



Physics of Microphones

Applications and Techniques for Studio and Live Sound

Steve Savanyu – Buford T. Hedgehog Productions

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1



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Background info...

Executive Producer – Buford T. Hedgehog Productions

- 45+ years experience in audio industry
 - Studio/Live Recording
 - Live Sound
 - Audio for Video
 - Broadcast
 - Event Streaming
- Working, gigging sound guy...
- Formerly Director Educational Services Audio-Technica U.S., Inc.



2



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Microphones – A Brief Look Back...



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Microphones - Today

Thankfully, technology has improved!



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Microphones – Still Hold their value...



\$3899.00 - Ebay



\$2395.00 - Ebay



\$1799.00 - Ebay

5

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Microphones – Still Hold their value...

Think about that old DAT Machine, Analog Console or Desktop Computer ...



\$3899.00 - Ebay



\$2395.00 - Ebay



\$1799.00 - Ebay



\$4700.00 – Reverb.com



\$49.00 - Ebay



\$00.00 – Dumpster

6



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Signal to Noise... Feedback

Signal to Noise

Signal is the desired sound source.

Noise is everything else.

Expressed in a ratio

Acoustical Feedback

Acoustical feedback occurs when the Sound Pressure Level (SPL) of the amplified sound at the microphone is equal to, or greater than that of the original source sound



7



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Recording Vs. Live Sound

Recording =
Creativity, experimentation,
new techniques, pushing the envelope



Live Sound =
Damage control; preventing problems
before they can happen...



8

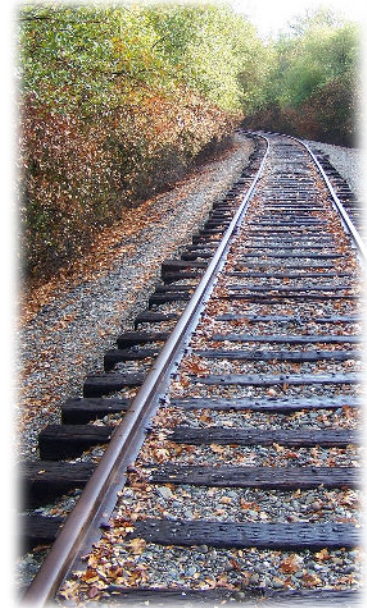


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Nature of Sound

Sound is Pressure...

- Vibrations
- Transmitted through a medium
 - Most common – Air



10

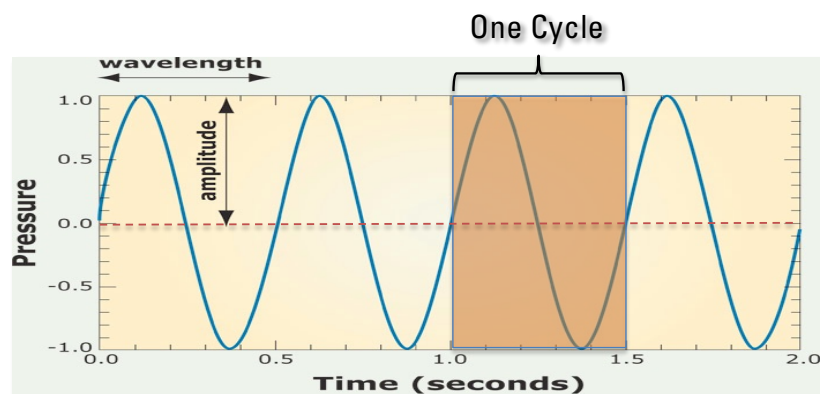


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Nature of Sound

Sound wave and its components

- Frequency
- Amplitude
- Wavelength
- Velocity (Speed)
- Phase



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Nature of Sound

Frequency and directionality...

- High frequencies – Behave like a spotlight..



- Low Frequencies – Behave like a bare lightbulb...



12



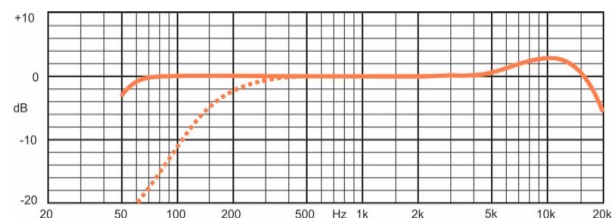
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Nature of Sound

Frequency response curves...

Graphical representation of how a device reproduces the relative amplitudes of all frequencies presented to its input

- Wider (low to high) is better
- Flatter is Better
- Tailored Response



Dotted line indicates activation of low-cut filter

13



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Nature of Sound

The human voice...

- Voice range: Approximately 100Hz - 6kHz
- 80 percent of voice energy: Below 500Hz
- "Presence" range: Between 2kHz and 5kHz
 - Maintains intelligibility
 - Key for dialog
 - Voice sounds "near to you"



14



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Physics of Microphones

- How they generate sound
- How they capture sound
- Making the connections
- Specialty microphones

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Transducers

Mechanical device that converts one form of energy to another



Loudspeaker:

Converts electrical energy to mechanical energy to acoustic energy



Microphone:

Converts acoustic energy to mechanical energy to electrical energy

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Transducers

Speaker being used as a microphone...



17



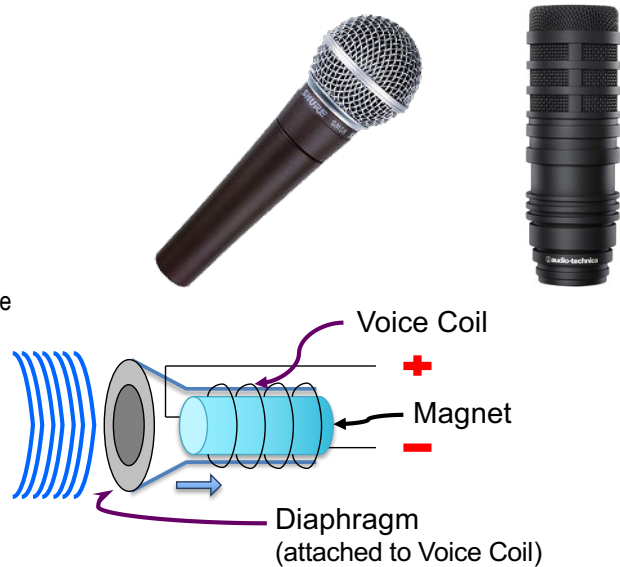
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Dynamic Microphones

Magnetic induction – Moving coil

Works like a *motor*...

- Diaphragm attached to coil of wire suspended within a magnetic structure
- Air pressure hitting diaphragm causes it to move
- Attached coil of wire moves over magnet
- Coil's movement generates voltage



18



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Dynamic Microphones

Extremely rugged
Can take a lot of abuse

EV664 was known as
the Buchanan Hammer

- EV Sales Manager Lou Burroughs used one to pound nails into a 2x4 board
- EV635A was rugged handheld that took a lot of abuse by frustrated news reporters



19



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Dynamic Microphones

Pros:

- Extremely rugged, can take a lot of abuse
- Handle unlimited amount of sound pressure
- Do not require power to operate
- Affordable



Cons:

- Not very sensitive
- Low output levels
- Do not handle transients well
- Difficult to miniaturize



20



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Condenser Microphones

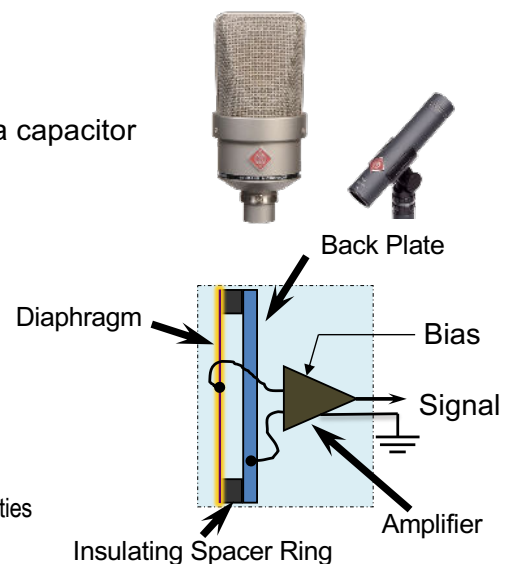
Variable Capacitance – Electrostatic

Electrically charged back plate and diaphragm form a capacitor

- Air pressure hitting diaphragm causes it to move
- Diaphragm's movement in relation to back plane varies capacitance
- Very small signal is created, needs to be amplified

Integral FET (Field Effect Transistor) Amplifier

- Boosts small signal to useable level
- Must be close to capsule (high impedance circuit)
- Can be sensitive to static electricity
- Requires voltage to operate
- Amplifier may have input pad (-10 dB), allows for higher SPL capabilities



21



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Condenser Microphones

Externally Biased or Electret...

Externally biased

- Backplate is charged from external voltage source (Power supply or phantom power)
- Higher voltage is used to polarize the backplate
- Provides higher output / better signal to noise ratio
- Sometimes referred to as "True Condenser"



Electret (back electret)

- Backplate is permanently charged
- Originally electret condensers were considered inferior performers
- Can be powered by an internal battery (only powers electronics)
- Most small condenser capsules today are electrets (iPhone, Lav, etc.)
- The AT5040 and AT5047 boutique mics are electrets



22



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Condenser Microphones – Solid State or Vacuum tube?

Defines the internal amplifier technology used in the microphone...

Solid State Mics

- Can be powered via battery or phantom power
- Have standard XLR-type output connector
- Use FET transistor amplifier stage
- Some say they have brighter sound
- Typically, are less expensive



Vacuum Tube Mics

- Require external (high-voltage) power supply
- Use special cable between power supply and Mic
- Require warm-up time before use
- Some say tube has a "warmer" sound
- Vintage tube mics can be very pricy



23



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Condenser Microphones

Pros:

- Higher sensitivity to sound
- “Hotter” output level
- Wider frequency response
- Handle transients well
- Better dynamic range
- Easy to miniaturize



Cons:

- Require voltage to operate
- High humidity can affect operation
- Have SPL handling limit due to internal electronics
- Cheaper condensers can be noisy
- Can be fragile



24



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Ribbon Microphones

Why are ribbon mics so popular now?



Back in the Analog days

DAT
Digital Audio Tape



The “New” Digital realm



25

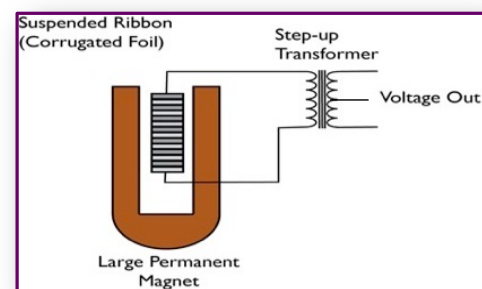


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Ribbon Microphones

Corrugated foil ribbon suspended between the poles of a large permanent magnet

- Often called a Velocity or Pressure Gradient Mic
- First commercial versions by RCA in 1930's
- Principle of magnetic induction
 - Ribbon is very thin (thinner than human hair...)
 - Air hitting ribbon causes it to move
 - Movement of ribbon cuts magnetic force lines inducing very small voltage
- Step-up transformer boosts voltage to something useable



26



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Ribbon Microphones

- Original Ribbon mics were very fragile
 - Strong puff of air destroyed the ribbon
 - Voltage across ribbon vaporized it
 - They needed to be stored properly (Vertically)
- Vintage ribbon mics command high price
 - Still in use today
 - Have increased in value



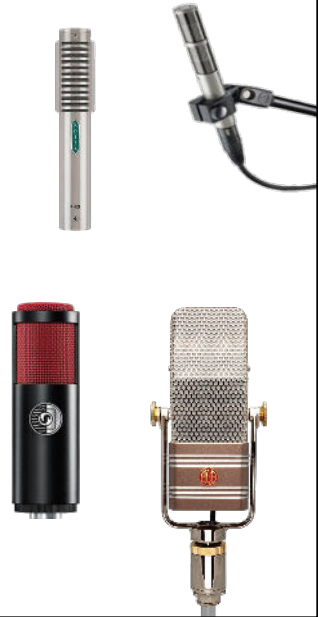
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Ribbon Microphones

- New models:
 - Active electronics to interface properly (impedance-match) with today's consoles, mic preamps, and digital audio interfaces
 - Smaller but more powerful magnet structure
 - Special baffle and ribbon structure minimizes wind effects
- Devices are available to boost Ribbon mic output
 - Cloud Lifter
 - Royer deBooster
 - Klark Teknik CT1



28



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Ribbon Microphones

Pros:

- Smooth silky highs
- Naturally, warm low end
- Good on transients
- Can handle higher SPL
- New models more robust

Cons:

- Voltage can vaporize ribbon
- Very fragile (older models)
- Low output level
- Can be physically large



29



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Output Level – Open Circuit Sensitivity

Sensitivity = amount of output for a given input signal

- Standardized measurement method used by all microphone manufacturers
- Can be stated in two ways:
 - dB SPL
 - Less negative values = higher sensitivity (-40 dB vs. -60 dB)
 - Millivolts
 - Higher value = higher sensitivity

Reference SPL of 1 Pa (Pascal) = 94 dB SPL is standard used for sensitivity measurements



30



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Output Level – Open Circuit Sensitivity

- Measure microphone output with a known audio input
 - 1 kHz tone
 - 94 dB SPL (= 1 Pascal)
- Measurement results
 - dB referenced to 1 Volt (Negative numbers!)
 - Millivolts
- Higher output = more sensitive microphone

Millivolt meter



Test Tone: 1 kHz set to 96 dB SPL



Mic under test

31



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Output Level – Open Circuit Sensitivity

Condenser microphone: -36 dB (15.8 mV) re 1V at 1 Pa

Dynamic microphone: -54.5 dB (1.85 mV) re 1V at 1 Pa

Dynamic microphone (Neodymium): -51 dB (2.8 mV) re 1V at 1 Pa

Ribbon (passive) microphone: -53 dB (2.25 mV) re 1V at 1 Pa

Ribbon (active) microphone: -41.5 dB (8.3 mV) re 1V at 1 Pa



Sensitivity defines the preamp/mixer gain required to achieve a desired output...
When comparing microphones this will determine the gain difference necessary to get the same output level

When comparing microphones this will determine the gain difference necessary to get the same output level

32



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Diaphragm Size... Big or Small?

Large diaphragm microphones (> 1" capsule)

- Classic studio vocal microphone (big vocal sound)
- Large diaphragm = more low end, warm, natural sound
- Available in single or multi-pattern configurations
- Larger/thicker diaphragm more durable in high SPL



Small diaphragm microphones

- Better transient response (quicker)
- Sound brighter, more detail
- More articulation, less coloration
- Good choice for woodwinds, strings or other delicate orchestral instruments where lots of detail needs to be captured



33



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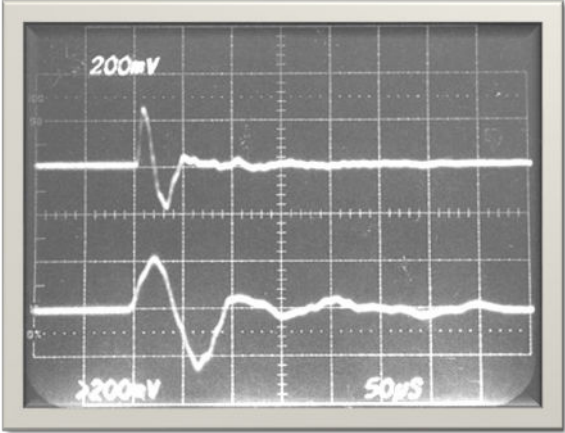
Transient Response Comparison

When the triangle is struck what do we see?



Condenser microphone:
The element responds quickly and stops quickly

Dynamic microphone:
The element responds slowly and continues to oscillate due to motor effect and mass of diaphragm/coil assembly



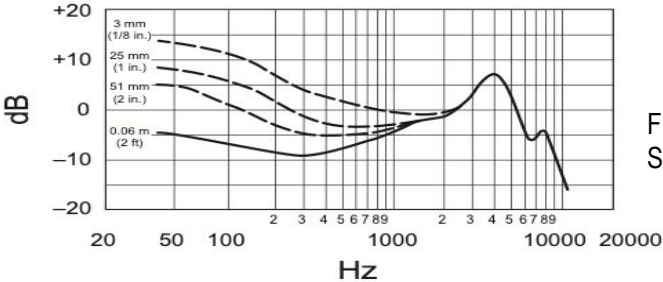
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Proximity Effect

As you move closer to microphone low frequencies increase



Frequency response graph for Shure Beta 52 Kick Drum Mic



These mics do not exhibit proximity effect...



35



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Microphone Types – In a Nutshell

Dynamic



- Handle unlimited SPL's
- Don't require power
- Can take a lot of abuse
- Difficult to miniaturize

Condenser



- Have "hotter" output
- Much wider frequency response
- Require power to operate
- Can be made really tiny

Ribbon



- Have smooth top-end, rich low-end
- Handle high SPL
- New models more rugged
- Traditional big studio mic

Choose Condensers for most recording applications... Dynamics for high SPL sound sources... Ribbons to tame the "harsh digital edge"...



36



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Pickup Pattern... Directionality

How microphone responds to sound arriving from different directions

- Omnidirectional – Favors all directions equally
- Directional – Favors a specific direction
 - Favored Direction – "ON AXIS"
 - Other Directions – "OFF AXIS"



All microphones are "born" omnidirectional...

Manufacturers engineer specific mechanical/acoustical designs to affect directionality or pickup pattern!

Manufacturers engineer specific mechanical/acoustical designs to affect directionality or pickup pattern!

37

Polar Pattern - Directionality

Directional Mic has ports on capsule

Omnidirectional Mic has no ports on capsule

38

Pickup Pattern... Directionality

Polar Pattern – Graphical Representation

- Microphone's 3-dimensional pickup characteristics represented in a two-dimensional graph
- Allows comparison between models and types
- They can vary at different frequencies
- 1 KHz is most common measurement frequency

Wide **Narrow** **Exception**

Polar Pattern Examples...

Omnidirectional Cardioid Supercardioid Hypercardioid Line+ Gradient (Shotgun) Bi-directional (Figure 8)

39



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Multi-pattern Microphones

- Provides multiple switchable polar patterns in one microphone
- Two separate diaphragms / capsules mounted back-to-back
- Signals are combined in different ways to achieve mono signals
 - No voltage on rear diaphragm = Cardioid pattern
 - Equal in-phase voltage to both diaphragms = Omni pattern
 - Rear diaphragm voltage equal, but out of phase (reversed polarity) = Bidirectional Figure-of-Eight pattern



40

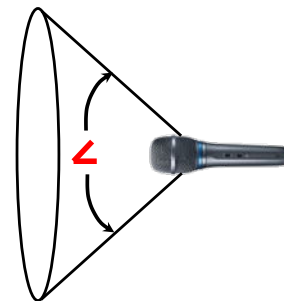


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Pickup pattern... Know the Angles...

Acceptance Angle

- Measurement of the optimum coverage angle in which a microphone will pickup sounds
- Outside the acceptance angle audio level and performance will drop off steeply
- Determined by the microphones polar pattern and physical design



Null Angle

- A measurement of the point in a directional pattern microphone where maximum sound rejection occurs
- In relation to the front of the microphone or on-axis position
- This point is key to minimizing the effects of acoustical feedback when using microphones with monitor speakers in live situations



41



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Pickup pattern... Know the Angles...

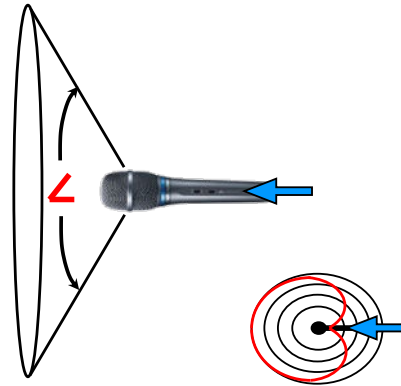
Microphone – Cardioid

Cardioid Acceptance Angle

- 131 degrees for typical cardioid
- Classic "heart-shaped" pattern

Cardioid Null Angle

- 180 degrees off axis for typical cardioid
- Ideal for use with monitor speakers to control/minimize feedback



A *Subcardioid* mic is almost omnidirectional, with a more rounded off-axis point

42



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Pickup pattern... Know the Angles...

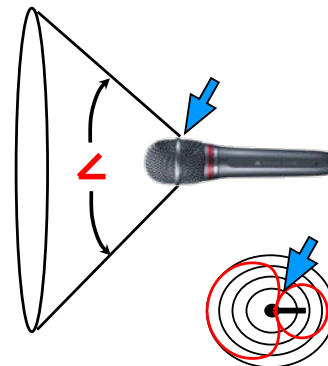
Microphone – Hypercardioid

Hypercardioid Acceptance Angle

- 105 degrees typical
- Small rear lobe... sensitive to sound

Hypercardioid Null Angle

- 110 degrees off axis for typical hypercardioid
- Do not place monitor speaker directly in front of mic as the lobe can cause feedback



A *Supercardioid* mic has a 115-degree acceptance angle and a slightly smaller rear lobe

43



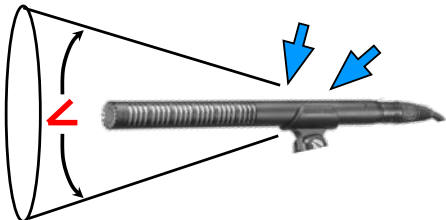
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Pickup pattern... Know the Angles...

Microphone – Line + Gradient (Shotgun)

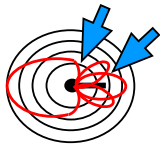
Line+ Gradient Acceptance Angle

- ~ 30 degrees typical
- Several small rear lobes pick up sound



Line+ Gradient Null Angle

- Several rear lobes – based on length of mic
- Can pick up ceiling reflections when used indoors
- Use shorter shotgun mic or cardioid mic indoors

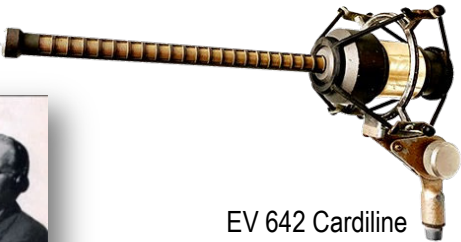
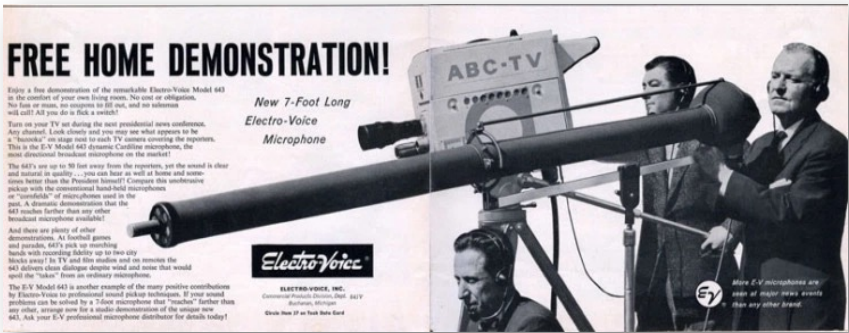


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Pickup pattern... Know the Angles...

Microphone – Line + Gradient (Shotgun) back in the day...

EV 643 Cardiline (7-foot-long version!)



EV 642 Cardiline



EV 644 Soundspot



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Pickup pattern... Know the Angles...

Microphone – Bi-directional (Figure of 8)

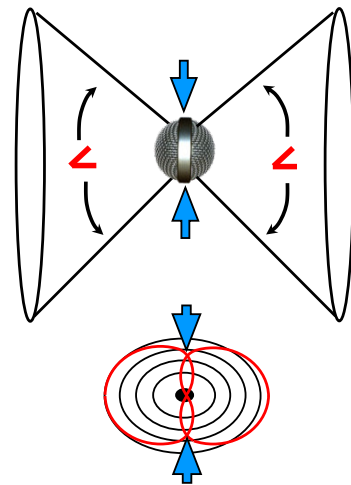
Bi-directional Acceptance Angle

- 130 degrees typical
- Equal amount on front and rear of capsule

Bi-directional Null Angle

- 90 degrees off axis
- Either side of capsule

Ribbon mics by design naturally have this pickup pattern



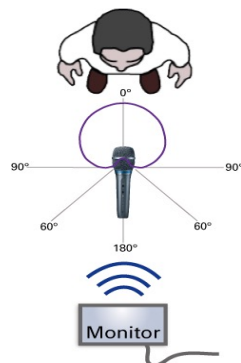
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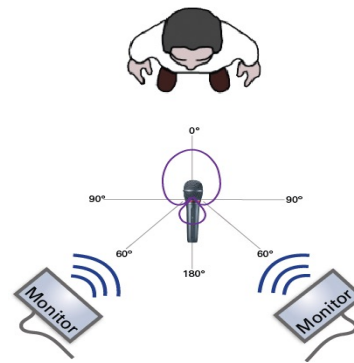
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The Angles and Stage Monitors

Lead vocalist...



Cardioid Microphone



Hypercardioid Microphone

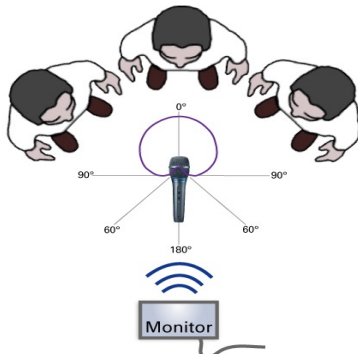
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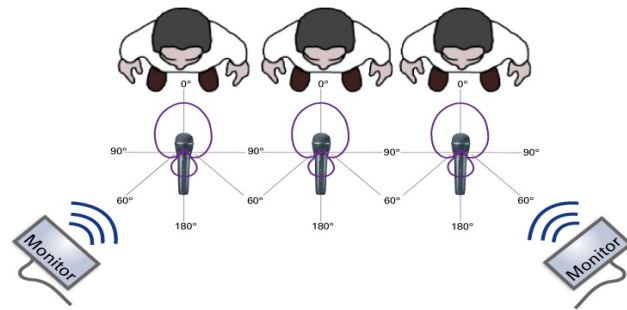
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The Angles and Stage Monitors

Background singers...



Cardioid Microphone



Hypercardioid Microphones

48



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Pickup vs. Distance

Inverse Square law (physics 101...)

- Sound becomes weaker as it travels away from the source at a rate we can mathematically calculate
- When the distance increases by a factor of 2 (doubles), the sound level decreases by a factor of 4 (the square of 2).
- This results in a drop of 6 dB in sound pressure level (SPL), which is a substantial decrease
- And, when the distance is cut in half (divided by 2), the sound level *increases* by 6 dB.



49



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Pickup vs. Distance

Laws of physics say...

The closer you are... The louder you Get!

- Moving from 1" to 2" = -6 dB drop
 - Moving from 2" to 4" = -6 dB drop
 - Moving from 4" to 8" = -6 dB drop
- Thus, moving from 1" to 8" = -18 dB drop

It takes 4x the power to increase +6 dB



50

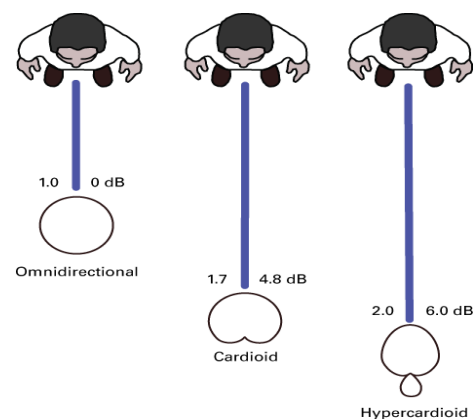


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Pickup vs. Distance

Working Distance

- Usable working distance is based on environment and pickup pattern
- Microphones do not have "Reach"
- Some microphones reject unwanted sound off axis, improving working distance
 - Line+ Gradient
 - Ultra-Cardioid



Working distance and effectiveness in rejecting reverberation in same space / noise level environment

51



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Transparent vs. Adjacent – Working Distance

Transparent

- Volume change vs. working distance is more gradual (level drops off slowly)
- Sound more natural and less forced
- Can be deployed at greater distances
- More sensitive to sounds
- Can pick up more background noise



Adjacent

- Volume change vs. working distance is more pronounced (level drops off quickly)
- Emphasize voice in a “tight close-up way”
- Work best when kept fairly close to sound source
- Less sensitive to sounds
- Rejects more background noise



52



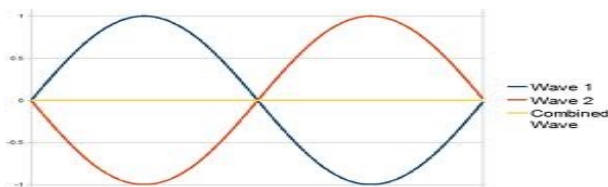
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Polarity and Phase

Phase is wave relationship over time... Polarity is electrical connections...

Reverse polarity (Pins 2 and 3) of XLR connector on one mic

- Often called “Phase” reversal adapters
- Pre-made adapters or DIY ones
- Some consoles offer function via button
- Puts the audio 180 degrees out of phase on second mic
- Allows microphones to operate in a “push – pull” arrangement



53



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Sound Pressure Level - SPL

Maximum SPL rating in microphones

- Loudest sound before distortion in microphone
- Expressed in Decibels (dB)
- Larger value is better
- Dynamic mics typically handle much higher SPL levels than other types
- In condenser microphones, it is often the electronics that overload on loud sounds



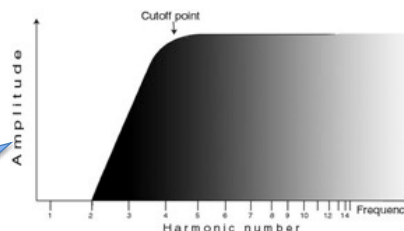
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The High-Pass or Low-Cut Filter

Useful tools they are



- Engage "Low Cut" on all condenser microphones except for low-frequency sources: Kick drum, bass guitar, etc....
- Vocals will pop out of the mix
- Helps minimize pickup of mechanical noise (mic mount/stand, cable, etc.)
- If you don't have "Low Cut"... roll off low frequencies using low frequency EQ control or HPF switch on the associated mixer channel

55

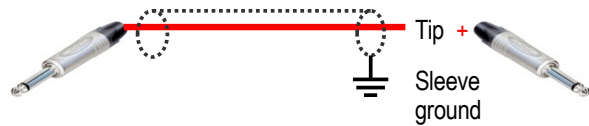


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Making the Connections

Unbalanced audio

- 2 Pin 1/4" Tip/Sleeve connectors are used
- Signal travels in one direction
 - Tip is Positive Voltage
- Shield or ground connects to the Sleeve
- Noise induced across the line cancels can cause hum
- Common connection for:
 - Musical instruments
 - Consumer audio equipment
 - Some low-cost microphones



56

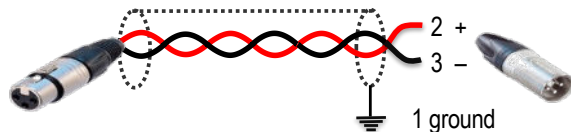


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Making the Connections

Balanced Audio

- Originally designed by telephone company
- Signal travels in both directions
 - Signals are reversed in polarity
 - Positive pressure on diaphragm results in + voltage on Pin 2
- Shield or ground does not connect to connector shell
- Noise induced across the line cancels out
- Microphones use 3-Pin connectors (XLR)
- Line level connections can be 1/4" TRS Phone Plugs



57



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Making the Connections

Early ways to connect...



Canon "O" Series



Canon "P" Series



Canon "UA-3" Series



Canon "XL" Series



Original Cannon XLR's

And ones we hate...



Amphenol MC4M



Amphenol MC3M – MC3F



Switchcraft "Button"

58



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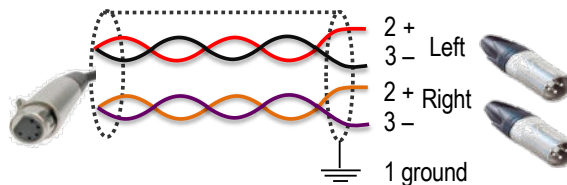
Making the Connections

Balanced stereo output

- 5 Pin connectors are used (XLR)
- Individual twisted pairs for balanced signal
- Share common shield
- Many Stereo Microphones use this configuration



Pin 1 – Sleeve
Pin 2 – Left +
Pin 3 – Left -
Pin 4 – Right +
Pin 5 – Right -



59

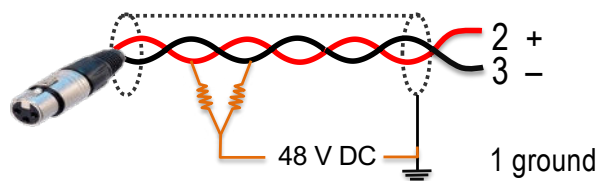


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Phantom Power

DC voltage applied across a balanced line to power microphone's electronics

- Delivered on same two conductor shielded cable used to carry the audio signal
- Works with balanced line only
- Voltage appears across signal leads and shield
- Voltage ranges from 9 – 52V DC
- 48 Volt most common



Sources for phantom power

- Mixer, preamp, interface
- External power supply
- Battery in microphone (not true phantom power)



60



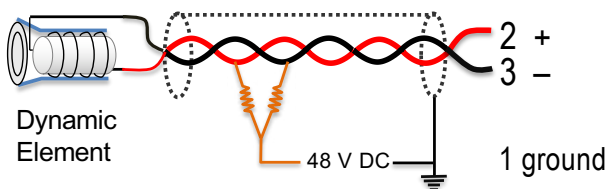
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Phantom Power

DC voltage applied across a balanced line to power microphone's electronics

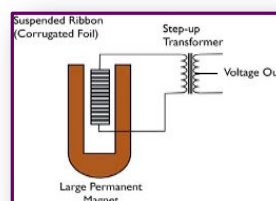
Does not affect dynamic mics

- Dynamic elements "coil" appears only on + side of power (Pins 2 & 3 of balanced line)
- No connection is made to ground



Can damage some vintage ribbon mics!

- Transformer in the microphone is center-tapped to ground
- Current flow can cause ribbon to blow like a fuse
- Use caution when connecting vintage ribbon mics!



61



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SMOKIN' HOT® microphone power adapter

Makes cheap microphones sound really expensive...
and expensive microphones sound really HOT!



Only \$9.99 (\$22.00 west of the Mississippi). Order yours online today.

Disclaimer: Non-professional use only. Not responsible for misuse. Keep small children, and drummers away at all times. Always use proper protective eyewear. Do not use in wet conditions. Downloadable version only. Hum specs not available.

Hmm, my expensive mic worked really great, right before I plugged it in...



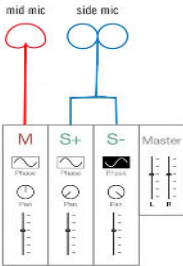
62



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Stereo Microphones

- Two condenser elements with individual outputs
- Element configuration determines type
 - Cardioid capsules in X-Y pattern – Provides L+R Stereo
 - Cardioid and Figure-of-eight capsules in MS (Mid-Side) arrangement
 - Outputs fed through MS-Matrix Decoder
 - Varying level ratio of Mid capsule to Side capsule allows width of stereo field to be increased or decreased



63



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Binaural Microphones

- 3D recording technique that simulates what a person hears
 - Based on mechanics of how we hear
 - Ears are omnidirectional microphones in a spaced array
 - Works along with shape of human head to perceive directionality
- Playback is through headphones for full effect
 - Provides lifelike imaging
- Microphone options
 - Microphones worn in person's ears
 - Microphones incorporated into "human head" fixture
 - Have simulated ear "pinnae" to funnel sound to mics
 - Spacing based on average human head size



Neumann KU-100
Binaural "Fritz" head



3Dio Binaural Rig



Roland CS-10EM "in-ear" microphones

64



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Surround Sound Microphones

- Single microphone captures multi-channel surround sound
 - Does not require signal manipulation or processing
 - Compatible with all surround sound encoding/playback formats
 - Applications include broadcast, live event recording
- Holophone H2
 - Up to 7.1 channels
(left, center, right, left surround, right surround, center rear, and top)
 - Works with any 8-channel preamp
- Holophone H3
 - Up to 5.1 channels
(5 multi-directional full bandwidth elements, 1 LFE element)
 - Works with any 6-channel preamp



Holophone H2 Pro



Holophone H3D

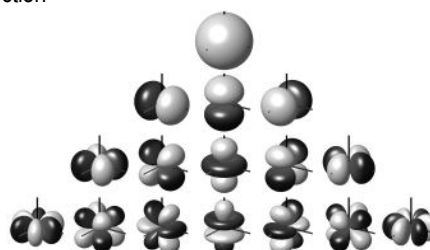
65



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Ambisonic – Background

- Method to capture 3-dimensional 360-degree audio (3-dimensional extension of M/S Stereo)
 - Adds additional difference channels for height and depth
 - Not tied to any specific speaker configuration for playback – can be decoded to any type of speaker array
 - Most widely used today is First Order (4-channel B format)
 - Four channels represent different polar patterns pointing in specific direction
 - W - omni-directional polar pattern, containing all sounds in the sphere, coming from all directions at equal gain and phase
 - X –bi-directional pattern (figure-8) pointing forward
 - Y –bi-directional pattern (figure-8) pointing left
 - Z – bidirectional pattern (figure-8) pointing up
 - Higher order B-formats (more channels) can provide higher spatial resolutions
 - Up to sixth-order ambisonics with 49 channels
- Two conventions based on channel arrangement
 - AmbiX – W Y Z X; FuMa – W X Y Z



First, Second, Third Order Ambisonics Diagram
By Dr Franz Zotter <zotter@iem.at>

66



Holophone H3D

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Ambisonic Microphones

- The First-Order Ambisonic Microphone (Tetrahedral Mic)
 - Four discrete capsules in a single “handle”
 - Condenser capsules (small or large diaphragm)
 - Cardioid patterns
 - Analog XLR outputs x4
 - Can model spatially coincident microphones
- Higher Order (HOA) Ambisonic Microphones
 - Second order – 8 capsules
 - Third order – 32 capsules
 - Output can be Analog XLR, Dante, USB, or Firewire
 - Allows for greater resolution in the 360 space
 - Can model spaced microphone arrays
 - Decca Tree, ORTF, Double M/S, etc.



Sennheiser Ambio Core Tetramic Rode NT-FS1



Elginmike em32 Core Octomic Voyage VA-SAM-1D

67



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Ambisonic Recording

- Recording with ambisonic Mic
 - The four signals referred to as “Ambisonics A-format”
 - Recorded as four discrete mono channels
 - Transformed to B-format by matrix to W,X,Y,Z channels
 - Special ambisonic DAW Plugins
- B-format components can be combined to derive virtual microphones
 - Any first-order polar patterns (Omni, Cardioid, Hyper, Figure-8)
 - Create coincident stereo pairs (Blumlein, Surround arrays)
 - These virtual microphones can be manipulated in post-production
 - Pick out desired sounds and suppress unwanted sounds
 - Balance between direct and reverberant sound can be fine tuned during mixing



Rode SoundField Plugin



Waves Ambisonic plugin

68



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Microphone Techniques for the really tough stuff...



Based on many years of audio experience and all-around common sense...

Here are the insider secrets and techniques on how to mike some of the more challenging sound sources out there...

69



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Acoustic Instruments – MIKING A BANJO...

DON'T!



70



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Acoustic Instruments – MIKING AN ACCORDIAN...

DON'T!



71



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Acoustic Instruments – MIKING A BAGPIPES...

DON'T!



72



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Vocals – IN THE STUDIO...

What is wrong here??



73



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Vocals – PUBLIC SPEAKING...

What is wrong here??



74



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Electric Instruments – MIKING A GUITAR AMP...

I don't think this will work...



75



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Wind Instruments – Saxophone

How to mic a sax.... NOT!



76



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Acoustic Drums

How many microphones do I need?



77



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Broadcast (Newsman's) Loop for Lavalier Microphones

- Secure mic in the clip
- Loop cable up and around into the clip
- Clip mic to clothing
- Secure cable to back side of clip between clip and clothing
- Dress remainder of cable behind talent's clothing



78



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Physics of Microphones

Applications and Techniques for Studio and Live Sound

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79