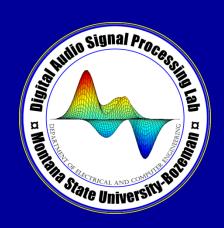# A Tutorial on Acoustical Transducers: Microphones and Loudspeakers

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EELE 217 Science of Sound

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Test Sound

Outline

- Introduction: What is sound?
- Microphones
  - Principles
  - General types
  - Sensitivity versus Frequency and Direction
- Loudspeakers
  - Principles
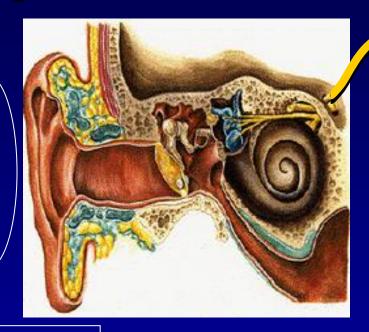 - Enclosures
- Conclusion

Transduction

- *Transduction* means converting energy from one form to another

- *Acoustic transduction* generally means converting sound energy into an electrical signal, or an electrical signal into sound

- Microphones and loudspeakers are acoustic transducers
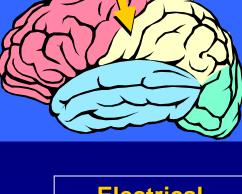
Acoustics and Psychoacoustics

Mechanical to Acoustical

....

Acoustical propagation (reflection, diffraction, absorption, etc.)

Acoustical to Mechanical

Mechanical to Electrical (nerve signals)

Electrical to Psychological

What is Sound?

- Vibration of air particles
- A rapid fluctuation in air pressure above and below the normal atmospheric pressure
- A *wave* phenomenon: we can observe the fluctuation as a function of time and as a function of spatial position

Sound (cont.)

- Sound waves propagate through the air at approximately 343 meters per second
  - Or 1125 feet per second
  - Or 4.7 seconds per mile ≈ 5 seconds per mile
  - Or 13.5 inches per millisecond ≈ 1 foot per ms
- The speed of sound (c) varies as the square root of absolute temperature
  - Slower when cold, faster when hot
  - Ex: 331 m/s at 32ºF, 353 m/s at 100ºF

Sound (cont.)

- Sound waves have alternating high and low pressure phases

- Pure tones (sine waves) go from maximum pressure to minimum pressure and back to maximum pressure. This is one *cycle* or one waveform *period* (*T*).

T

Wavelength and Frequency

- If we know the waveform *period* and the speed of sound, we can compute how far the sound wave travels during one cycle. This is the *wavelength* (λ).

- Another way to describe a pure tone is its *frequency* (*f*): how many cycles occur in one second.

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Wave Relationships

- $c = f \cdot \lambda$ [m/s = /s · m]
- $T = 1/f$
- $\lambda = T \cdot c$
  - c = speed of sound [m/s]
  - f = frequency [/s]
  - λ = wavelength [m]
  - T = period [s]
  - Note: *high* frequency implies *short* wavelength, *low* frequency implies *long* wavelength

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Sound Amplitude and Intensity

- The amount of pressure change due to the sound wave is the sound *amplitude*

- The motion of the air particles due to the sound wave can transfer energy

- The rate at which energy is delivered by the wave is the sound *power* [W (watts)]

- The power delivered per unit area is the sound *intensity* [W/m^2]

Microphone Principles

- Concepts:
  - Since sound is a pressure disturbance, we need a pressure gauge of some sort
  - Since sound exerts a pressure, we can use it to drive an electrical generator
  - Since sound is a wave, we can measure simultaneously at two (or more) different positions to figure out the direction the wave is going

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Microphone: Diaphragm and Generating Element

- Diaphragm: a membrane that can be set into motion by sound waves
  - Sensitivity: how much motion from a given sound intensity

- Generating Element: an electromechanical device that converts motion of the diaphragm into an electrical current and voltage
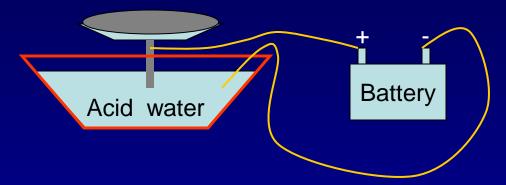 - Sensitivity: how much electrical signal power is obtained from a given sound intensity

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Electrical Generators

- Variable Resistor

- Variable Inductor

- Electromagnetic

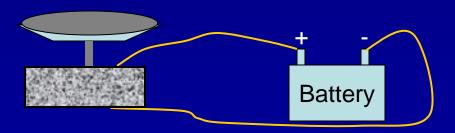- Variable Capacitor

- Piezoelectric

- Other exotic methods…

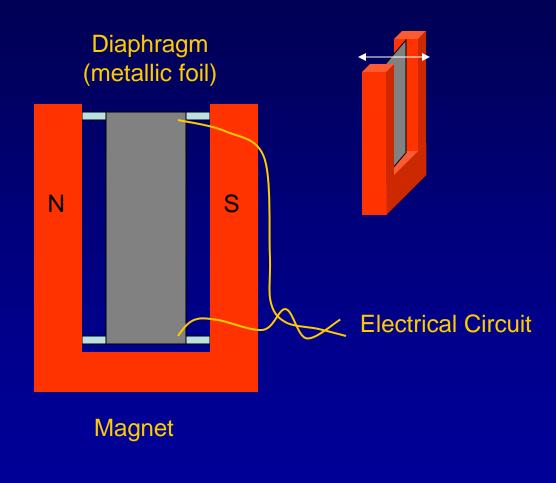# The First Microphones…

- Alexander Graham Bell (variable resistor)

Acid   water

Battery

- Carbon granules (variable resistor)

Battery

Ribbon Microphone

Diaphragm
(metallic foil)

N   S

Magnet

Electrical Circuit
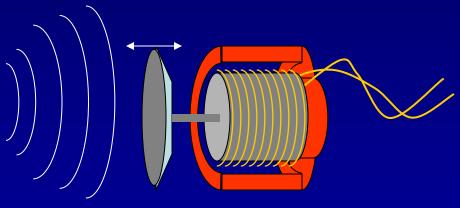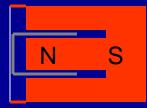
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Dynamic Microphone

- Diaphragm moves a coil of wire through a fixed magnetic field: Faraday's Law indicates that a voltage is produced

N   S

Piezoelectric Microphone

- Piezoelectric generating element: certain crystals produce a voltage when distorted (piezo means "squeeze" in Greek)
- Diaphragm attached to piezo element
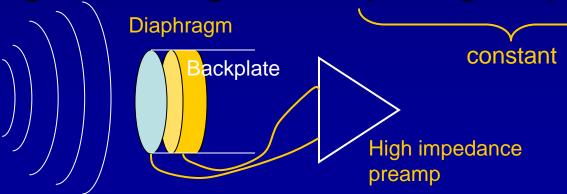- Rugged, reasonably sensitive, not particularly linear

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Capacitor (Condenser) Mic

- Variable electrical *capacitance*
  - British use the word "condenser"
- Currently the best for ultra sensitivity, low noise, and low distortion (precision sound level meters use condenser mics
- Difficult to manufacture, delicate, and can be too sensitive for some applications

Condenser Mic (cont.)

- Capacitance = charge / voltage
- Capacitance ≈ ε A / d

  A = area, d=distance between plates

  ε = permittivity
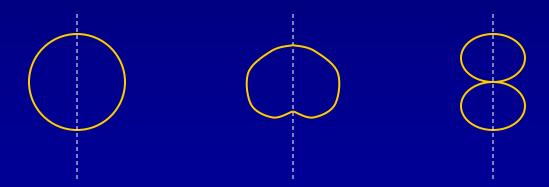- signal voltage ≈ d · (charge / (ε · A))

Diaphragm

Backplate

constant

High impedance preamp

Microphone Patterns

- A single diaphragm acts like a pressure detector

- Two diaphragms can give a *directional* preference

- Placing the diaphragm in a tube or cavity can also give a directional preference

Microphone Patterns (cont.)

- Omnidirectional: all directions
- Unidirectional or Cardioid: one direction
- Bi-directional or 'figure 8': front and back pickup, side rejection

Microphone Coloration

- Most microphones are *not* equally sensitive at all frequencies
  - The human ear is not equally sensitive at all frequencies either!
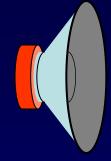- The frequency (and directional) irregularity of a microphone is called *coloration*
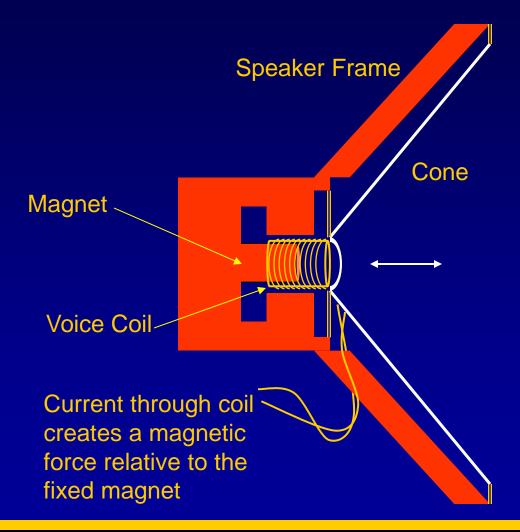- Example:

Loudspeakers

Loudspeakers

- Diaphragm attached to a *motor element*
- Diaphragm motion is proportional to the electrical signal (audio signal)
- Efficiency: how much acoustical power is produced from a given amount of input electrical power

Moving Coil Driver

Speaker Frame

Cone

Magnet

Voice Coil

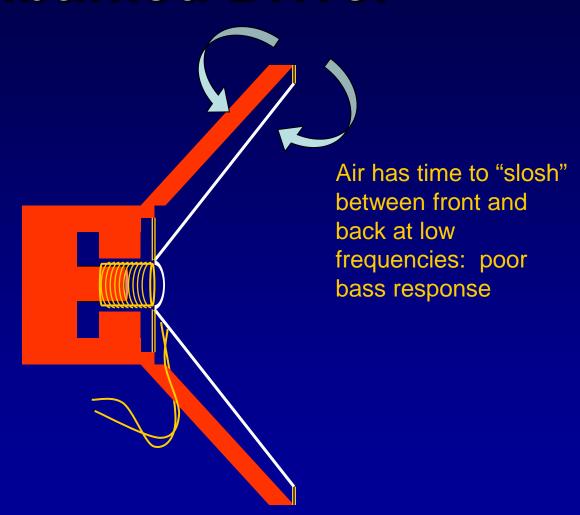Current through coil creates a magnetic force relative to the fixed magnet

Mechanical Challenges

- Large diameter diaphragm can produce more acoustic power, but has large mass and directional effects

- Diaphragm displacement (in and out) controls sound intensity, but large displacement causes distortion

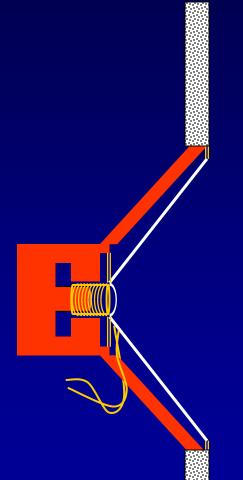- Result: low frequencies require large diameter and large displacement

Unbaffled Driver

Air has time to "slosh" between front and back at low frequencies: poor bass response

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Baffled Driver (flush mount)

Baffle prevents front-back interaction: improved low frequency performance

Loudspeaker Enclosure

- Enclosure is a key part of the acoustical system design
- Sealed box or acoustic suspension
  - enclosed air acts like a spring
- Vented box or bass-reflex
  - enclosed air acts like a resonator
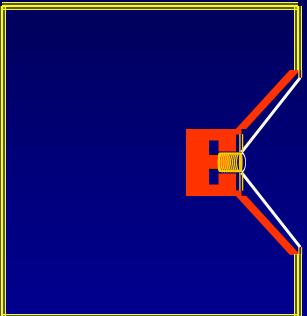- Horns and baffles

Acoustic Suspension

Sealed box acts as a stiff "air spring"

Enclosed volume chosen for optimum restoring force
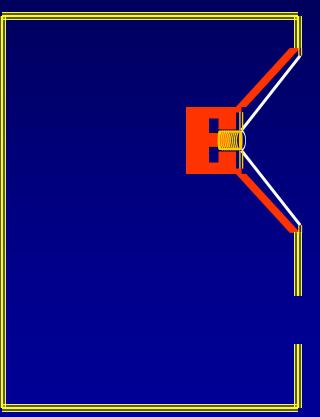
Relatively weak (compliant) cone suspension

Greatly reduced nonlinear distortion!

Ported (Resonant) Enclosure

Ported box is a Helmholtz resonator.

Enclosed volume and port size chosen to boost acoustic efficiency at low frequencies: reduces required cone motion for a given output, allowing lower distortion.

Driver acts as a direct radiator at frequencies above box resonance.

Port (hole): radiates only at frequencies near box resonant frequency, but *reduces* cone motion.

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Other Loudspeaker Issues

- Multi-way loudspeakers: separate driver elements optimized for low, mid, and high frequencies (woofer, squawker, tweeter)

- Horns: improve acoustical coupling between driver and the air

- Transmission line enclosures

- Electrostatic driver elements

- 'Powered' speakers

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Conclusions

- Microphone: a means to sense the motion of air particles and create a proportional electrical signal

- Loudspeaker: a means to convert an electrical signal into proportional motion of air particles

- **Engineering tradeoffs exist: there is not a single *best* solution for all situations**