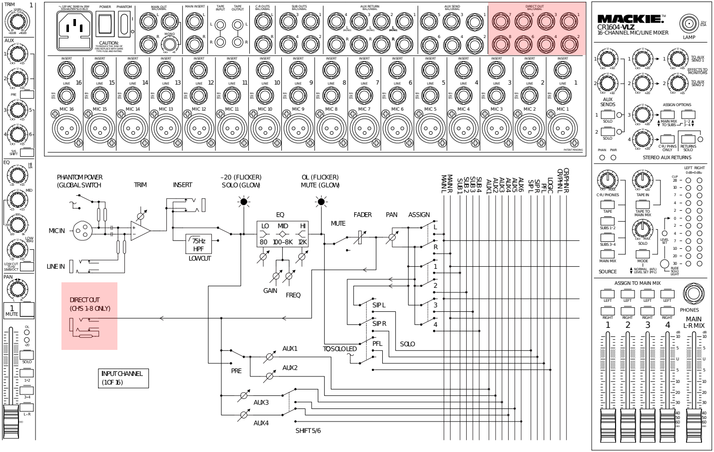


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Auxiliary sends

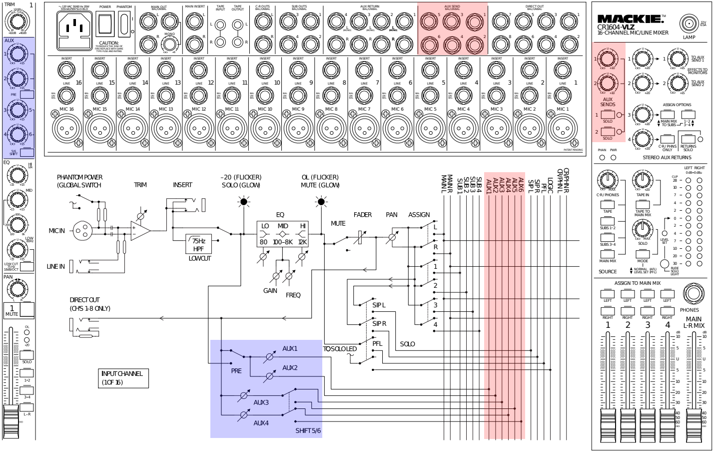


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Pre-fader auxiliaries

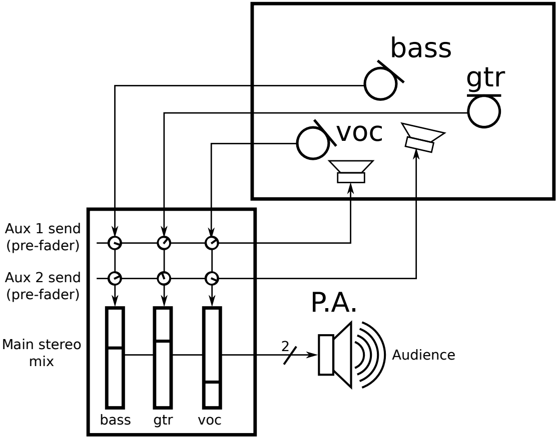


Figure: Using pre-fader auxiliaries for providing independent mixes on on-stage monitor loudspeakers

Post-fader auxiliaries

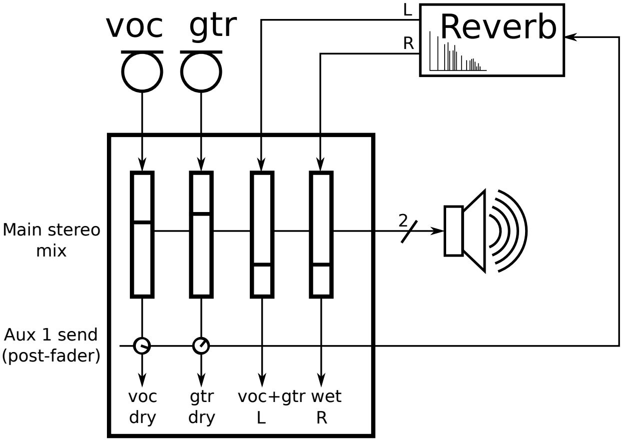


Figure: Using a post-fader auxiliary for a mix-in effect

Auxiliary returns

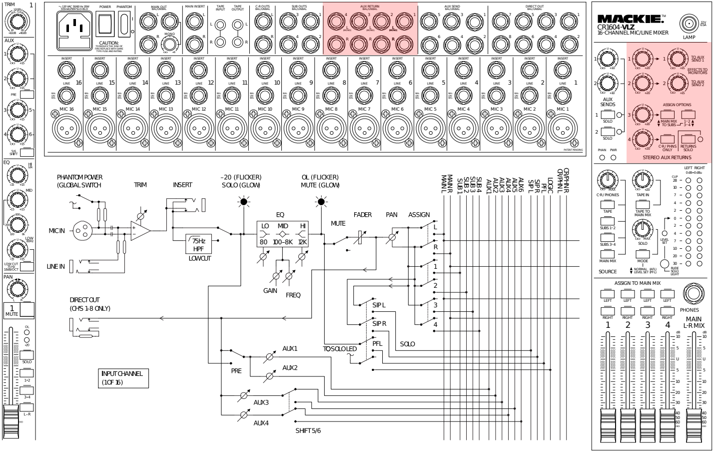


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Panpot or balance control

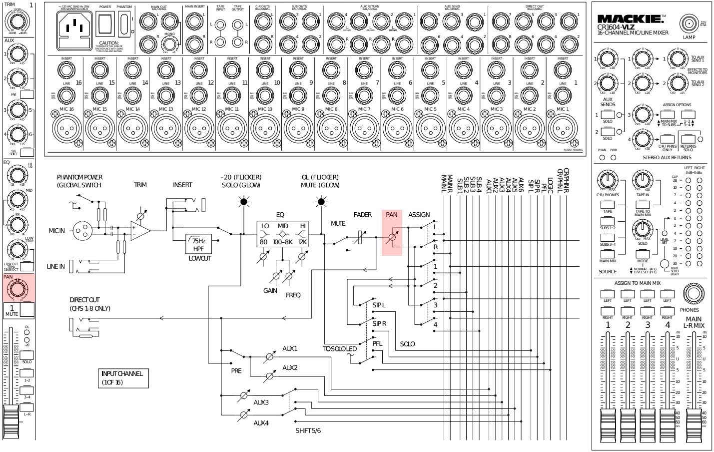
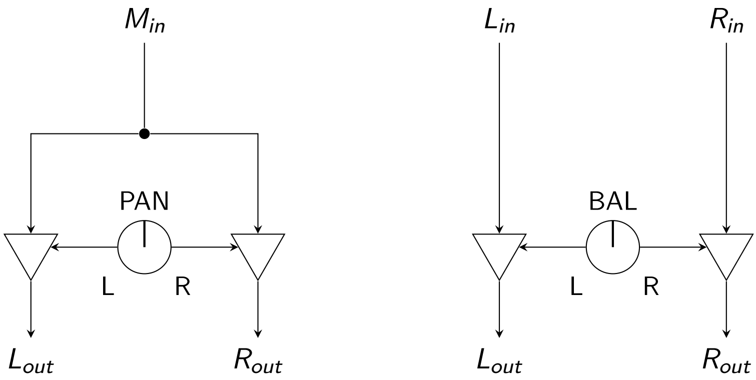


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Panpot or balance control



(a) Panpot (mono input)　(b) Balance control (stereo input)

Figure: Panpot vs. balance control

Solo function

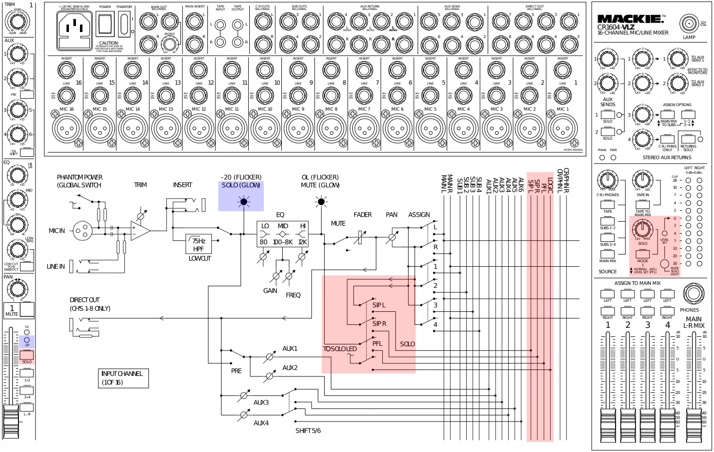


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Solo function

Mode	Meaning	Output bus used	Application
PFL	Pre-fader listening	Solo (mono)	Live mixing
AFL	After-fader listening	Solo (mono)	
SIP	Solo-in-place	Main mix (stereo)	Mixdown

Table: Solo modes (cf., Thompson 2005, p. 76)

Routing inputs to outputs

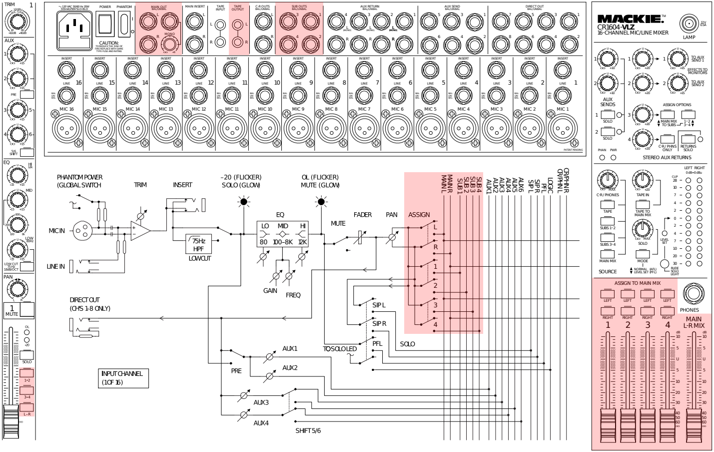


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Signal meters

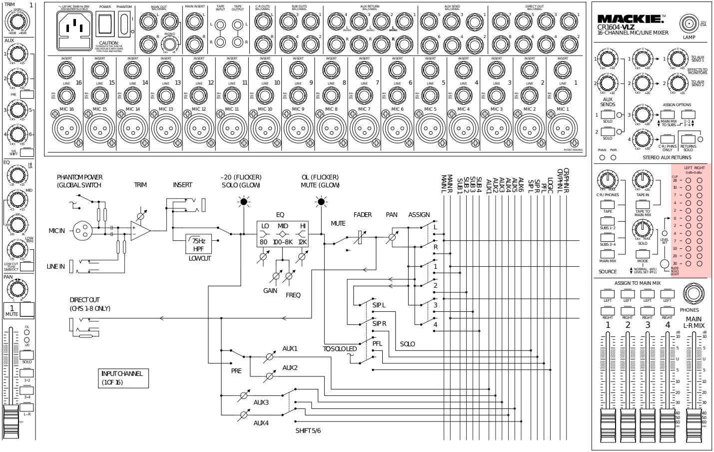


Figure: Mackie CR1604 VLZ mixer ()

Main inserts

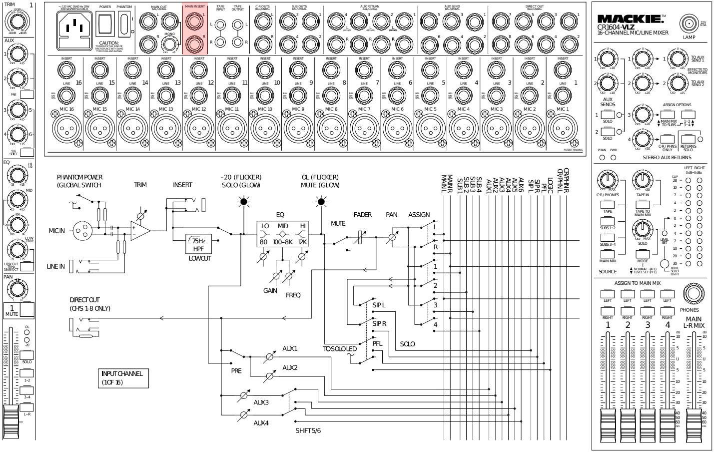


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Control-room monitoring

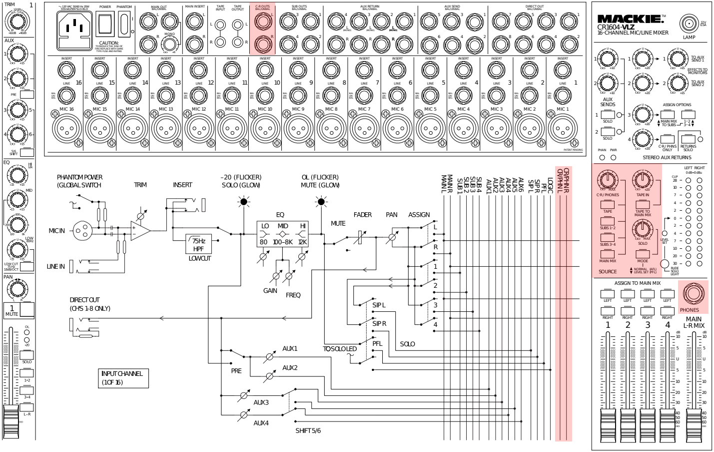


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.)

Tape return

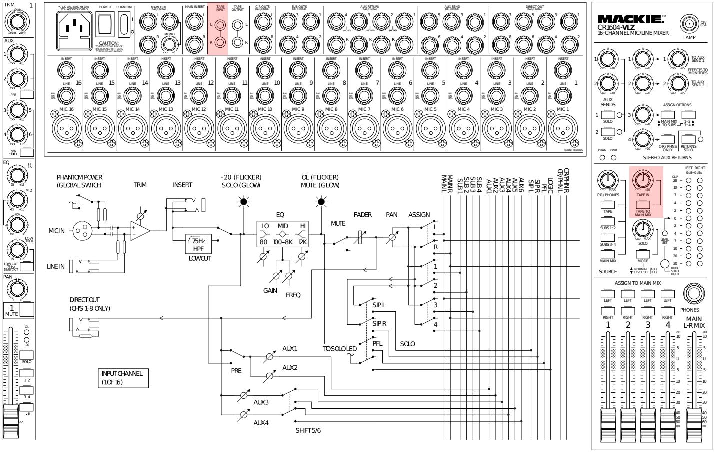


Figure: Mackie CR1604 VLZ mixer (© LOUD Technologies Inc. With edits.

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 15: Student presentations: Recording session plans

Massachusetts Institute of Technology
Music and Theater Arts

Monday, October 31, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 16: Mixing strategies

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, November 2, 2016

Mixing strategies

Rayburn (2011)
Senior (2014)

Izhaki (2011b)
Senior (2011a)

Katz (2014b)

Figure: The music production process (after Eargle 2003a, p. 326)

Balance

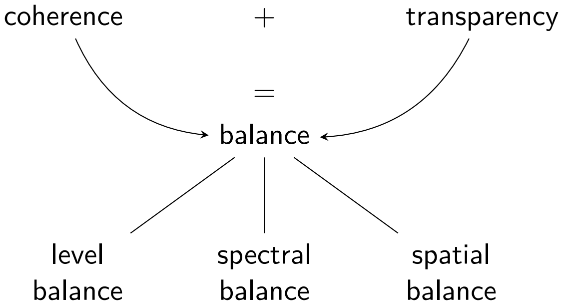


Figure: Balance as a union of coherence and transparency

Spectral balance

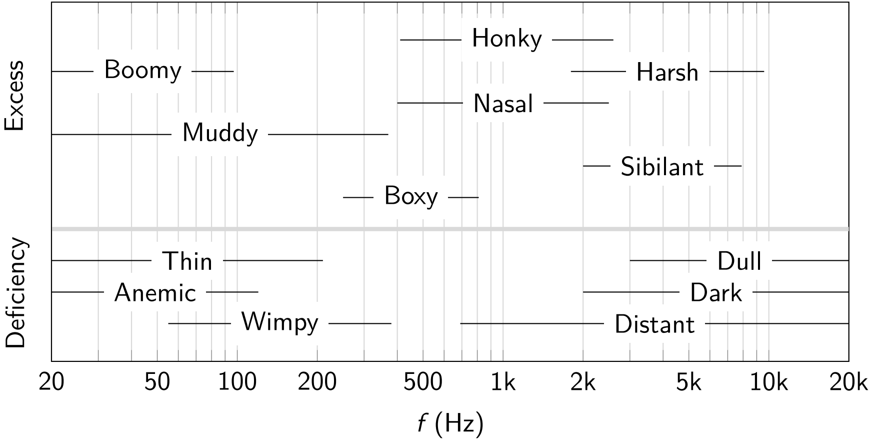
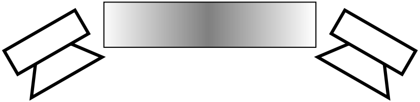


Figure: Qualitative descriptions of over- or underemphasis of different frequency ranges (after Izhaki 2011a, fig. 14.4)

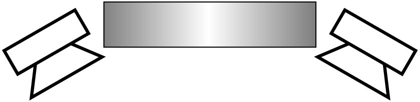
Spatial balance

The essence of stereo is a sense of spatiality, not a set of mono images panned to different positions on the stereo stage. (Eargle 2003b, p. 330)

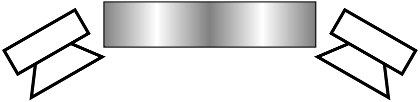
Spatial balance



(a) I mix



(b) V mix



(c) W mix

Figure: Spatially imbalanced mixes (after Izhaki 2011b, figs. 6.5–6.7)

DAW parameter automation

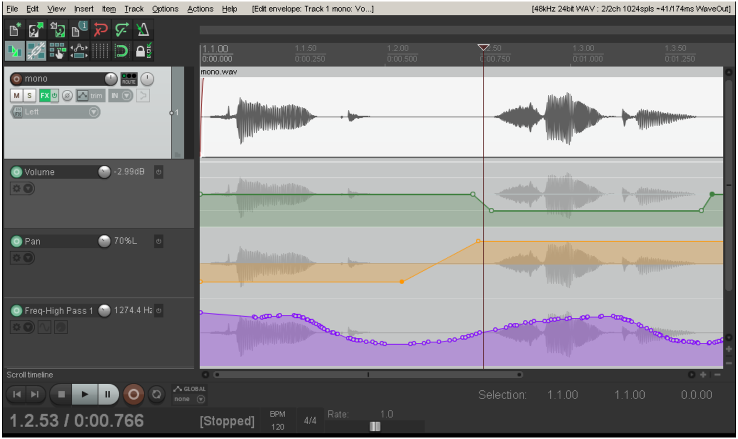
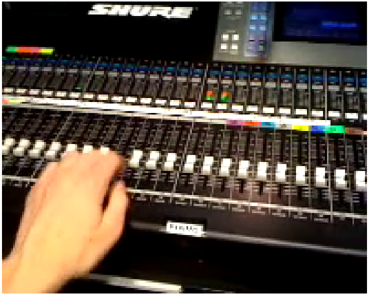


Figure: Parameter automation in Reaper ()

DAW parameter automation

(a) Fader art (© YouTube user 'SeldomSleek')



(b) VCA group (© YouTube user 'osxdude')

Figure: Motorized faders on a mixing console.

DAW parameter automation

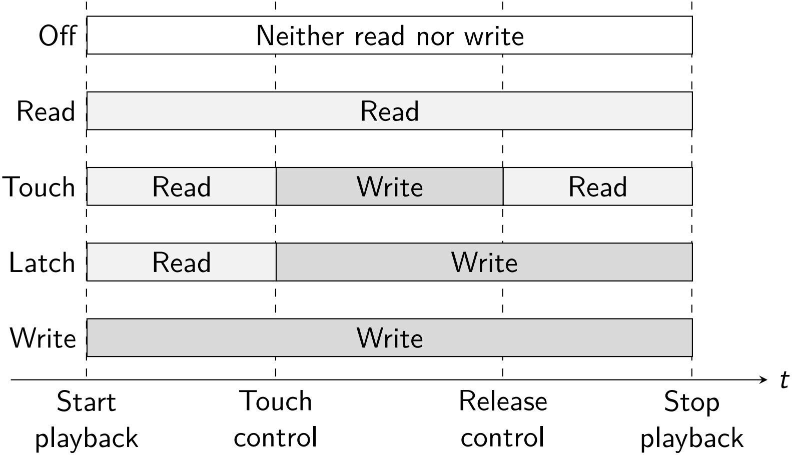


Figure: Five common automation modes (after Izhaki 2011b, fig. 27.2)

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 17: Recording session 1 (piano solo)

Massachusetts Institute of Technology
Music and Theater Arts

Monday, November 7, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 18: Room acoustics & reverberation

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, November 9, 2016

Room acoustics & reverberation

For centuries architects have been working on the problem of acoustics. They tried to solve it on the drawing board. They drew straight lines from the sound source to the ceiling, assuming the sound would bounce off at the same angle, like a billiard ball from the cusion, and continue on its way. But all these diagrammatic representations are nonsense. (Loos 1912, p. 108)

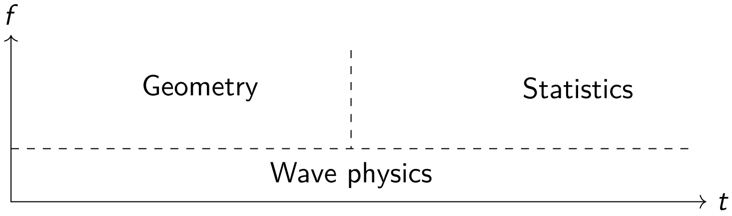


Figure: Mathematical description of room acoustics (Graber 2002, p. 3)

Flutter echoes & resonances

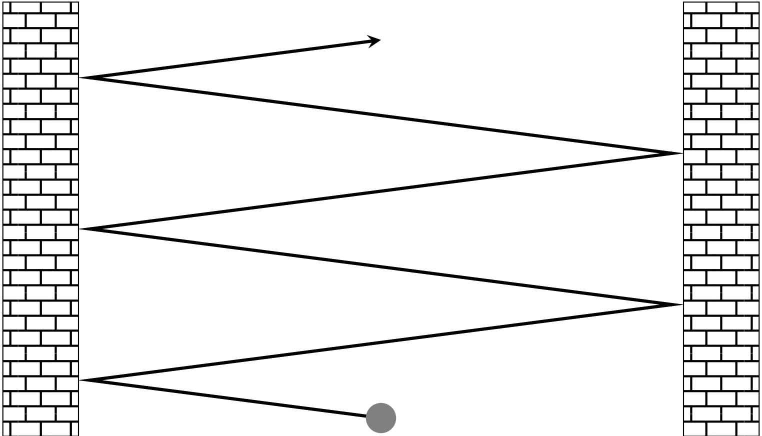
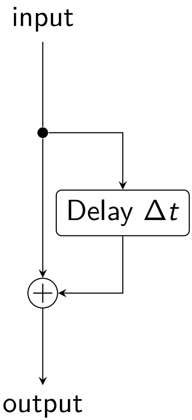
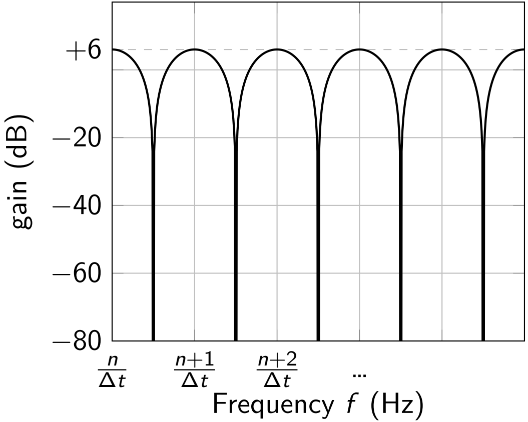


Figure: Reflections from hard, parallel surfaces

Comb filters



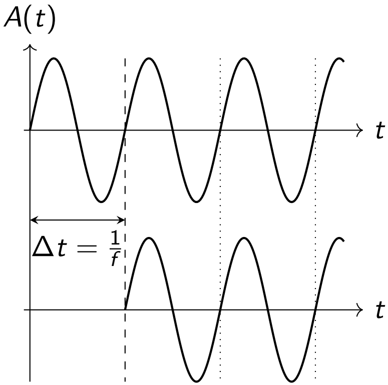
(a) Flow chart



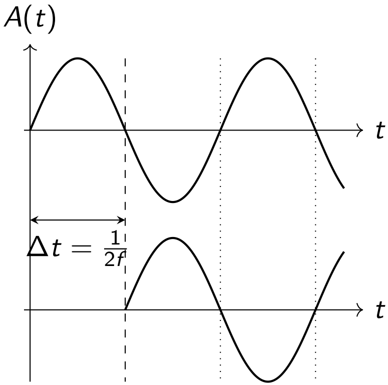
(b) Frequency response (note linear x axis)

Figure: Principle of a comb filter

Comb filters



(a) Constructive interference



(b) Destructive interference

Figure: Mixing a signal with a delayed copy of itself results in an interference pattern that depends on frequency.

Comb filters

$$\Delta t = \frac{\Delta d}{c} = \frac{d_2 - d_1}{c} = \frac{2\sqrt{h^2 + \left(\frac{d_1}{2}\right)^2} - d_1}{c}$$

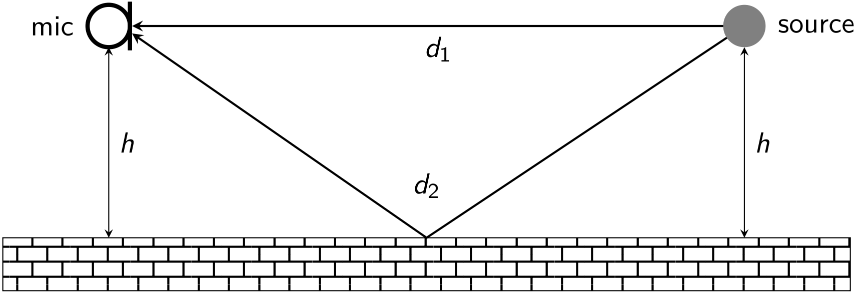


Figure: Comb filter effect caused by single reflection

Standing waves

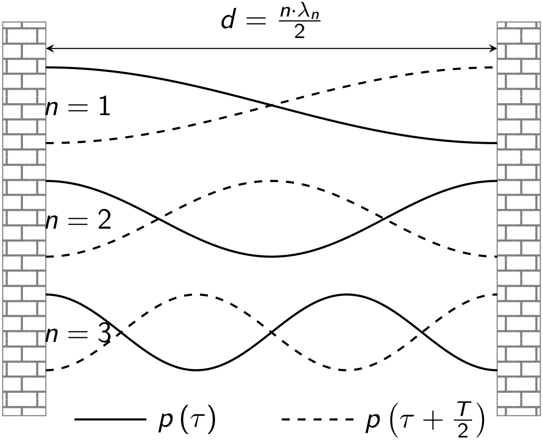


Figure: Sound pressure p for a standing wave between two parallel walls

Room modes

Room modes

$$f_n = \frac{n \cdot c}{2 \cdot d}$$

- f_n ... modal frequencies (Hz)
- n ... mode number ($n \in \mathbb{N} = 1, 2, 3, \dots$)
- c ... speed of sound ($\mathrm{m\,s^{-1}}$)
- d ... distance between walls (m)

	Length 11.57 m	Width 4.93 m	Height 4.10 m
n	Room mode/Hz		
1	14.8	34.8	41.9
2	29.6	69.6	83.7
3	44.5	104.4	125.6
4	59.3	139.2	167.4
5	74.1	174.0	209.3
6	88.9	208.8	251.1

Table: First-order room modes of the Sonic Arts Lab at the New Zealand School of Music in Wellington

Natural reverb

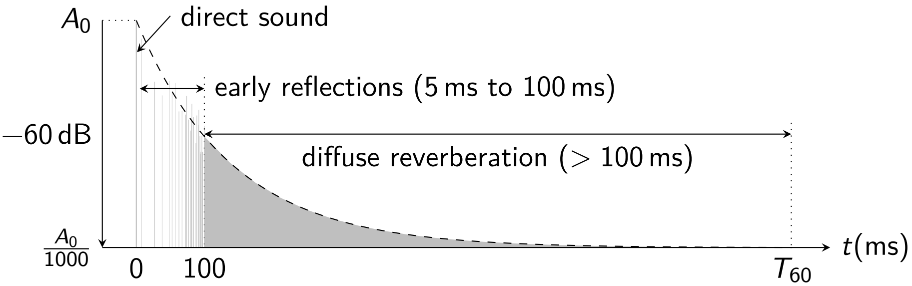


Figure: Typical impulse response of a room

Reverberation time T_{60}

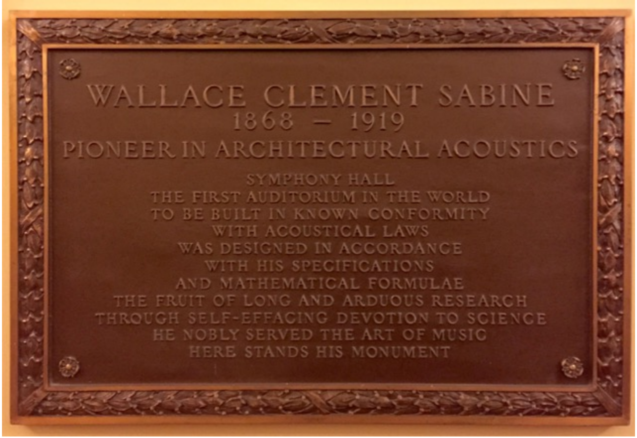


Figure: Plaque in the foyer of Boston Symphony Hall memorizing Wallace Sabine ()

Reverberation time T_{60}

Reverberation time T_{60}

Time it takes SPL in a given room to drop by 60 dB

$$T_{60} \approx 0.161 \cdot \frac{V}{S \cdot \alpha}$$

- T_{60} ... reverberation time (s)
- 0.161 ... magic number ($\mathrm{s\,m^{-1}}$)
- V ... total room volume (m^3)
- S ... total room surface (m^2)
- α ... average absorption coefficient ($0 \leq \alpha \leq 1$)
- $S \cdot \alpha$ ... total absorption (sabins $\equiv \mathrm{m}^2$)

Reverberation time T_{60}

Room type	T_{60}/s
Vocal booth	0.1–0.2
Control room	0.2–0.3
Living room	0.4–0.5
Recording studios	0.4–0.6
Lecture room	0.6–0.9
Cinema	0.7–1.0
Rock venue (1000 m^3 to 10 000 m^3)	0.6–1.6
Theatre	1.1–1.4
Opera house	≈ 1.6
Concert hall (classical music)	1.8–2.2
Cathedral	> 5
Large sports venue	10

Table: Typical values for reverberation time T_{60} (DPA 2015a)

Reverberation time T_{60}

Material	α 125 Hz	α 500 Hz	α 2000 Hz
Acoustical tile	0.20	0.65	0.65
Brick wall (unpainted)	0.02	0.03	0.05
Heavy carpet on heavy pad	0.10	0.60	0.65
Concrete (painted)	0.01	0.01	0.02
Heavy draperies	0.15	0.55	0.70
Fiberglass blanket (7.5 cm thick)	0.60	0.95	0.80
Glazed tile	0.01	0.01	0.02
Paneling (0.30 cm thick)	0.30	0.10	0.08
Plaster	0.04	0.05	0.05
Vinyl floor on concrete	0.02	0.03	0.04
Wood floor	0.06	0.06	0.06

Table: Absorption coefficient α for different materials (Hartmann 2013, p. 165)

Critical distance d_c

Critical distance d_c

Distance from a sound source in a given room at which acoustic energy of direct vs. diffuse sound field are equal

$$d_c \approx 0.057 \cdot \sqrt{\frac{V}{T_{60}}}$$

- d_c ... critical distance (m)
- 0.057 ... magic number ($\sqrt{\mathrm{s\,m^{-1}}}$)
- V ... room volume (m^3)
- T_{60} ... reverberation time (s)

Critical distance d_c

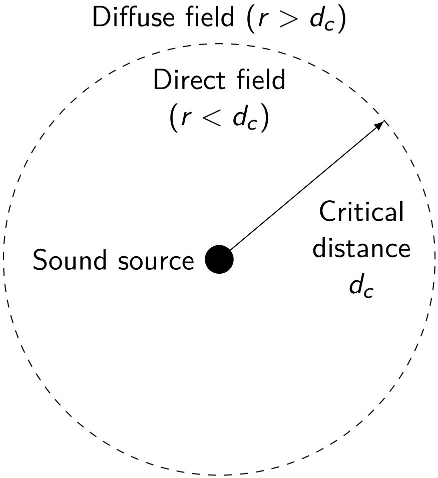


Figure: Direct and diffuse field in a room are separated by the critical distance d_c

Critical distance d_c

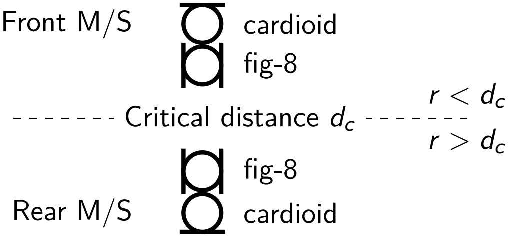


Figure: Variation of the Double M/S surround recording technique (after Rumsey and McCormick 2009, p. 554)

Echo chambers

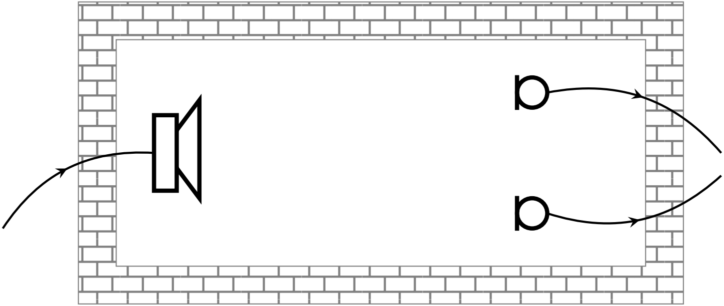


Figure: Principle of a reverberation chamber. Note that a stereo output signal is generated for a mono input – a property also of most more modern reverbs.

Echo chambers

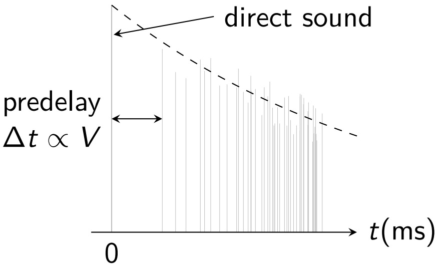


Figure: In artificial reverberation, *pre-delay* simulates the distance to the closest wall

Plate reverbs

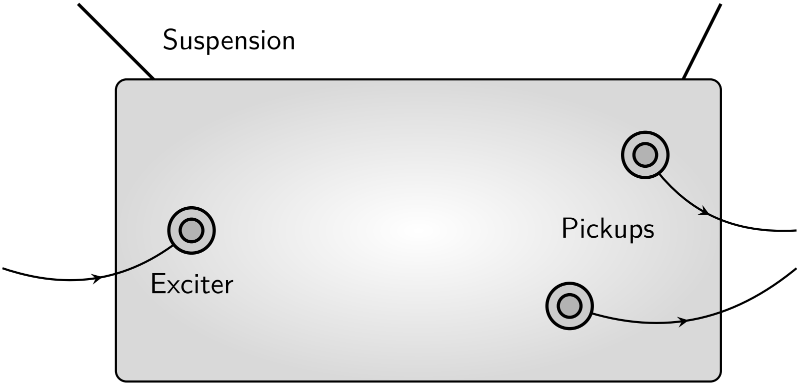


Figure: Principle of a plate reverb

Plate reverbs

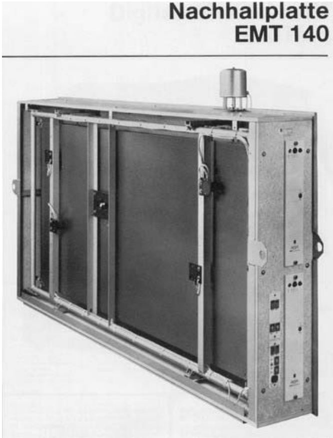


Figure: EMT 140 plate reverb ()

Plate reverbs

Figure: Universal Audio software plugin emulating the EMT 140 plate reverb

Plate reverbs

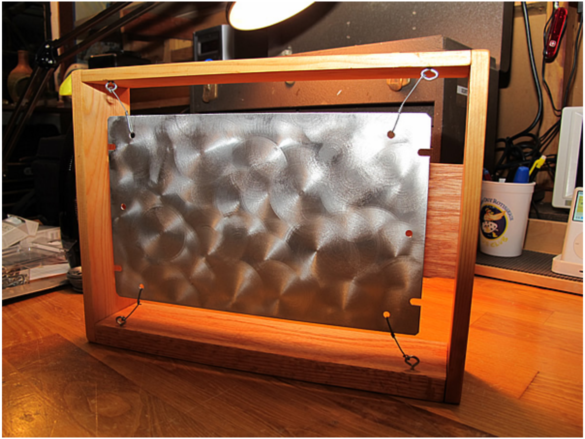
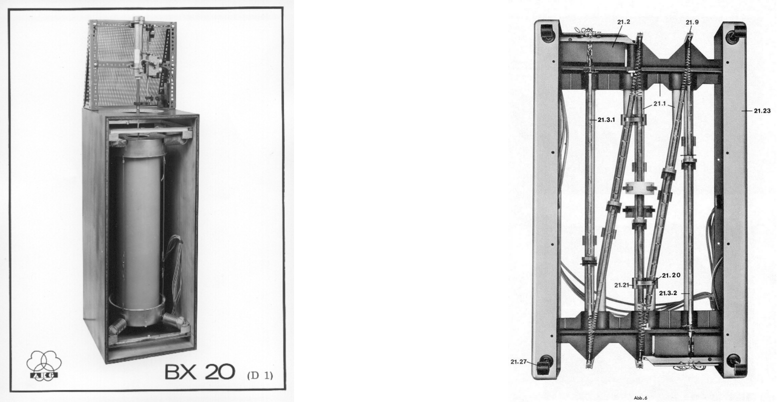


Figure: Small-scale DIY plate reverb ()

Spring reverbs



(a) Inside (b) Cutaway

Figure: AKG BX-20 spring reverb ()

Spring reverbs

Figure: AKG BX-20 spring reverb ()

Spring reverbs

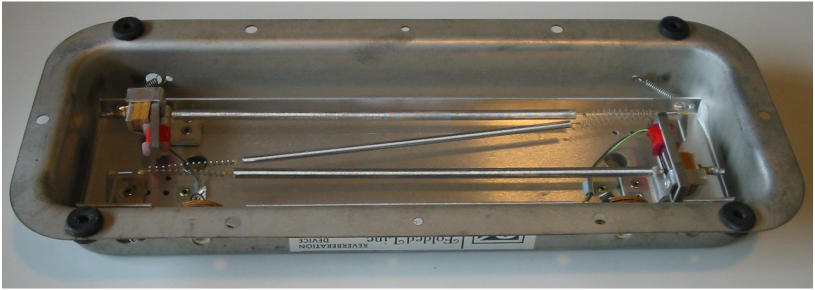


Figure: O. C. Electronics *Folded Line* spring reverb ()

History

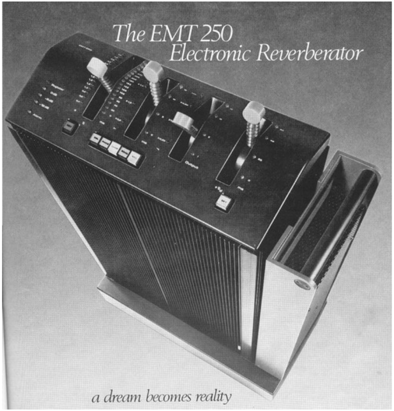


Figure: EMT 250 digital reverberator from 1976 (© Elektronik, Mess- und Tonstudiotechnik Wilhelm Franz. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

History

(a) Lexicon 224 from 1978 (© Sound on Sound)

(b) Lexicon 480L from 1986 (© unknown)

Figure: Early digital reverberators.

History

Figure: Publison Infernal Machine 90 digital audio processor (ca. 1987)

Algorithmic reverbs

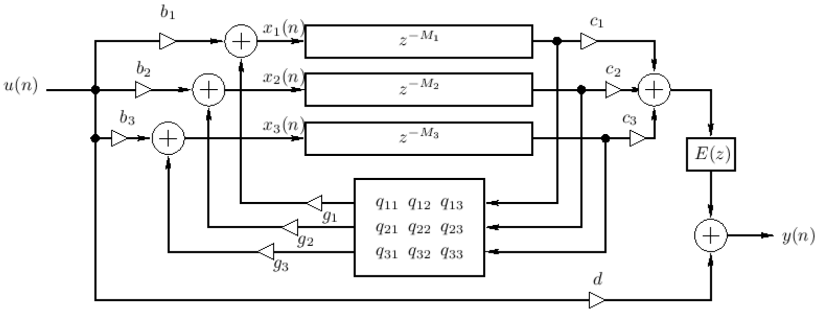


Figure: Feedback delay network for artificial reverberation (J. O. Smith 2010, fig. 3.10.)

Algorithmic reverbs

Parameter	Description
Room size	Volume V of simulated space (often presets)
Decay time	Corresponds to T_{60}
Wet/dry balance	Ratio of reverberated ('wet') to original ('dry') sound
HF cutoff	Low-pass filter to dampen reflections
Stereo width	Decorrelation of L & R output signals
Pre-delay	Simulates distance to closest wall

Table: Typical software reverb control parameters (cf., Eargle 2003c, p. 239)

Inverted graphic EQs

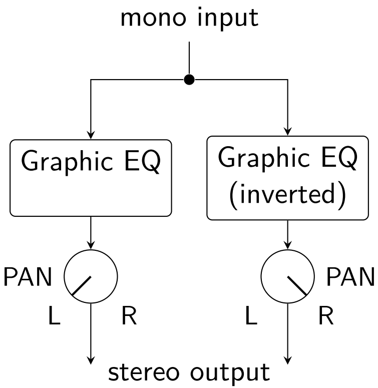


Figure: Stereo enhancer based on inverted EQs (after Senior 2011b, fig. 18.3)

Delay plus mirrored panning

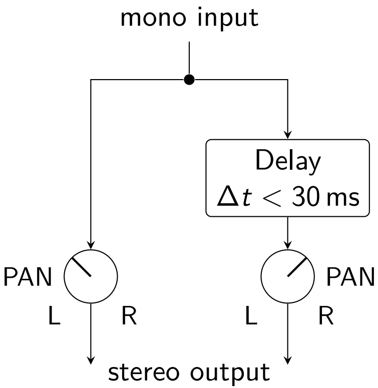


Figure: Stereo enhancer based on Haas delay (cf., Senior 2011b, pp. 267 f.)

Delays plus pitch shifting

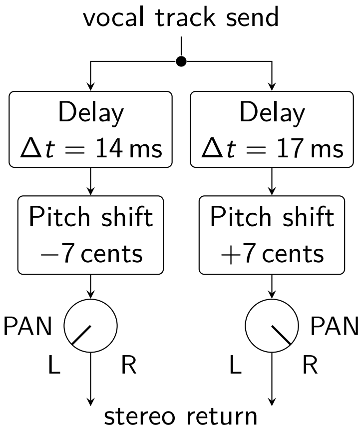


Figure: Stereo enhancer based on pitch shift and delay as a mix-in effect for vocal tracks (after Senior 2011b, fig. 18.4)

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 19: Recording session 2 (Love and a Sandwich)

Massachusetts Institute of Technology
Music and Theater Arts

Monday, November 14, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 20: Recording session 3 (Pscience Phiction)

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, November 16, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 21: Quiz, review, preview

Massachusetts Institute of Technology
Music and Theater Arts

Monday, November 21, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 22: Sound quality & critical listening

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, November 23, 2016

Sample rate

There came a point when we realised that the magical octave above 20 kHz was as important as that below it. (Rupert Neve, in: Schoepe 2006, p. 67)

Sample rate

[W]henever I work at a very high sample rate, and then return to the "standard" (44.1 kHz) version, the lower rate sounds worse, although after a brief settling-in period, it doesn't sound that bad after all [...]. (Katz 2014b, p. 25)

Bit depth

(a) 16 bit

(b) 8 bit

Figure: Gangnam style in 16 vs. 8 bits ()

Bit depth

(a) 16 bit

(b) 8 bit

Figure: Neil Young in 16 vs. 8 bits (Courtesy of Andy Roo. . Source: https://en.wikipedia.org/wiki/File:Neil_Young_in_Nottingham_2009_(k).jpg)

Ear training

Most people, who approach me because they're unhappy with their mixes think that's it's their processing techniques that are letting them down, but in my experience the real root of their problems is usually either that they're not able to hear what they need to [due to inferior monitoring], or else that they haven't worked out how to listen to what they're hearing [due to insufficent ear training]. (Senior 2011a, p. 2)

Ear training

Figure: The human 'ear' (pinna) ()

Ear training

Ear training is actually mind training, because the appreciation of sound is a learned experience and the more we experience, the more we learn. (Katz 2014b, p. 25)

Ear training

Make passive ear training a lifelong activity (Katz 2014b, p. 25)

Rhythm, melody, harmony

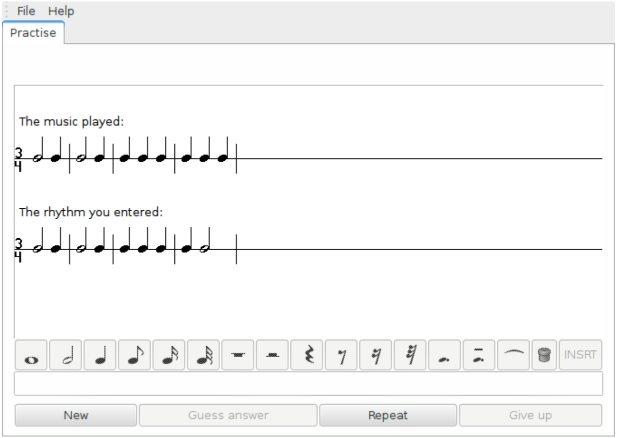


Figure: GNU Solfege (open source; Mac, Win, Linux)

Rhythm, melody, harmony

Figure: “Transcribe both parts” (key and first note for both staves given). Example from an entry exam for the *Tonmeister* program at the Vienna University of Music.

Distinguishing sampled from 'real' pianos

(a) Yamaha CFX concert grand

(b) Yamaha P80 digital piano

Figure: Grand piano vs. digital piano ()

Identifying tiny differences

Make a test master with 0.5 dB difference in equalization of one band. Can you hear the difference in a blind test? (Katz 2014b, p. 30)

Listening beyond the ears

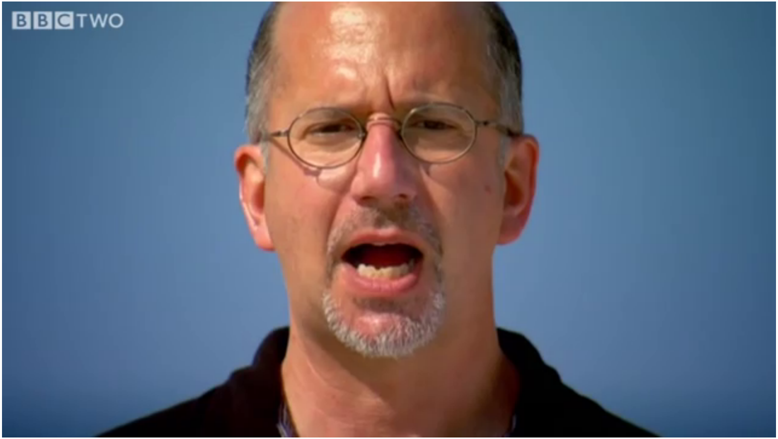


Figure: McGurk Effect (from 0'36" in the video)

Listening beyond the ears

Don't underestimate the importance of audio voodoo; what we believe to be true has a power of its own. (Katz 2014b, pp. 30 f.)

Subjective listening tests

Listening test terminology

- Objective tests (models) vs. subjective tests (human subjects)
- Blind tests & double-blind tests (subject and tester blinded)
- Preference vs. discrimination (or equality) tests

Software tool `squishyball`

- Open-source command-line tool by 'Monty' Montgomery (`xiph.org`)
- Implements basic subjective listening test methodologies
- On Debian-based Linux systems (e.g., Ubuntu):
  `sudo apt-get install squishyball`

Casual comparison

Katz' Law

> *The length of silence between two successive plays [in a comparative listening test] is porportional to the number of incorrect conclusions.* (Katz 2014b, p. 30)

Demo

```
squishyball --casual A.wav B.wav C.wav D.wav [...]
```

- Use 1, 2, 3, or ↑, ↓ keys to switch between samples
- Samples are presented in specified order (no randomization)
- Single trial without selection

(AB) or XY: Paired comparison

Question

Which of 2 samples is preferred?

Demo

```
squishyball -n 5 --ab A.wav B.wav
```

Notation

- A, B … knowns
- X, Y … unknowns
- (AB) … order unknown (can be AB or BA)
- Hence, (AB) = XY

- -n … number of trials (defaults to 20)
- a, b: switch between samples
- A, B: select preferred sample and move on to next trial
- Presentation order re-randomized for each trial
- Samples are *known* to be different (not an equality test)
- Need to know in advance the attribute likely to change ☹

ABX test (Munson and Gardner 1950)

Objective

Perceptible difference between 2 samples? (equality test)

Method

Is X identical to A or identical to B?

Demo

```
squishyball -n 5 --abx A.wav B.wav
```

- -n … number of trials (default: 20)
- Sample order bias (always AB) ☹

A	B	X	Correct is:
A	B	**A**	A
A	B	**B**	B
a	b	x	to switch

Table: Possible presentation orders (re-randomized per trial) and squishyball key bindings to switch and select samples

(AB)X: Duo-trio test with constant reference

Objective

Perceptible difference between 2 samples?

Method

Is X identical to 1 or identical to 2?

- Not implemented in `squishyball`
- Partly eliminates sample order bias (can be ABX or BAX) ☺
- But not entirely (X always last) ☹

(A	B)	X	Correct is:
A	B	A	$X = 1$
B	A	B	
A	**B**	B	$X = 2$
B	**A**	A	

Table: Possible presentation orders (re-randomized per trial)

(XXY): Triangle test

Objective

Perceptible difference between 2 samples?

Method

Which of 3 samples is the odd one out?

Demo

```
squishyball -n 5 --xxy A.wav B.wav
```

- -n … number of trials (default: 20)
- Eliminates sample order bias ☺

(X	X	Y)	Correct is:
A B	A B	**B** **A**	⇧ + 3
A B	**B** **A**	A B	⇧ + 2
B **A**	A B	A B	⇧ + 1
1	2	3	to switch

Table: Possible presentation orders (re-randomized per trial) and squishyball key bindings to switch and select samples

Hearing disorders

[...] 52.5% of individual musicians [in the Chicago Symphony Orchestra] showed notched audiograms consistent with noise-induced hearing damage. (Doswell, Royster, and Killion 1991)

Hearing disorders

More than 200 drugs are known to cause tinnitus when you start or stop taking them. (NIDCD 2014)

Hearing protection

Figure: A pair of custom-moulded earplugs ()

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 23: Recording session 4 (piano trio)

Massachusetts Institute of Technology
Music and Theater Arts

Monday, November 28, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 24: Recording session 5 (violin & piano duet)

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, November 30, 2016

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 25: Mastering techniques

Massachusetts Institute of Technology
Music and Theater Arts

Monday, December 5, 2016

Mastering techniques

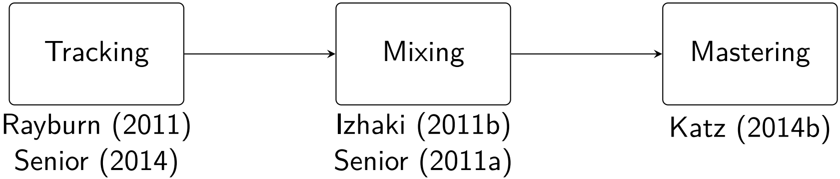


Figure: The music production process (after Eargle 2003a, p. 326)

Mastering techniques

Figure: The legendary Audiobomber in his mastering studio (© Audiobomber. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

History of mastering (record cutting)

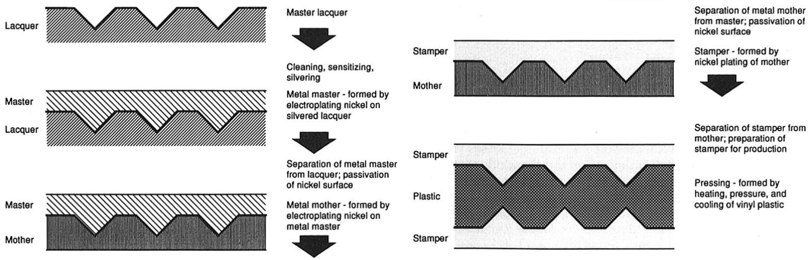


Figure: Record replication process (Eargle 1996b, p. 488.)

Processing chain

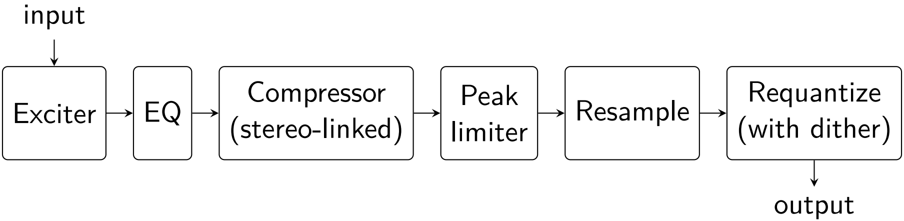


Figure: Typical mastering chain (cf., Katz 2014b, p. 131; Christopher Ariza 2012, pp. 257 f.)

Exciter

Figure: Original Aphex Aural Exciter from 1975 (© Aphex Electronics. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Exciter

Figure: Software plugin recreation of Aphex Aural Exciter by Waves ()

Exciter

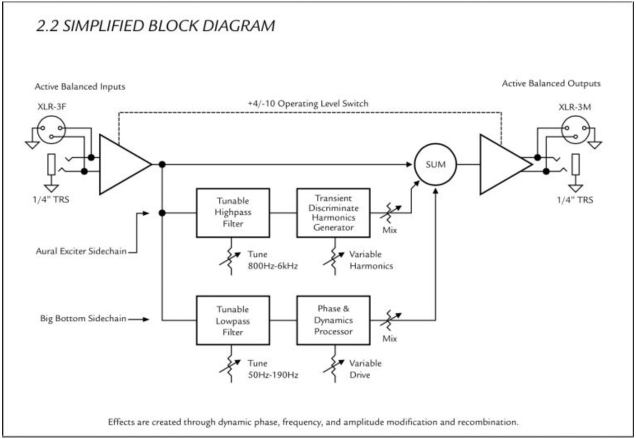


Figure: Block diagram of a recent Aphex Aural Exciter model ()

Stereo compressor

Music mastering compression recipe (Katz 2014a, pp. 84, 93)

- Attack time: 30 ms to 300 ms (average: 100 ms)
- Release time: 50 ms to 500 ms (average: 150 ms to 250 ms)
- Ratio: $^{1.5}\!/_{1}$ to $^{2}\!/_{1}$. Threshold: −20 dB to −10 dB
- More subtle: Ratio: $^{1.01}\!/_{1}$ to $^{1.1}\!/_{1}$. Threshold: −40 dB to −30 dB
- "Delicate painting": Ratio: $^{1.01}\!/_{1}$. Threshold: −3 dB

Stereo compressor

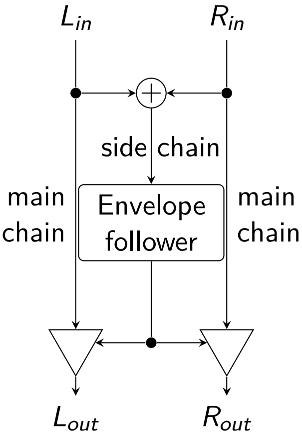


Figure: Stereo compressor

Stereo enhancer (M/S processing)

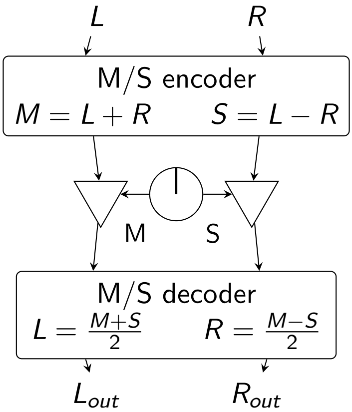


Figure: M/S-based stereo enhancer (cf., Senior 2011a, pp. 262 ff. Katz 2007a, pp. 210 ff.)

Peak limiter

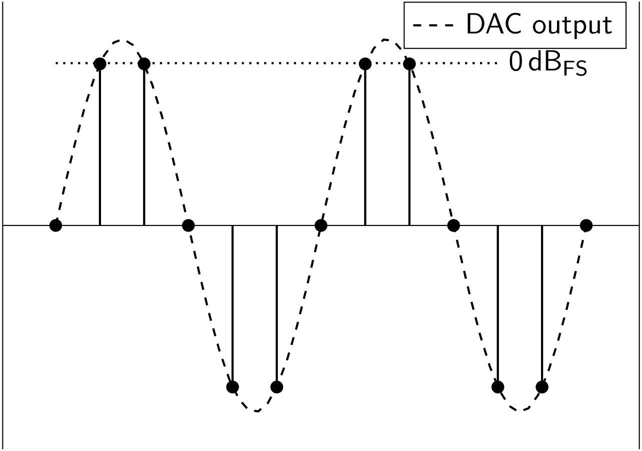


Figure: Inter-sample peaks in D/A conversion

21M.380 Music and Technology
Recording Techniques & Audio Production
Lecture 26: Workshop: Command-line sound editing

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, December 7, 2016

Why edit sound on the command line?

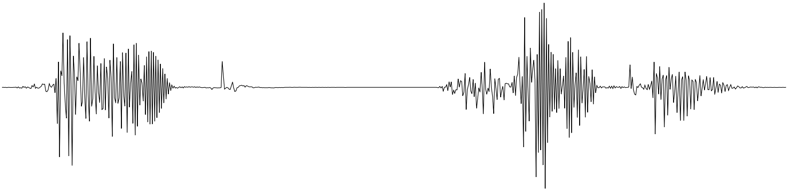


Figure: Graphical representation of sound

Why edit sound on the command line?

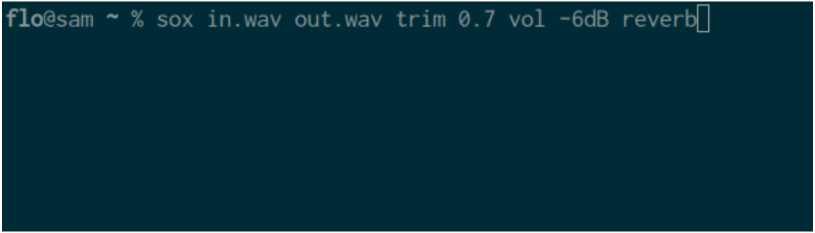


Figure: Command-line sound editing with SoX

Potential applications

- Playing & recording
- File format conversions
- Channel number conversions
- Resampling
- Bit depth conversions
- DC offset removal
- Normalizing
- File format conversions
- Zeropadding
- Dithering
- Inversion (reverse playback)
- Phase corrections
- Effects
- Metadata retrieval & analysis
- Mixing multiple files
- Concatenating multiple files

Advantages

- No visual belief system (what you *hear* is what you hear)
- Faster (no need to load GUIs or waveforms)
- Efficient batch-processing (applying editing sequence to multiple files)
- Self-documenting (simply save an editing sequence to a script)
- Imaginative (might give you different ideas of what's possible)
- Way cooler (let's face it) ☺

Software packages

Program	.deb package	Function
`mplayer`	`mplayer`	Play *any* media file
`sndfile-info`	`sndfile-programs`	Metadata retrieval
`sndfile-convert`	`sndfile-programs`	Bit depth conversion
`sndfile-resample`	`samplerate-programs`	Resampling
`lame`	`lame`	MP3 encoder
`flac`	`flac`	FLAC encoder
`oggenc`	`vorbis-tools`	Ogg Vorbis encoder
`ffmpeg`	`ffmpeg`	Media conversion tool
`mencoder`	`mencoder`	Media conversion tool
`sox`	`sox`	Sound editor
`ecasound`	`ecasound`	Sound editor

Table: Command-line programs for playing, converting, and editing media files

Real-world examples

```
# Convert .aif->.wav and 24->16 bit
sndfile-convert -pcm16 myfile.aif /tmp/myfile_16bit.wav

# Resample 96->48 kHz
sndfile-resample -to 48000 -c 0 /tmp/myfile_16bit.wav
↪ /tmp/myfile_16bit_48kHz.wav

# Trim file to remove glitch at end
sox /tmp/myfile_16bit_48kHz.wav myfile_master.wav trim
↪ 0:01.0 6:49.5

# Encode to MP3
lame -q $QUALITY -b $BITRATE myfile_master.wav
↪ myfile_master.mp3
```

Listing 2: Pre-production script for the *Silver Sounds* installation

Real-world examples

```
#!/bin/bash

flac -8 --delete-input-file *.wav
# Go to bed.

exit 0
```

Listing 3: Post-production script for the *24/7* sound installation

Opening the command line

Ubuntu (Unity)

- Ctrl + Alt + t
- Or type 'Terminal' in Dash

Mac OS X

- In Finder: Applications ▸ Utilities ▸ Terminal.app

Windows

- Start 〉 All Programs 〉 Accessoires 〉 Command Prompt

Prompt

Ubuntu (default)

```
user@host:~$
```

Mac OS X (default)

```
host:~ user$
```

Windows (example)

```
C:\Windows\system32>
```

- Indicates that command line is ready for input
- Appearance varies between systems (and can be customized)

Executing (and interrupting) commands

Example

```
host:~ user$ ls ↩
bla.txt foo.wav my.doc
host:~ user$
```

- Commands executed with ↩ and return to prompt on completion

Executing (and interrupting) commands

Example

```
host:~ user$ sleep 2 ↵
host:~ user$
```

- If prompt does not return, command is probably still at work
- Successful execution does not necessarily generate *any* printout!
- Terminate by force using Ctrl + c (careful when moving files!)
- Usually single command per line

Single command on multiple lines

Example

```
host:~ user$ sleep \ ↵
> 2 ↵
host:~ user$
```

- Split commands across multiple lines with backslash

Multiple commands on a single line

Example

```
host:~ user$ sleep 2; ls ↵
bla.txt foo.wav my.doc
```

- Multiple commands can be sequenced with semicolons.

Unix command structure

- Follows pattern: `command␣-flag[␣value]␣argument`
- Example: List (`ls`) all (`-a`) files in current directory (`.`)

Example

```
host:~ user$ ls -a . ↵
```

- *White space* carries meaning! `ls␣-a` ≠ `ls-a`
- Unix is *case sensitive*! `Desktop` ≠ `desktop`

Basic file system operations

Command	Meaning
`pwd`	Print working directory
`cd /path/to/target`	Change directory
`ls`	List current dir's contents
`ls -l`	More verbose `ls`
`ls -a`	Show also hidden files
`ls -lah`	Flags can be combined
`cp /path/to/source /path/to/target`	Copy source to target
`cp -r /path/to/dir /path/to/target`	Copy directory
`rm /path/to/file`	Remove file (for good!)
`rm -r /path/to/dir`	Remove dir (for good!)
`mv /path/to/source /path/to/target`	Move (rename) file or dir

Table: Basic file system operations on the Unix command line

The need for speed

Action	Meaning
↑	Go back in command history
↓	Go forward in command history
⇥	Auto-completion (turbo mode)
Ctrl + r	Recursive history search (super turbo mode)
`!cd`	Repeat last command that started with cd
`ls !*`	Repeat command (here: `ls`) with arguments from last call

Table: Gaining speed on the command line

The need for speed

Linux	macOS	Go to...
Ctrl + a	ctrl + a	Start of line
Ctrl + e	ctrl + e	End of line
Alt + f	⎋ + f	Next word
Alt + b	⎋ + b	Prev. word

Table: Key bindings for navigating within long commands

Absolute vs. relative path notation

Example

```
$ cd /Users/me ↵ (absolute)
$ pwd ↵
/Users/me
$ cd Desktop ↵ (relative)
$ pwd ↵
/Users/me/Desktop
```

- *Absolute path notation* starts from root directory (i. e., with a slash)
- *Relative path notation* starts from current working directory (no slash)

Absolute vs. relative path notation

Notation	Meaning
/	Root directory
.	Current directory
..	Parent directory
~	Current user's home dir
-	Previous dir (cd only)

Table: Synonyms for frequently used directories

Example

```
$ cd /; pwd; cd ~; pwd; cd .; pwd; cd ..; pwd; cd - ↵
```

Installation & testing

1. Download and install SoX:
   - Debian/Ubuntu: `$ sudo apt-get install sox` ↵
   - Mac:
     - Install Homebrew: `https://brew.sh/`
     - Install SoX: `$ brew install sox` ↵
   - Windows: `https://sourceforge.net/projects/sox/files/sox/14.4.2/sox-14.4.2-win32.exe`
2. Download example sound files from OCW page: MIT21M_380F16_`sox_audio_files.zip`
3. Unpack examples sounds to `sox_audio_files/`
4. Confirm SoX works:

   ```
   $ sox --version ↵
   ```

   Should print SoX version number (14.4.2)

Getting help

- Built-in help: `$ sox --help` ↵
- Online documentation:
  `http://sox.sourceforge.net/Docs/Documentation`
- HTML manual: `http://sox.sourceforge.net/sox.html`
- PDF manual: `http://sox.sourceforge.net/sox.pdf`
- Mailing lists (low-volume):
  `http://sourceforge.net/mail/?group_id=10706`

SoX command syntax

SoX command syntax

```
/path/to/sox /path/to/in.wav /path/to/out.wav <fx1> <fx2> ...
```

- Paths in absolute or (preferably) relative notation
- After issuing cd `/path/to/`, one can omit (most or all) paths ☺
- `<fx1> <fx2> ...` … effect chain

Hello world!

Example

```
$ cd /path/to/sox_audio_files/ ↵
$ play in.wav ↵
$ sox in.wav out.wav reverb ↵
$ play out.wav ↵
```

- Change to directory with sound examples
- Play input file `in.wav`
- Reverberate `in.wav` and save result to `out.wav`
- Play output file `out.wav`

Recording & playing sound

Example

```
$ rec foo.wav trim 0 2 ↵
$ play foo.wav ↵
```

- Record 2 seconds of audio and play result
- Doesn't work on Windows? Try this (with `0` for `<device_number>`):

Example

```
$ sox -t waveaudio <device_number> foo.wav trim 0 2 ↵
$ sox foo.wav -t waveaudio <device_number> ↵
```

Recording & playing sound

Example

```
$ soxi foo.wav ↵ (soxi, not sox!)
$ soxi -r foo.wav ↵
$ soxi -t foo.wav ↵
$ sox foo.wav -n stat ↵ (sox, not soxi!)
$ sox foo.wav -n stats ↵ (stats, not stat!)
```

- Get information about recorded file (5 methods)

Generating test signals

Example

```
$ sox -n out.wav synth 3 sine 500-900 vol 0.1 ↵
$ play out.wav ↵

$ sox -n -r 48000 out.wav trim 0 4:33 ↵
$ play out.wav ↵
```

- Generate and play 3 s low-level sine sweep (500 Hz to 900 Hz)
- Generate and play 4’33” of silence (overwrites previous out.wav)

Level & phase adjustments

Example

```
$ play in.wav ↵

$ sox in.wav out.wav vol -6dB ↵
$ sox in.wav out.wav vol 0.5 ↵
$ sox -v 0.5 in.wav out.wav ↵

$ play out.wav ↵
```

- Listen to input file first
- Reduce level by $-6\,\mathrm{dB}$ = half gain (3 methods)
- Play output

Level & phase adjustments

Example

```
$ play in.wav vol -6dB ↵
$ sox in.wav out.wav vol -0.5 ↵
```

- Test without writing to out.wav
- Negative gain factors additionally invert phase

Level & phase adjustments

Example

```
$ sox in.wav out.wav norm -3 ↵

$ sox in.wav -n stats ↵
$ sox out.wav -n stats ↵
```

- Normalize to −3 dB peak level (do *not* append dB!)
- Confirm by comparing statistics of `in.wav` and `out.wav`

Cutting & splicing

Example

```
$ sox in.wav out.wav trim 0 1 ↵
$ sox in.wav out.wav trim 0.8 0.6 ↵
```

- Extract first second (trim <start> <duration>)
- Extract seconds 0.8–1.4
- Time specified as hh:mm:ss.ms (redundant zeros can be omitted)

Concatenating & mixing

Example

```
$ play in1.wav in2.wav ↵
$ sox in1.wav in2.wav out.wav ↵
$ sox -m in1.wav in2.wav out.wav ↵
```

- Listen to input files
- Concatenate them to single file (or use `splice` effect)
- Mix them at equal levels (requires identical channel number)

Mono-to-stereo conversions

Example

```
$ play mono.wav

$ sox mono.wav pseudo_stereo.wav remix 1 1 ↵
$ sox mono.wav -c 2 pseudo_stereo.wav ↵

$ play pseudo_stereo.wav
```

- Play mono input file
- Create pseudo-stereo file from mono input (2 methods)
- Play pseudo-stereo output file

Mono-to-stereo conversions

Example

```
$ play left.wav right.wav ↩
$ sox -M left.wav right.wav true_stereo.wav ↩
$ play true_stereo.wav
```

- Play mono input files
- Create true stereo file from two mono input files
- Play true stereo output file
- Note that `-M` (merge) is different from `-m` (mix)!

Stereo-to-mono conversions

Example

```
$ play stereo.wav ↵

$ sox stereo.wav left_channel.wav remix 1 ↵
$ sox stereo.wav -c 1 left_channel.wav mixer -l ↵

$ sox stereo.wav right_channel.wav remix 2 ↵
$ sox stereo.wav -c 1 right_channel.wav mixer -r ↵
```

- Play stereo input file
- Extract left channel from stereo file (2 methods)
- Extract right channel from stereo file (2 methods)

Stereo-to-mono conversions

Example

```
$ sox stereo.wav mono_mixdown.wav remix 1,2 ↵
$ sox stereo.wav mono_mixdown.wav remix 1-2 ↵
$ sox stereo.wav -c 1 mono_mixdown.wav mixer 0.5,0.5 ↵
```

- Mix stereo down to mono (3 methods)

Swap stereo channels

Example

```
$ sox stereo.wav stereo_swapped.wav swap ↵
```

- Swap L & R channels of a stereo file

Sample rate conversions

Example

```
$ sox in.wav out.wav rate 8k ↵
$ sox in.wav -r 8k out.wav ↵
```

- Convert to 8 kHz (2 methods)

Miscellaneous effects

Example

```
$ play in.wav reverse ↩
$ play in.wav lowpass 440 ↩
$ play in.wav pad 0 2 reverb ↩
```

- Reverse playback
- Low-pass filter
- Reverberate (append 2 sec of silence first to avoid cutting off decay)

Miscellaneous effects

Example

```
$ play in.wav reverse pad 0 1 reverb reverse ↵
```

- Led-Zeppelinesque reverse echo

Miscellaneous effects

Example

```
$ play in.wav chorus 0.6 0.9 50.0 0.4 0.25 2.0 -t 60.0 0.32 \ ↩
    0.4 1.3 -s ↩
$ play in.wav echos 0.4 0.6 400.0 0.5 900.0 0.3 ↩
$ play in.wav echo 0.7 0.89 1000.0 0.1 ↩
$ sox in.wav out.wav highpass 500 rate 96k norm -12 dither ↩
```

- Chorus with arguments (check SoX manual for details)
- Multiple echos
- Single echo
- A sequence of processing operations

Noise reduction

Example

```
$ play noisy.wav ↵
$ play background_noise.wav ↵
$ sox background_noise.wav -n trim 0 1 noiseprof \ ↵
    noise_profile ↵
$ sox noisy.wav denoised.wav noisered noise_profile 0.3 ↵
$ play denoised.wav ↵
```

- Listen to noisy input
- Listen to isolated noise sample
- Step 1: Create noise profile
- Step 2: Denoise (0.3 is a denoise factor 0...1)
- Listen to denoised result

Noise reduction

Example

```
$ sox background_noise.wav -n trim 0 1 noiseprof | play \ ↩
  noisy.wav noisered ↩
```

- Or do as a single command using | (the 'pipe')

Example script

```
#!/bin/sh

# Above line: ”Execute with Unix shell”

# Comments start with hash (#)

# Command-line printout
echo ”Called $0 with $# arguments...”
echo ”Converting $1 to $2...”

# Actual sound processing in SoX
sox $1 $2 reverse pad 0 1 reverb reverse

exit 0  # Indicates successful execution
```

Listing 4: Shell script to generate reverse echo in the style of Led Zeppelin

Example script

Placeholder	Meaning
$#	Number of arguments passed to script
$0	Name of script (including path)
$1	First argument passed to script
$2	Second argument passed to script

Table: Placeholders in shell scripts

Make script executable

- Make script executable:

```
$ chmod +x /path/to/zeppelinify.sh ↵
```

- Execute script (/path/to/in.wav *must* exist):

```
$ /path/to/zeppelinify.sh /path/to/in.wav \ ↵
    /path/to/out.wav ↵
```

- Throws "Permission denied" error on OS X? Try:

```
$ cd /path/to/ ↵
```

followed by one of the following two commands:

```
$ ./zeppelinify.sh /path/to/in.wav /path/to/out.wav ↵
$ sh zeppelinify.sh /path/to/in.wav /path/to/out.wav ↵
```

Make script available system-wide

- Move script to a directory included in colon-separated list printed by:

```
$ echo $PATH ↵
/usr/local/bin:/usr/bin:/bin:...
```

- E.g., move `zeppelinify.sh` to `/bin/zeppelinify`:

```
$ sudo mv /path/to/zeppelinify.sh /bin/zeppelinify ↵
```

- Test from home directory:

```
$ cd ~ ↵
$ zeppelinify ↵
```

Exercise: SoX M/S decoder script

Task

Write an M/S decoder `ms2lr` in SoX, which can be called as

```
$ ms2lr ms.wav lr.wav ↵
```

- `ms.wav` … existing M/S-encoded file (M on ch. 1 & $\overleftarrow{S}$ on ch. 2)
- `lr.wav` … resulting decoded stereo file (L on ch. 1 & R on ch. 2)
- User should be able to specify *arbitrary* input and output file names
- Bonus: Abort with error message if called with < 2 arguments

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 27: Guest speaker Al Kooper

Massachusetts Institute of Technology
Music and Theater Arts

Monday, December 12, 2016

Guest speaker Al Kooper

Figure: Al Kooper (left) and Bob Dylan (right) ()

Guest speaker Al Kooper

Figure: Bob Dylan (standing) and Al Kooper (far right) during the recording session for *Like a Rolling Stone*

Guest speaker Al Kooper

Figure: At the Hammond organ, Columbia Studios New York, 1966 ()

Guest speaker Al Kooper

Figure: Al Kooper and Jimi Hendrix ()

Guest speaker Al Kooper

Figure: 21M.380 class visit

21M.380 Music and Technology
Recording Techniques & Audio Production

Lecture 28: Workshop: 5.1 surround sound

Massachusetts Institute of Technology
Music and Theater Arts

Wednesday, December 14, 2016

How to set up a 5.1 surround system

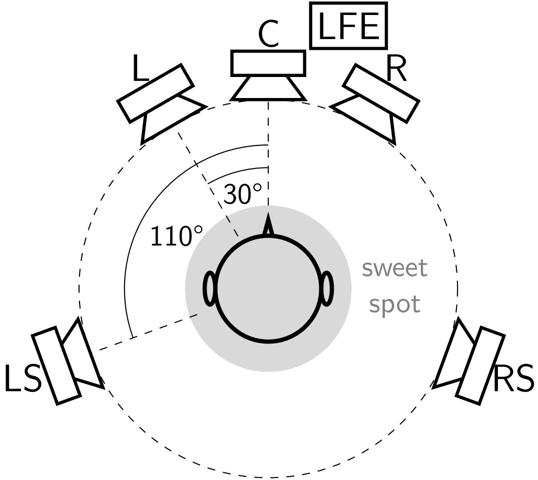


Figure: Standard 5.1 loudspeaker setup

How to set up a 5.1 surround system

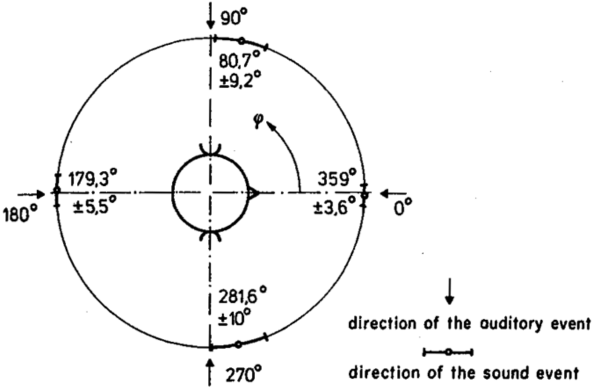


Figure: Localization blur in the horizontal plane. Experimental setup: 100 ms white noise pulses, head immobilized (Blauert 1996, p. 41.)

Mixing in 5.1

Standard	1	2	3	4	5	6	7	8
C|24, Film	L	C	R	LS	RS	LFE	—	—
SMPTE, ITU	L	R	C	LFE	LS	RS	—	—
DTS, ProControl Monitoring	L	R	LS	RS	C	LFE	—	—
D-Command, D-Control	L	—	C	—	R	LS	RS	LFE

Table: 5.1 channel order standards

Surround recording techniques

	Coincident arrays	Spaced arrays
Envelopment	☹	☺
Sweet spot size	☹	☺
Size & portability	☺	☹
Localization accuracy	☺	☹

Table: Coincident vs. spaced surround recording techniques (DPA 2016)

OCT

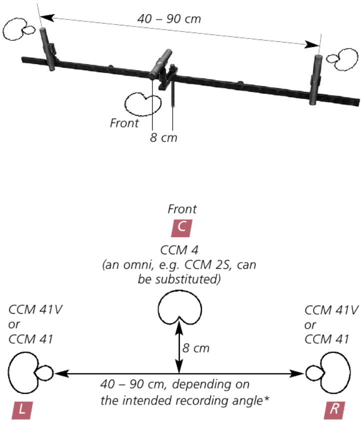


Figure: *Optimized Cardioid Triangle* (OCT), designed to capture the front channels (L, C, R) of a 5.1 setup ()

OCT 2

Figure: OCT 2 has the center mic shifted forward by 40 cm (by comparison to 8 cm for regular OCT) ()

OCT surround

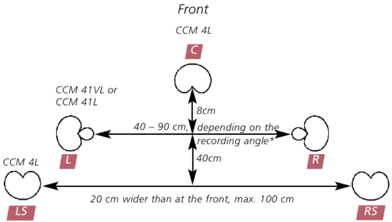


Figure: OCT surround features extra microphones to capture also the surround signals ()

Fukada tree

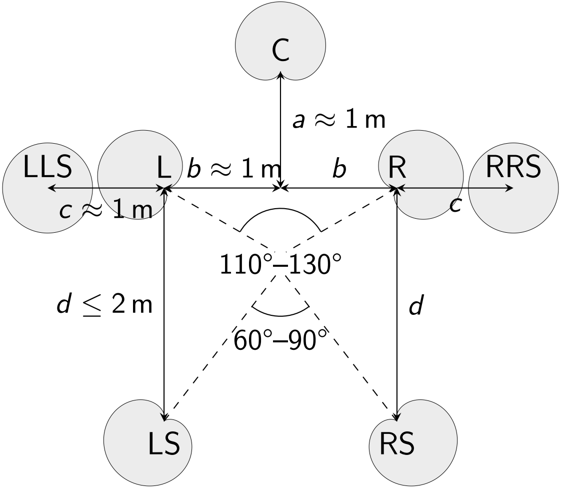


Figure: Fukada tree

INA-5

$2 \cdot \beta$	a/cm	b/cm	c/cm
100°	69	126	29
120°	53	92	27
140°	41	68	24
160°	32	49	21
180°	25	35	17.5

Table: Different INA-5 geometries (Rumsey and McCormick 2009, p. 550; Sengpiel 2005)

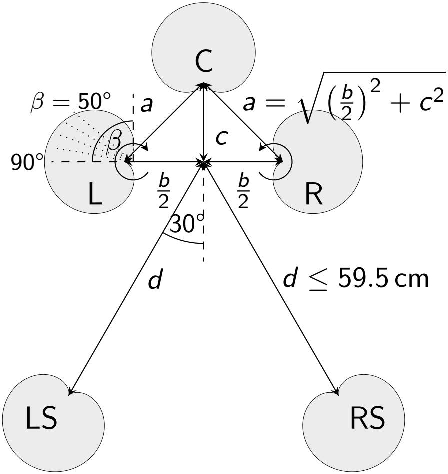


Figure: INA-5

INA-5

Figure: Brauner ASM5 microphone system and SPL Atmos-5.1 processor

INA-5

Figure: INA-5 configuration with Microtech Gefell M930 microphones

ORTF surround

Figure: ORTF surround system by Schoeps ()

ORTF surround

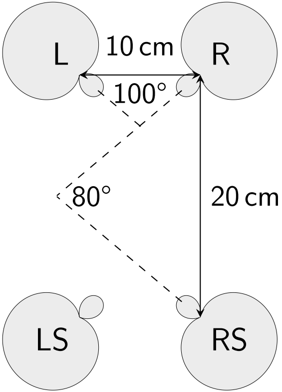


Figure: ORTF surround

Double M/S

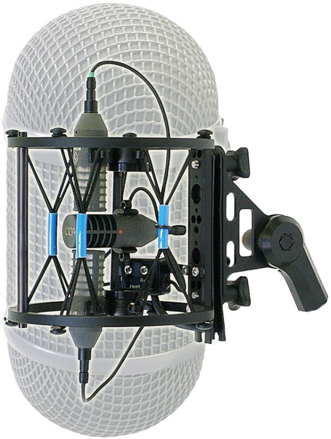


Figure: Double M/S (© Schalltechnik Dr.-Ing. Schoeps GmbH. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Double M/S

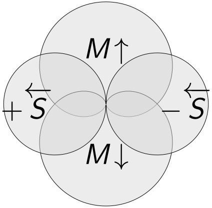


Figure: Double M/S principle

Double M/S to 5.1 decoder

$$
\begin{aligned}
C &= M\uparrow \\
L &= \frac{M\uparrow + \overleftarrow{S}}{2} \\
R &= \frac{M\uparrow - \overleftarrow{S}}{2} \\
LS &= \frac{M\downarrow + \overleftarrow{S}}{2} \\
RS &= \frac{M\downarrow - \overleftarrow{S}}{2}
\end{aligned}
$$

Double M/S

Figure: Double M/S with shotgun for front mid channel (© Schalltechnik Dr.-Ing. Schoeps GmbH.)

Schoeps KFM 360

Figure: Schoeps KFM 360 (© Schalltechnik Dr.-Ing. Schoeps GmbH. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/)

Schoeps KFM 360

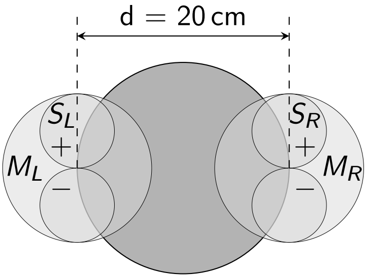


Figure: Schoeps KFM 360 principle

First-order ambsionic microphones

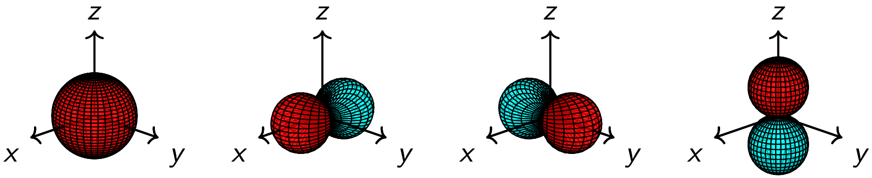


Figure: Theoretically required polar patterns for a *B format* recording

First-order ambsionic microphones

(a) SPS200 (© SoundField)

(b) TetraMic (© CoreSound)

Figure: First-order ambsionic microphones ()

First-order ambsionic microphones

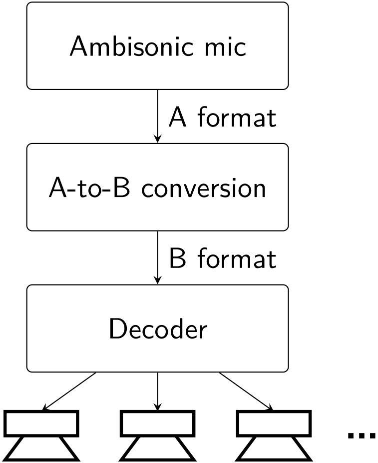


Figure: Ambisonic reproduction process

Microphone arrays

Figure: em32 Eigenmike microphones with 32 transducers each (© mh acoustics.)

IRT cross

Figure: IRT Cross used for atmo recording ()

IRT cross

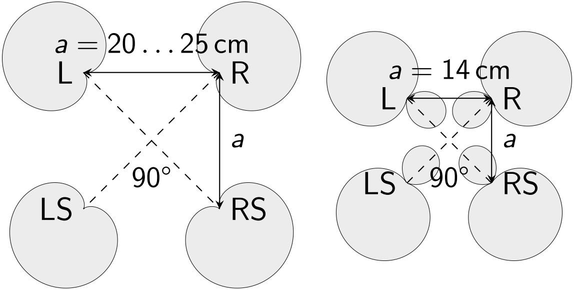


Figure: Two versions of the IRT cross

IRT cross

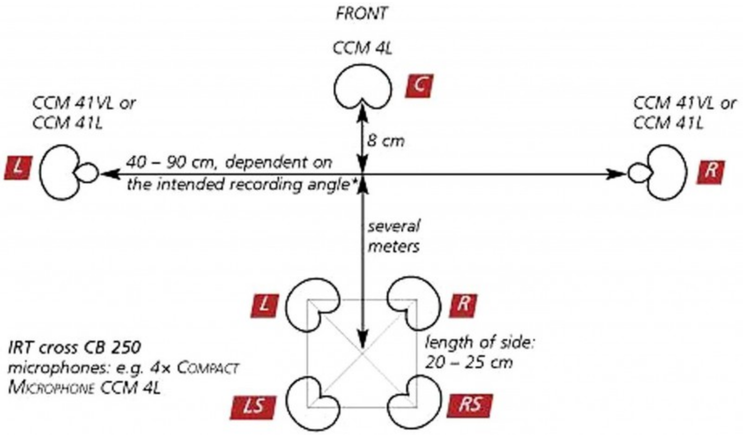


Figure: IRT cross in combination with OCT triangle ()

Hamasaki square

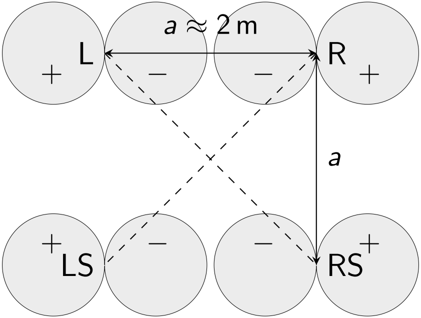


Figure: Hamasaki square

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