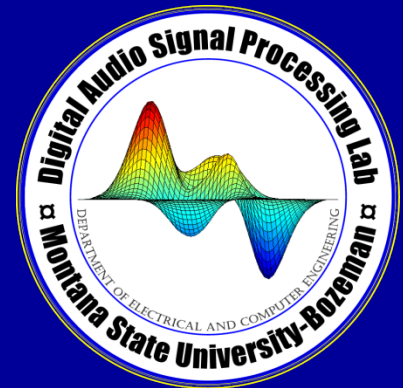# A Tutorial on Acoustical Transducers: Microphones and Loudspeakers

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*EELE 217 Science of Sound*

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# 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

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# Acoustics and Psychoacoustics
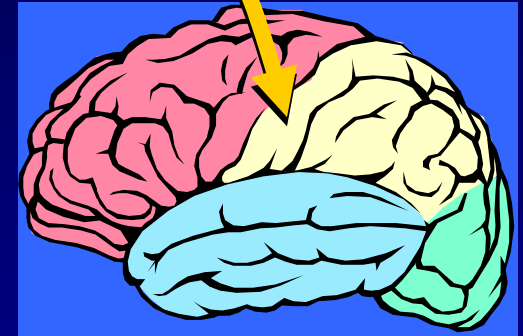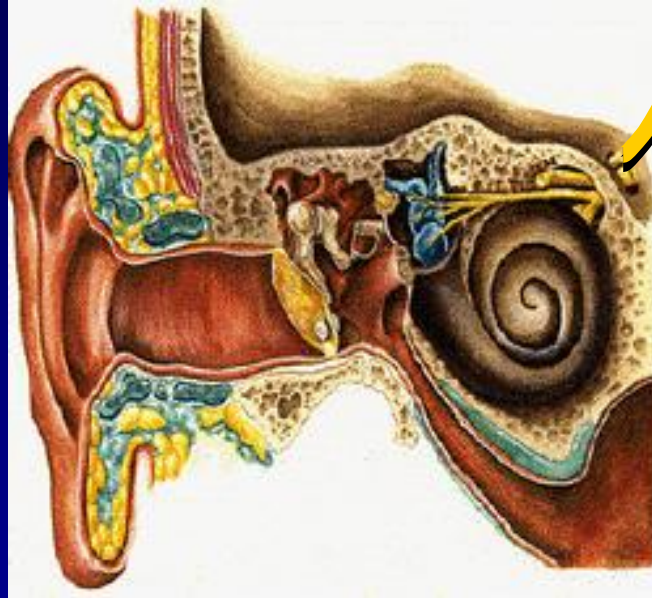


**Mechanical to Acoustical**

**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
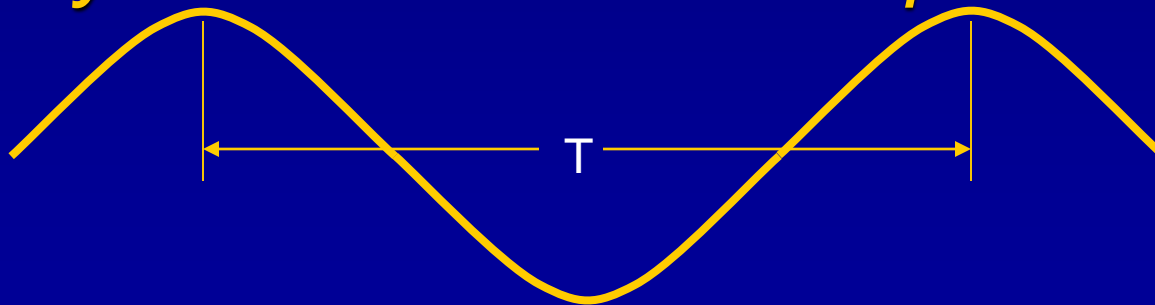
# Wavelength and Frequency

- 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.

# Wave Relationships

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

# 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

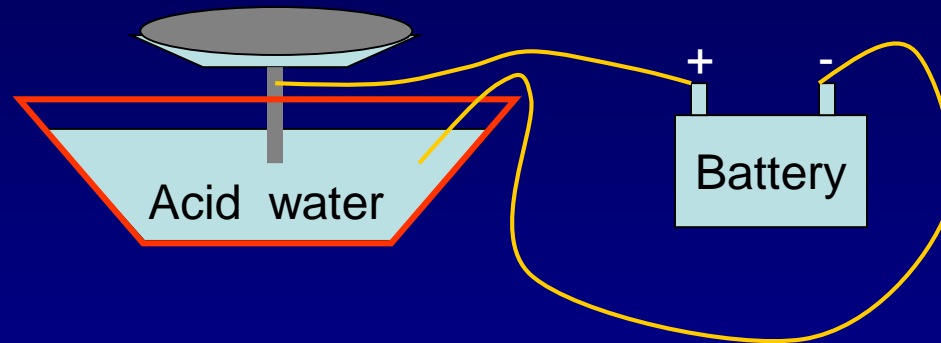# Microphone:  Diaphragm and Generating Element

- 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
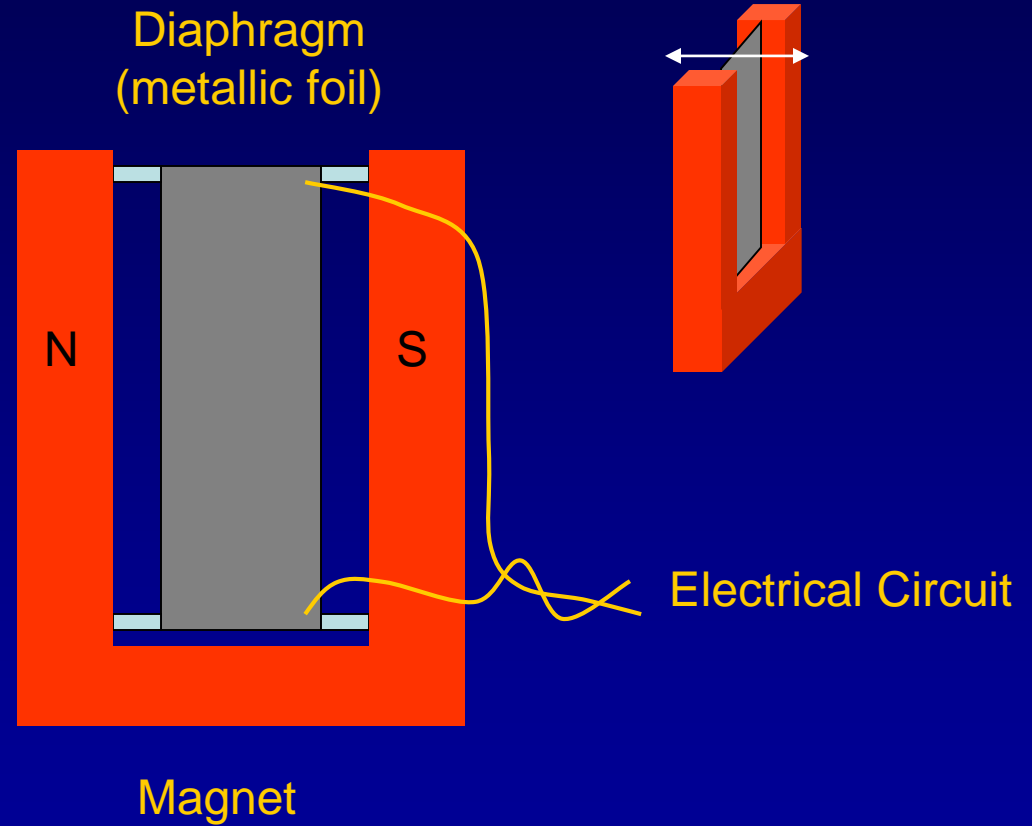- Piezoelectric
- Other exotic methods…

# The First Microphones…

- Alexander Graham Bell (variable resistor)

Acid   water

Battery

+   -

- Carbon granules (variable resistor)

Battery

+   -

# Ribbon Microphone

Diaphragm
(metallic foil)

N

S

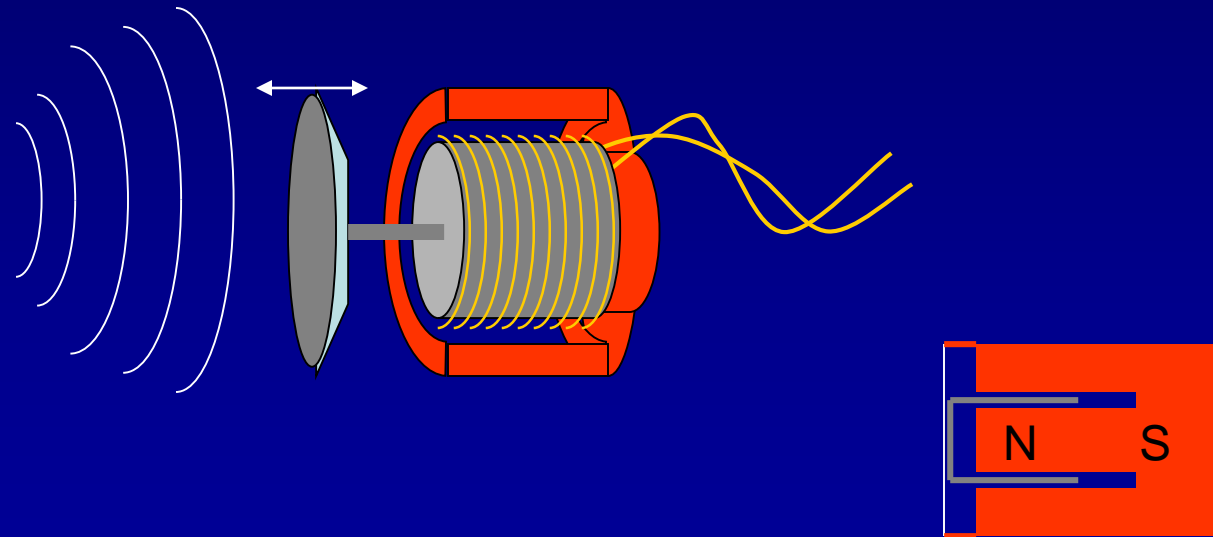Magnet

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
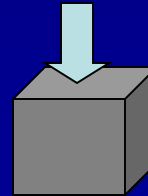
# Capacitor (Condenser) Mic

- 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
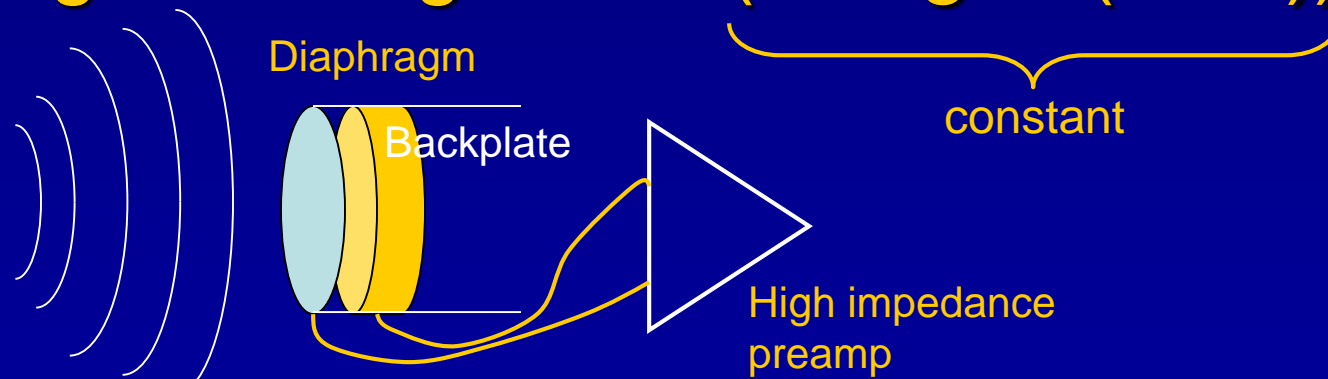
# Microphone Patterns

- 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
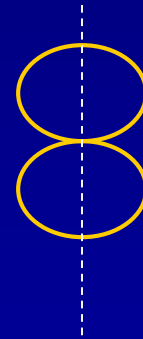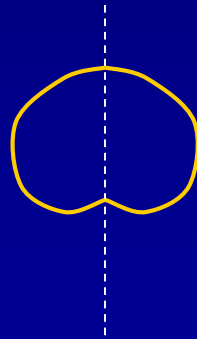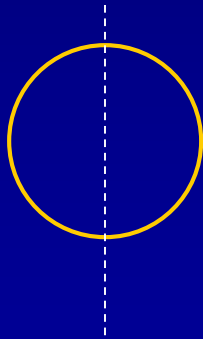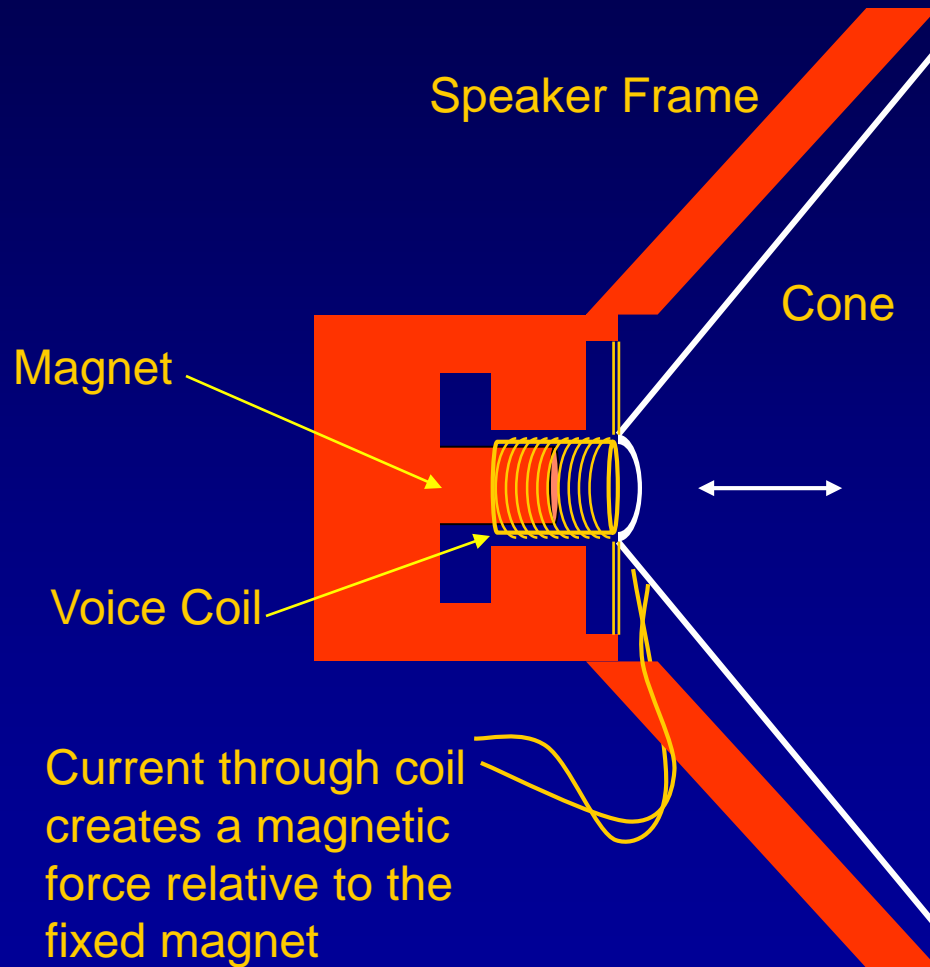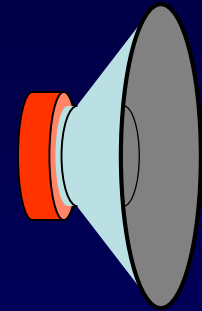
# Microphone Coloration

- 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:  Stereophile Microphone .wav

# 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
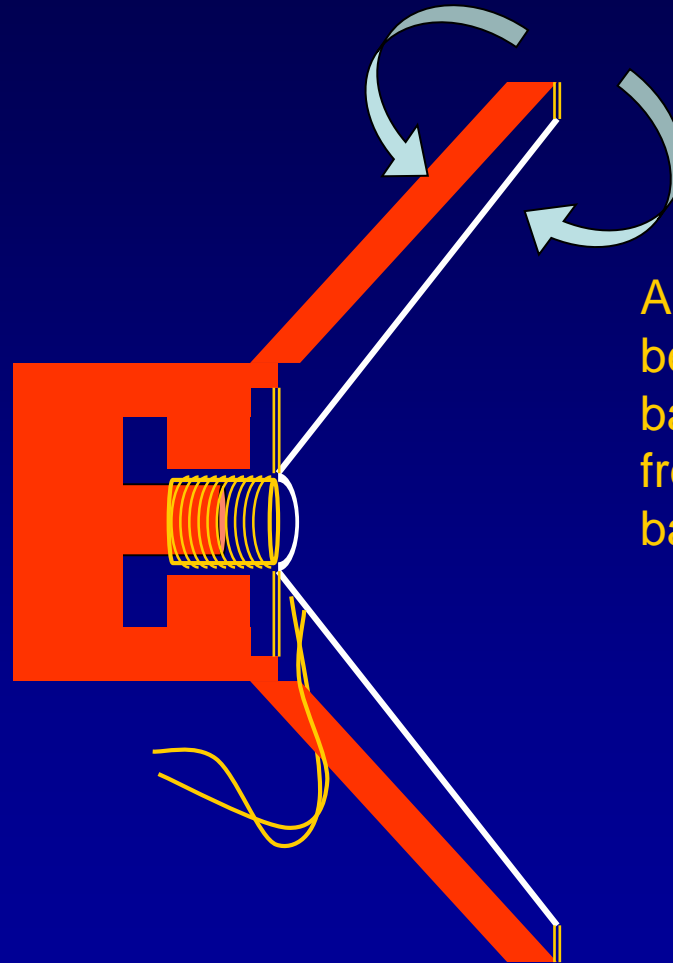


Air has time to "slosh" between front and back at low frequencies: poor bass response

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# Baffled Driver (flush mount)
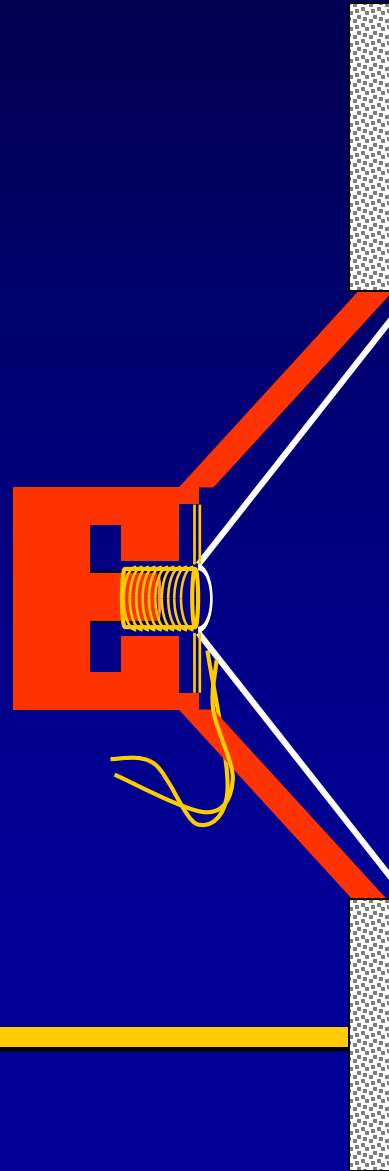
Baffle prevents front-back interaction:  improved low frequency performance

# 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

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# Acoustic Suspension



Sealed box acts as a stiff "air spring"

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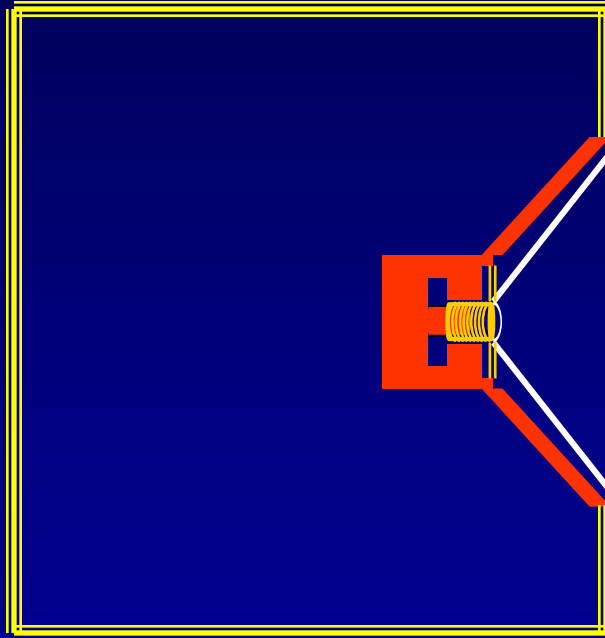
Relatively weak (compliant) cone suspension

Greatly reduced nonlinear distortion!

# 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.
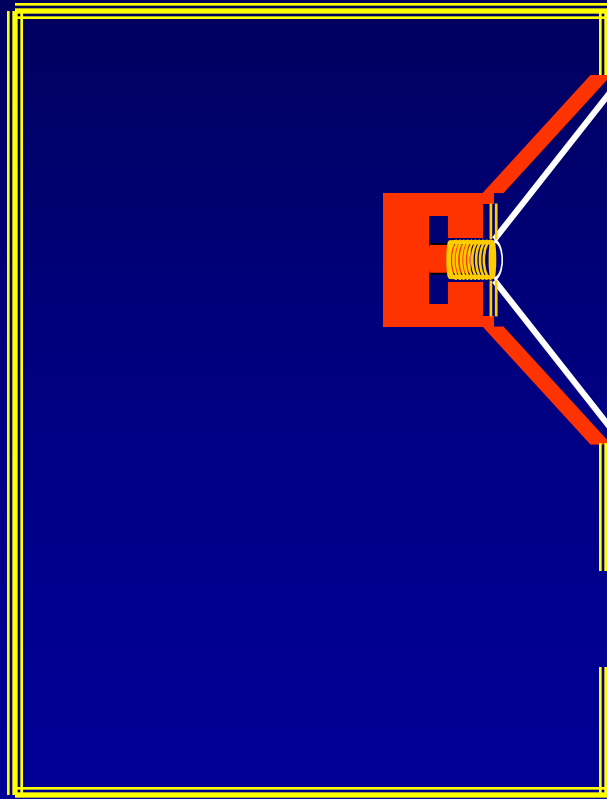


Driver acts as a direct radiator at frequencies above box resonance.

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

# 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

# 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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