A Tutorial on Acoustical Transducers: Microphones and Loudspeakers

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EELE 417/517 Acoustics and Audio Engineering

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Outline

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

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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

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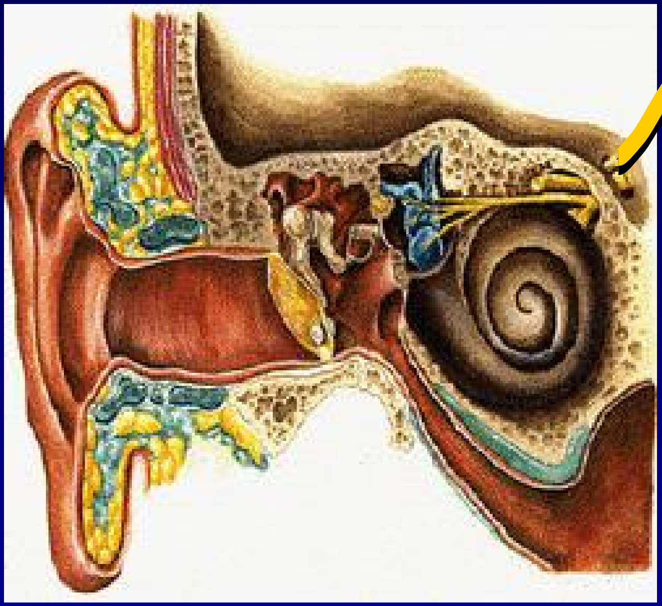
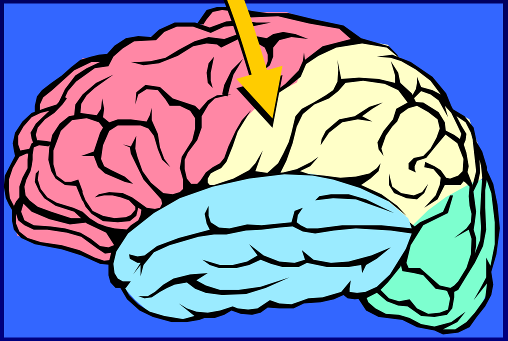
Acoustics and Psychoacoustics





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Mechanical to Acoustical

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

Acoustical to Mechanical

Mechanical to Electrical (nerve signals)

Electrical to Psychological

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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

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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

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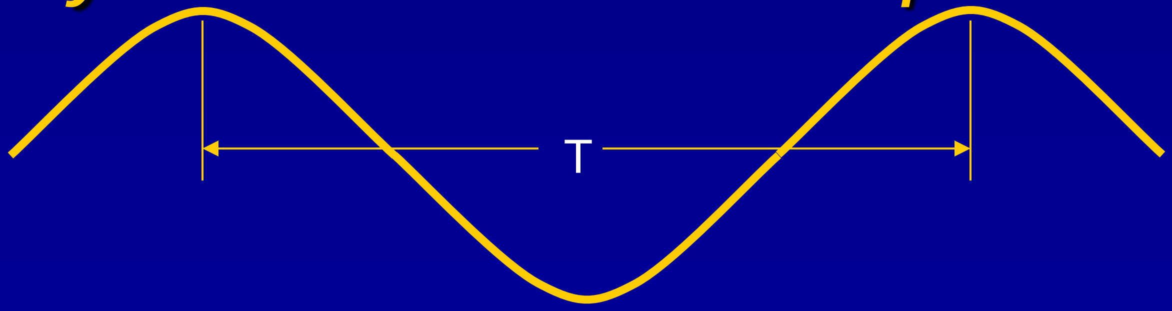
Sound (cont.)

- 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*).



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]

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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

Electrical Generators

- Variable Resistor
- Variable Inductor
- Electromagnetic
- Variable Capacitor
- Piezoelectric
- Other exotic methods…

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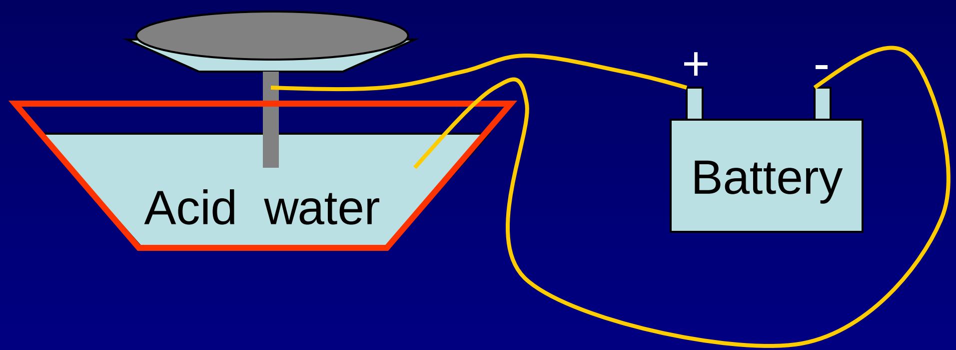
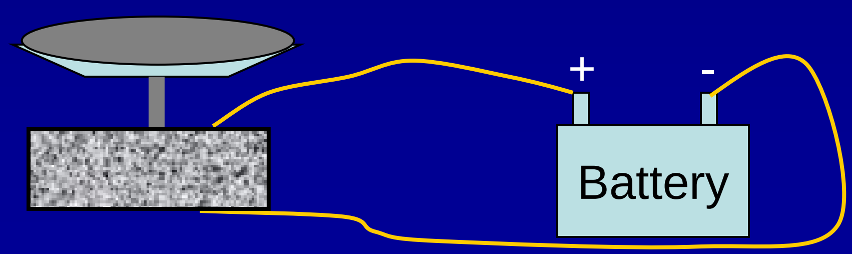
The First Microphones…

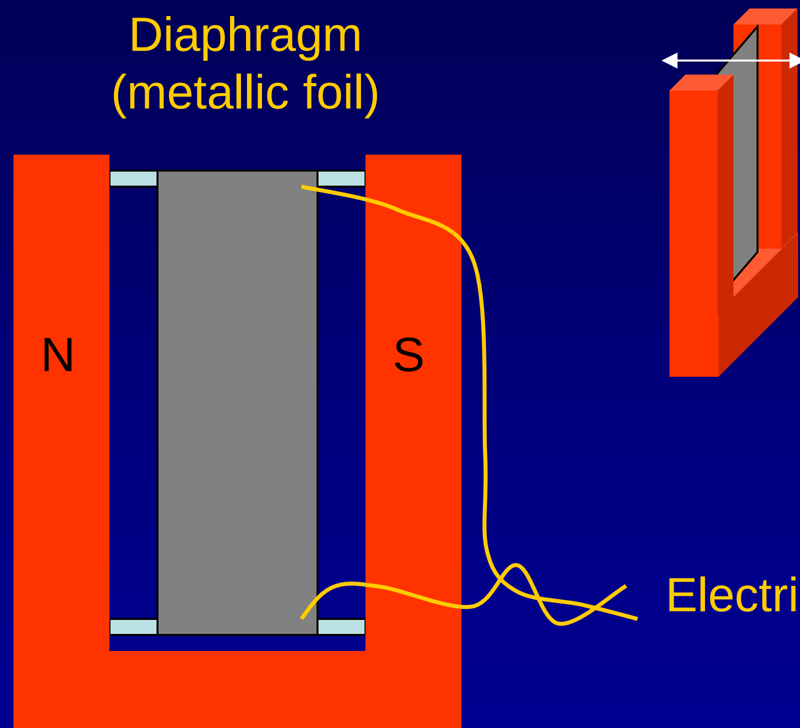
- Alexander Graham Bell (variable resistor)



- Carbon granules (variable resistor)

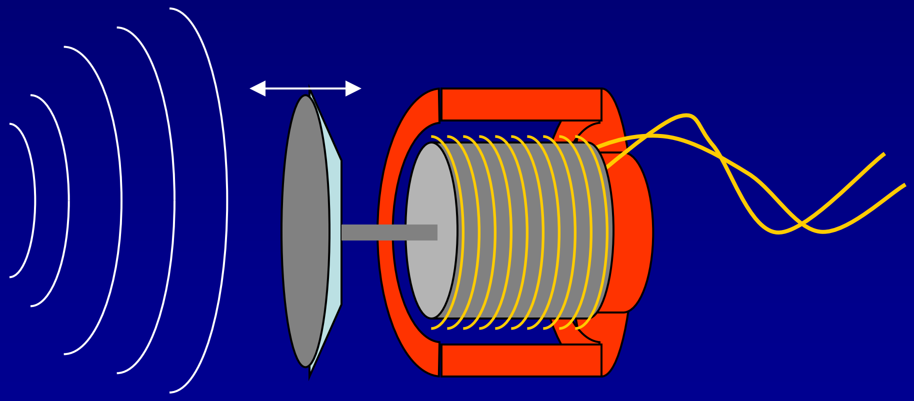


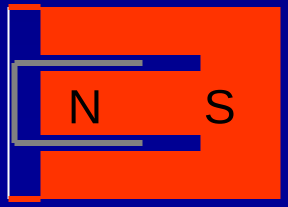
Ribbon Microphone



Dynamic Microphone

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





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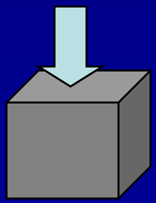
Piezoelectric Microphone

- 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

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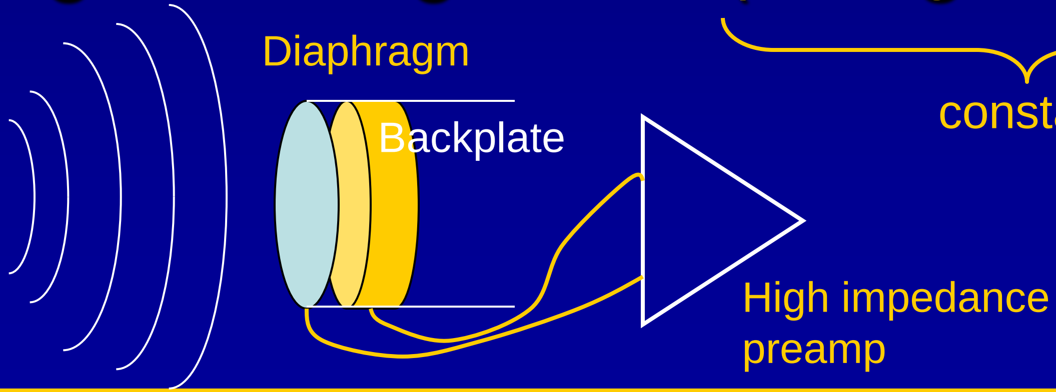
Condenser Mic (cont.)

- Capacitance = charge / voltage
- Capacitance $\approx$ ε A / d

  A = area, d=distance between plates

  ε = permittivity
- signal voltage $\approx d \cdot \underbrace{(\text{charge} / (\varepsilon \cdot A))}_{\text{constant}}$



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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

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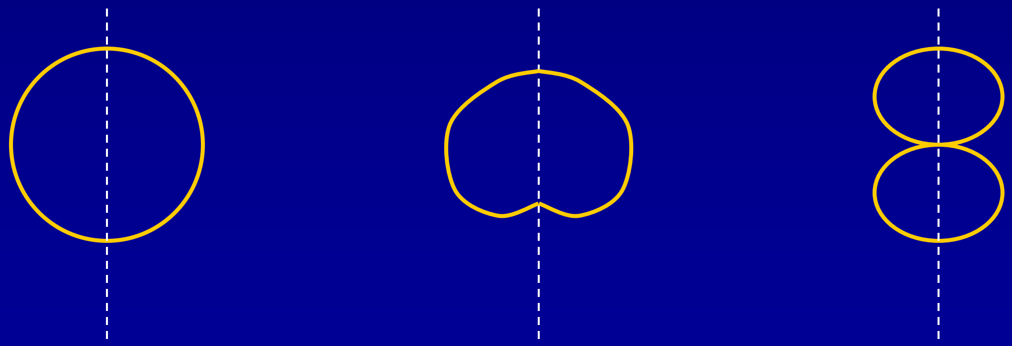
Microphone Patterns (cont.)

- 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: Stereophile Microphone .wav

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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

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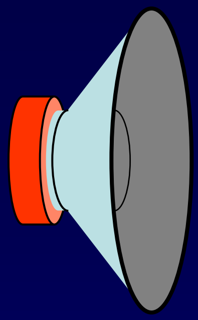
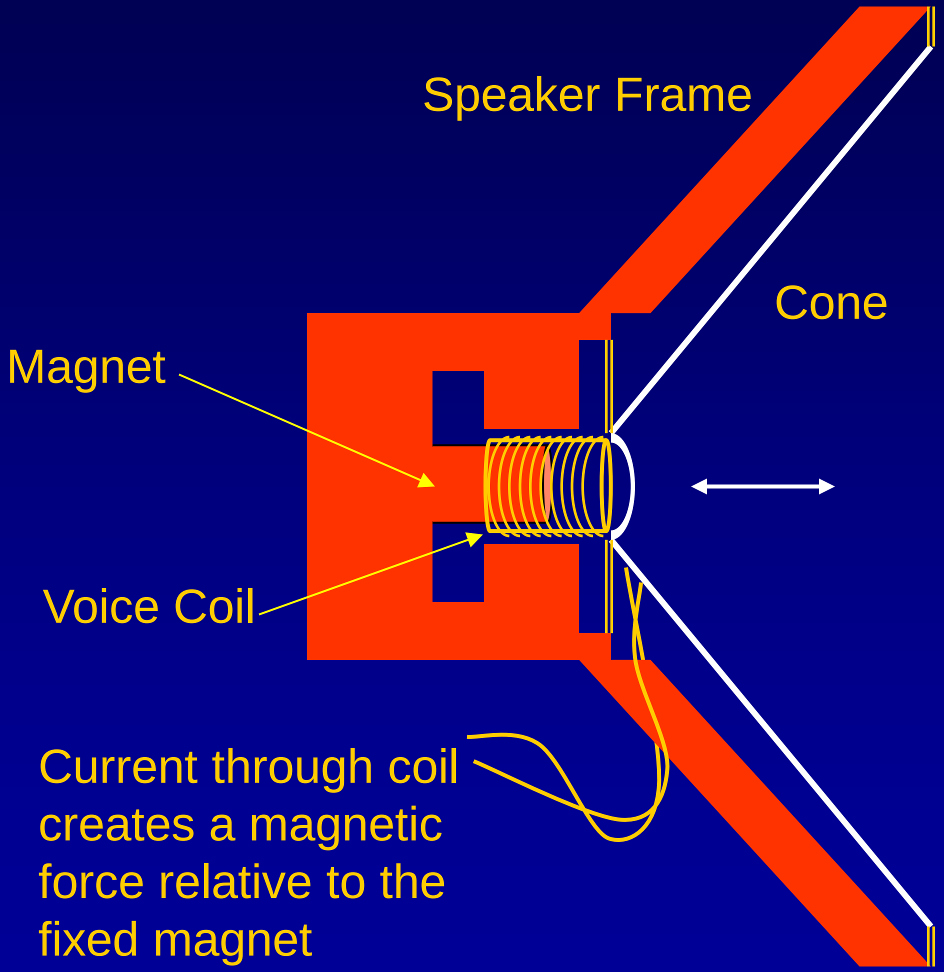
Moving Coil Driver





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

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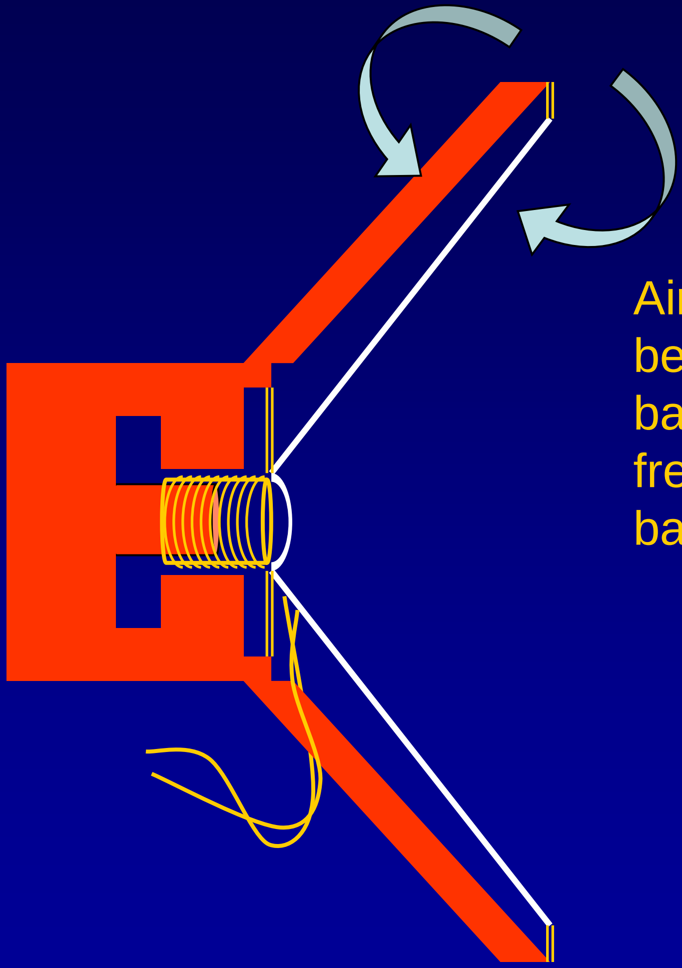
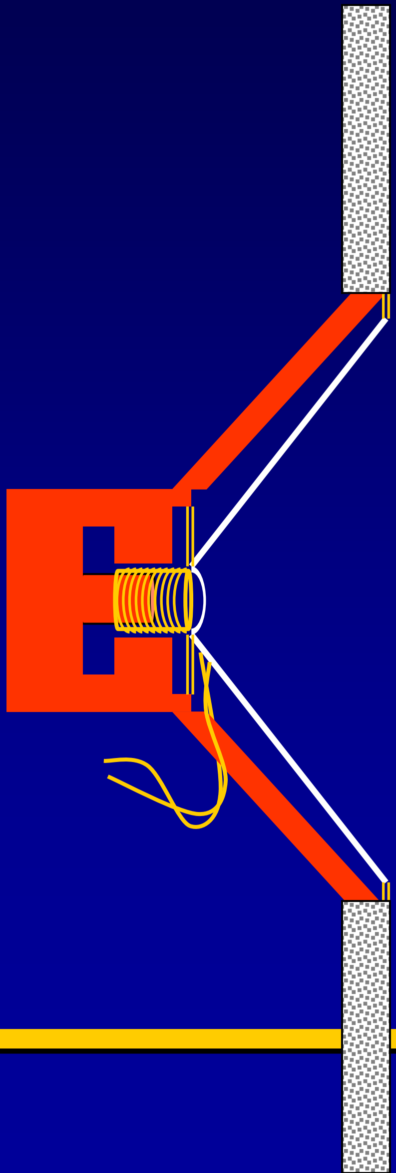
Unbaffled Driver



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

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

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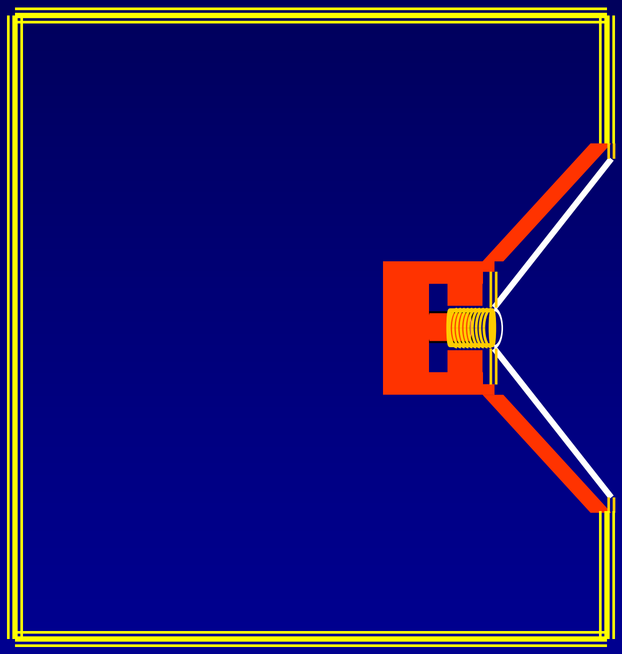
Acoustic Suspension

Sealed box acts as a stiff "air spring"

Enclosed volume chosen for optimum restoring force



Relatively weak (compliant) cone suspension

Greatly reduced nonlinear distortion!

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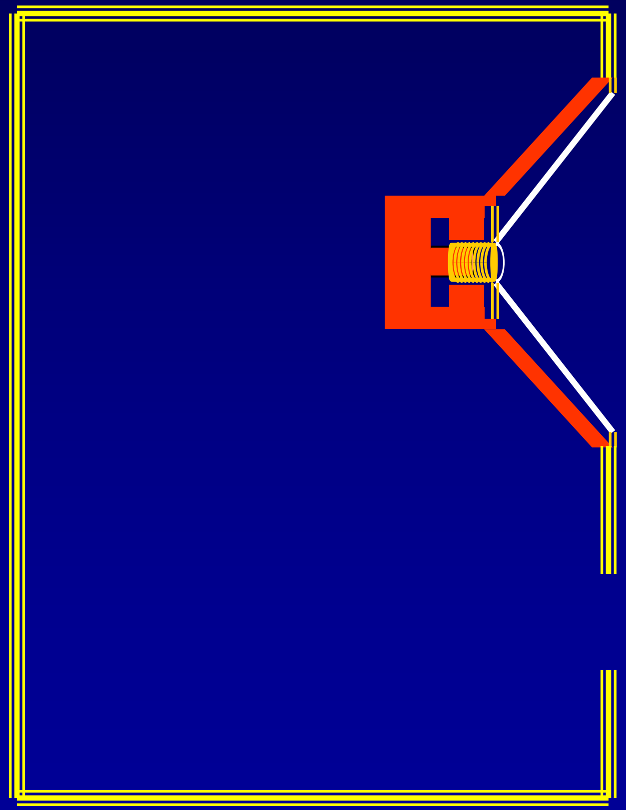
Ported (Resonant) Enclosure

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**

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