POLITECNICO
MILANO 1863

Microphones

SENSOR SYSTEMS

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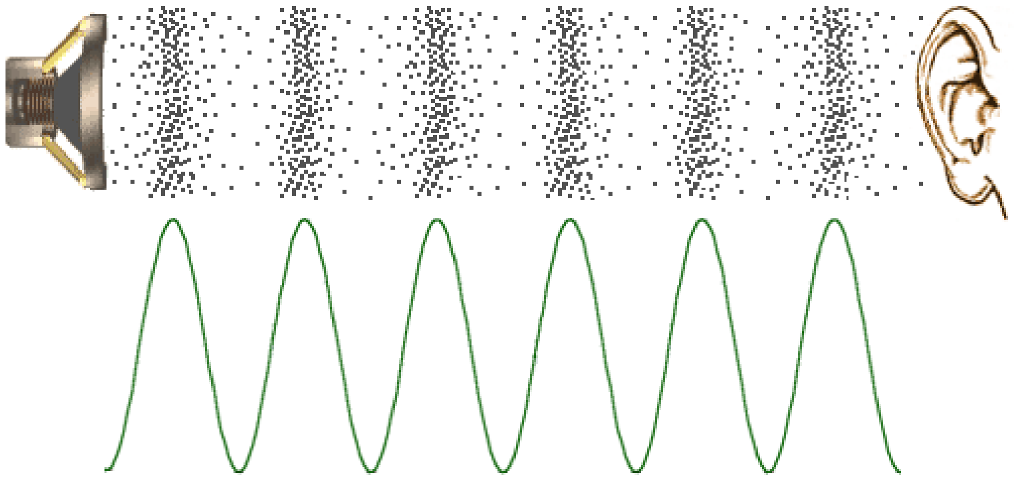
- Sound field quantities
- Microphones fundamentals
- Capsules: Dynamic and Condenser mic 2 ways of mics
- Phantom power Power supply to mic

sound = vibration that propagates as a typically audible mechanical wave of pressure and displacement, through a medium.

Sound is transmitted as longitudinal waves through gases and liquids

⇓

waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction



Vibration of medium particles

Position of air particles at rest

Position of air particles with sound

Particle displacement

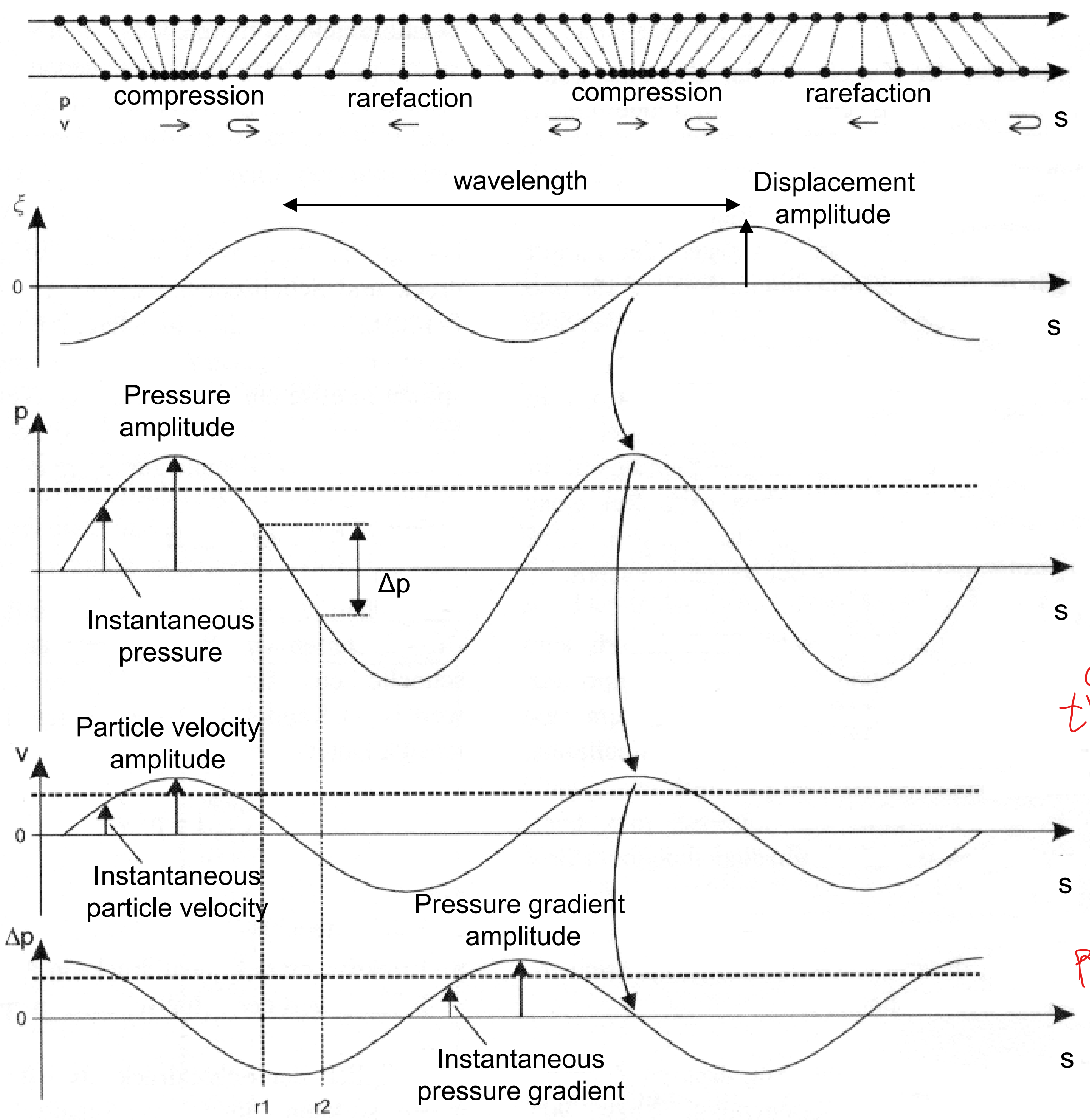
derivative

Particle pressure

derivative

Particle velocity

Pressure gradient



measured from the mic

depends on the type of mic

measured from mic

Relationships among quantities

$\therefore \xi(t) = \xi(\text{space})$

$\xi \sin(\omega t_0) = \xi \sin(\omega\, ms)$

Displacement amplitude: ξ

Particle velocity amplitude: $v = \omega \cdot \xi$

Pressure amplitude: $p = z \cdot v = \omega z \xi$

important because differ. mics measure particle pressure and

V=RI (equivalent)

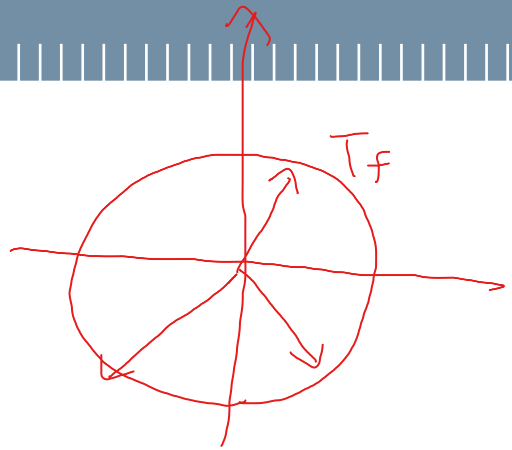
speed of sound

Specific acoustic impedance: $z = \rho \cdot c$ (in air at 20°C $z = 413 \frac{Ns}{m^3}$) specific for the medium

Angular frequency: $\omega = 2\pi f$

Sound speed: $c = \lambda \cdot f$ (in air at 20°C $c = 343 \frac{m}{s}$)

Intensity: $I = \frac{Power}{Area} = p \cdot v = \frac{p^2}{z} = zv^2 = z\xi^2\omega^2$



Microphones classification:

- Pressure transducers

  = respond to the pressure amplitude

  → omnidirectional → same sensitivity independent from direction

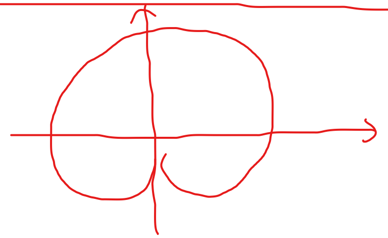
- Pressure gradient transducers

  Pressure gradient

  = respond to the sound pressure difference between two points (A and B)

  → directional pattern:

  - figure-8 characteristic
  - cardioid characteristic →
  - hyper-, super-, sub-cardioid characteristic

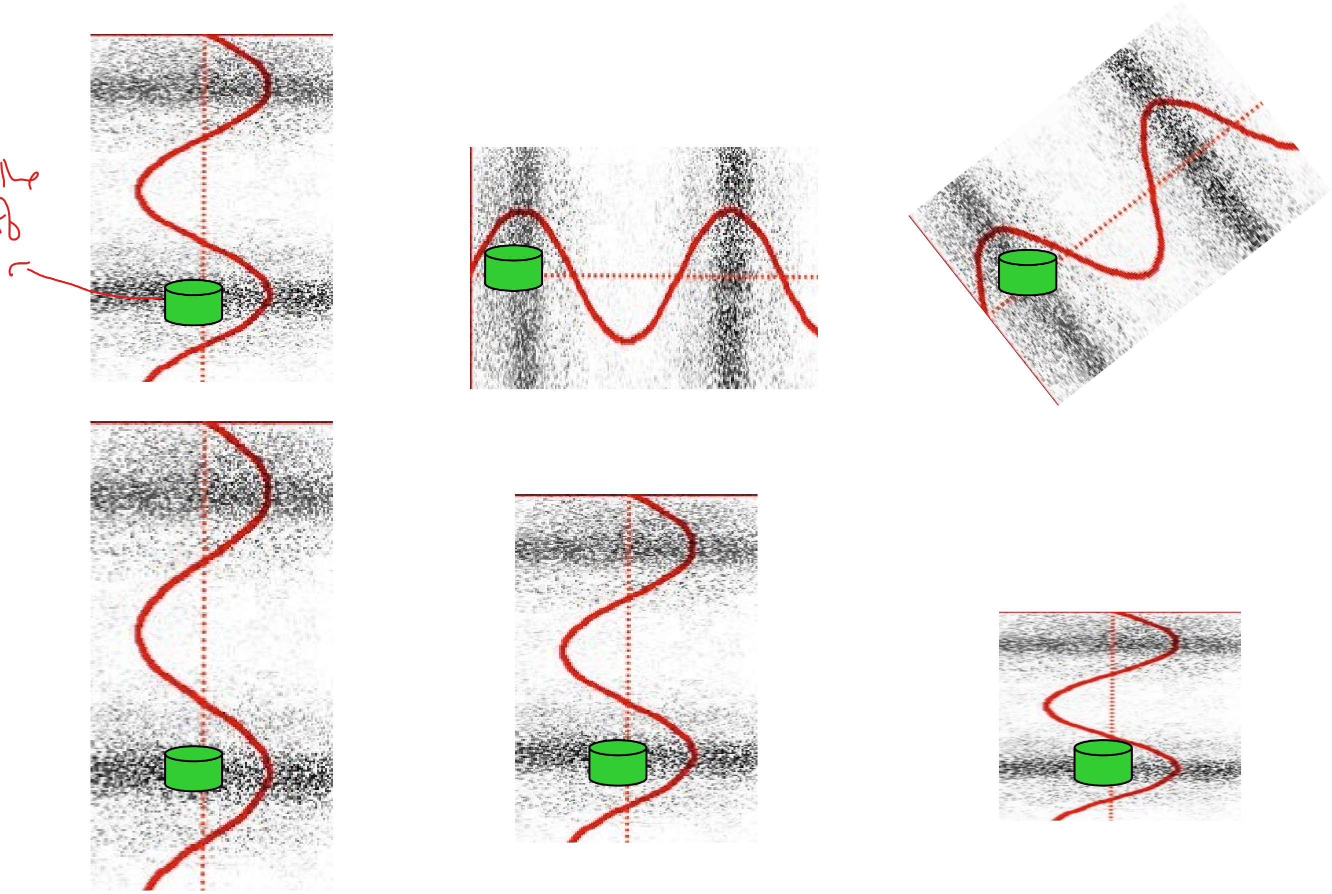


Field transmission factor (sensitivity): $\boxed{T_f = \frac{output\ voltage}{pressure\ amplitude\ (at\ the\ microphone)}}$ $\frac{\text{out}}{\text{in}}$

Only the front face is exposed to the sound field

→ the transducer responds equally to all sound pressure fluctuations occurring at its surface, regardless of the direction from which the sound waves emanate.

sensible element



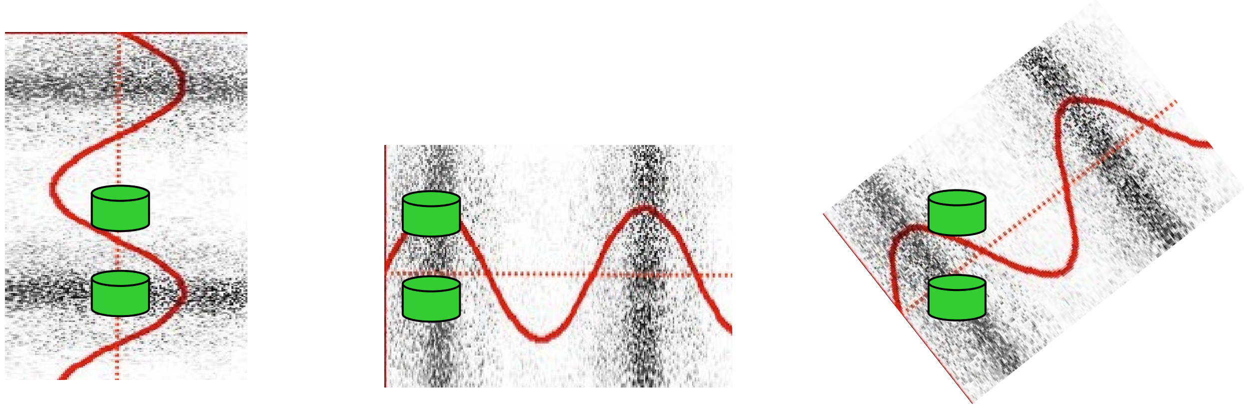
T_f independent from sound direction

T_f independent from sound frequency

Pressure gradient microphones

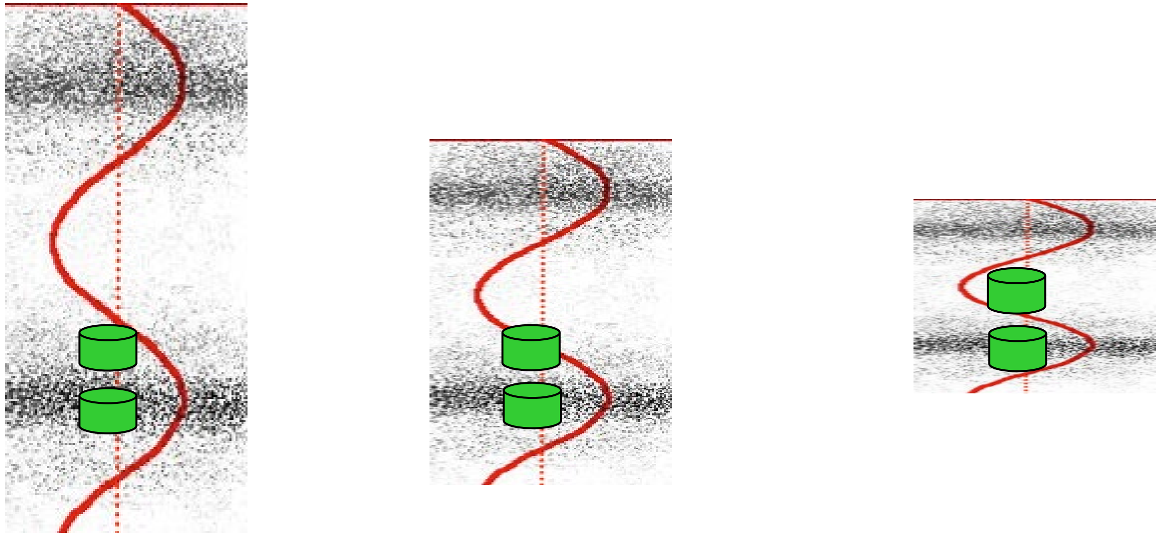
2 sensing point A and B

→ the transducer responds to the pressure difference between the two transducers



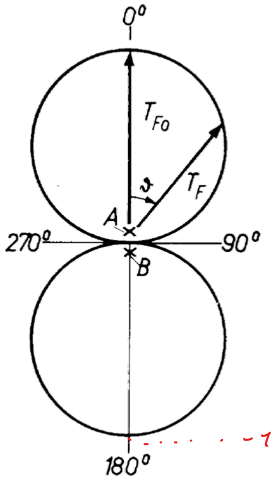
T_f dependent

from sound direction



T_f dependent

from sound frequency



pressure
=> gradient negative
exactly the opposite sinusoid of 0°

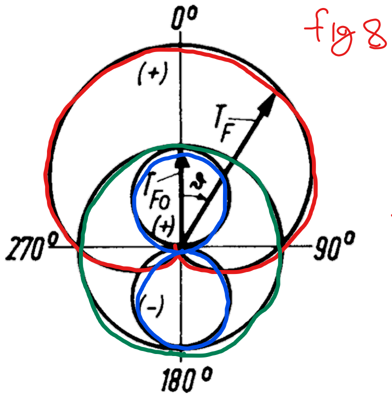
Figure-8

Transmission factor: $T_f = T_{f0} \cdot \cos\vartheta$

T_{f0} = transmission factor with sound arriving perpendicularly to the transducer

ϑ = angle between the perpendicular to the transducer and the direction of sound incidence

Omni(180) = T_f
fig8(180) = $-1 \cdot T_f$
⇓
0



$T_f = T_{f_0} + T_{f_0} \cdot \cos\vartheta$

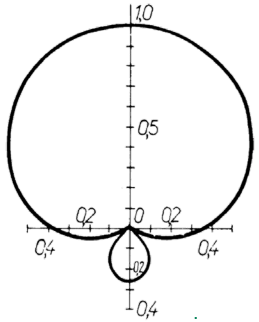
Cardiodic

Sum of Omni and Figure8

Transmission factor: $T_f = T_{f0} \cdot (1 + \cos\vartheta)$

depends on weight to sum the omni and fig-8

angle of incidence	sub-cardioid	cardioid	super-cardioid	hyper-cardioid	figure-8
90°	2.5 … 3.5 dB	6 dB	8,7 dB	12 dB	∞
180°	6 … 10 dB	∞	11,5 dB	6 dB	0 dB

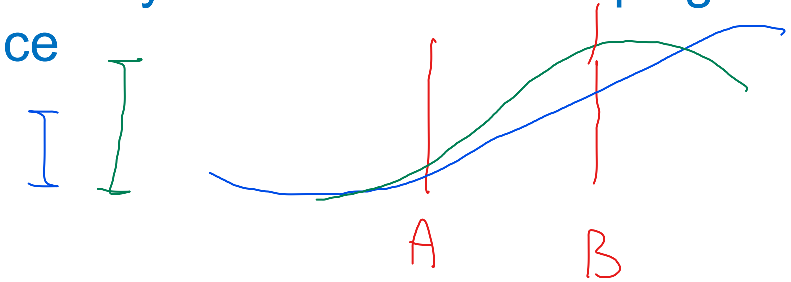


dependence on sound frequency

Hp: No decreasing of intensity

Plane sound field = each point of the field is characterized by the same pressure amplitude

→ pressure difference between points A and B occurs only because sound impinges on both points at equal strength but with a phase difference



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Pressure difference increases with rising frequency

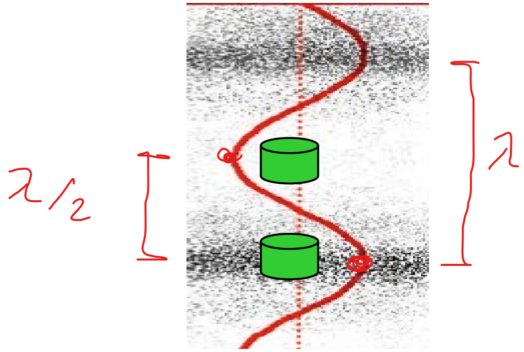
(pressure gradient represents a driving force which increases as the frequency rises)

→ max sensitivity of microphone

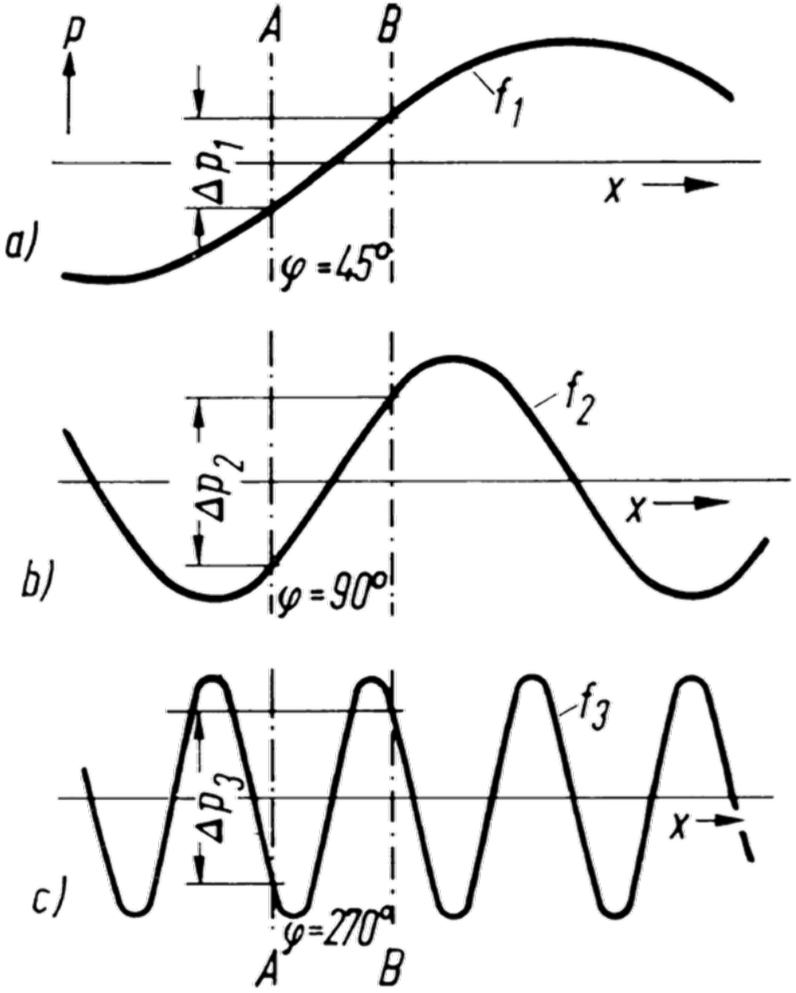
Transition frequency f_t is characteristic for each microphone type.

At frequency f_t: $\overline{AB} = {}^{\lambda}/_{2}$ ($\varphi = 180°$).

Above f_t the sound pressure difference Δp becomes smaller again.



Pressure gradient transducer



operating frequency only lesser than f_t

Transition frequency

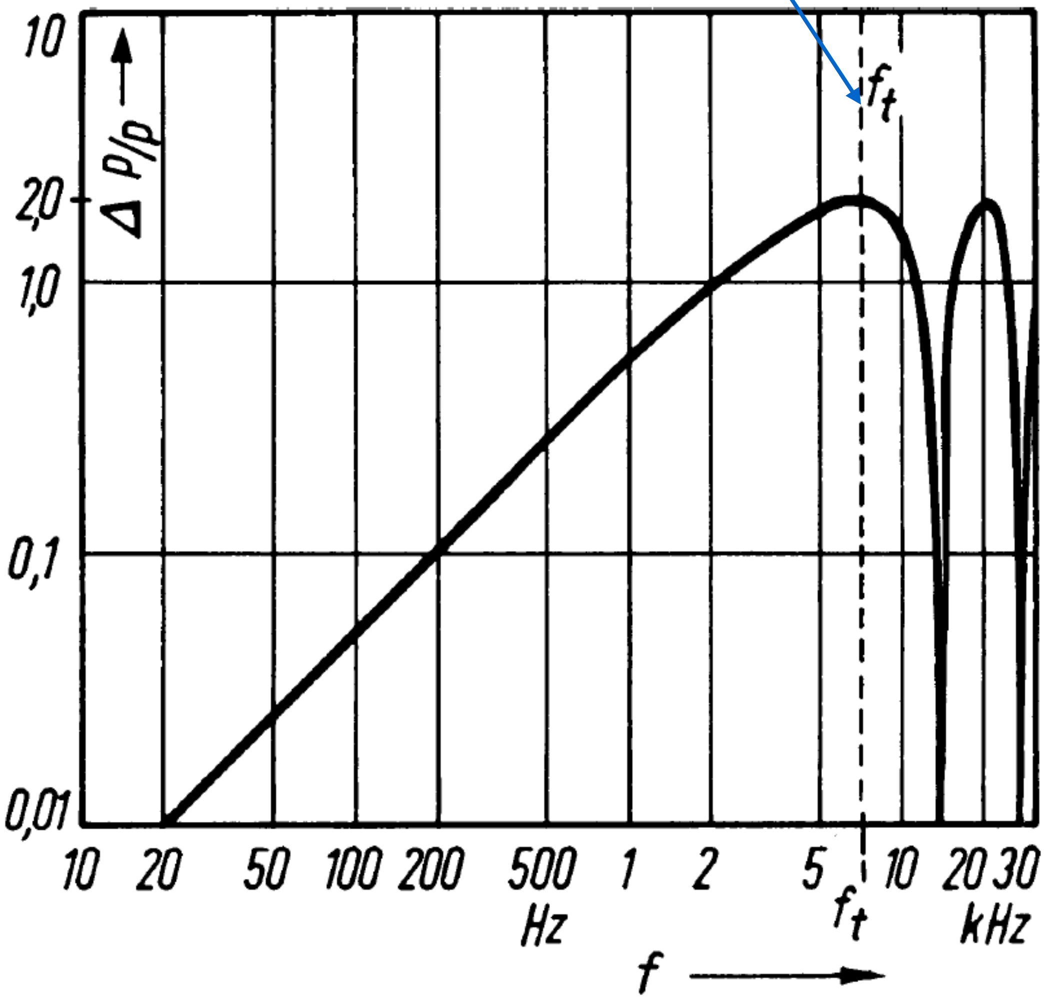
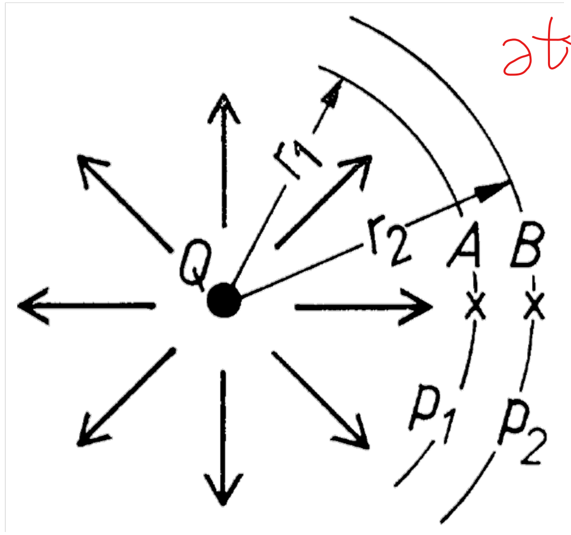
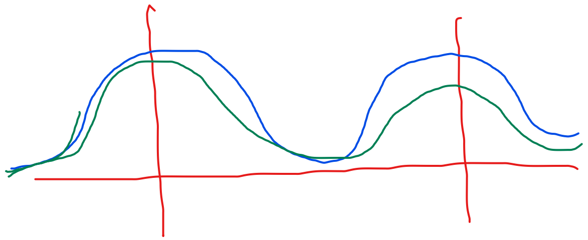


Figure-8 - spherical sound field



attenuates too

When a point source of sound is approached,
the sound pressure rises at a ratio of 1/r (r = distance)



- difference ≠ 0
- difference = 0

2 contributions to the output signal:

- phase-related Δp → frequency dependent → high frequency dominant
- distance-related Δp → frequency independent

most noticeable in the low frequency → sensitivity is very low, so contribution on phase shield not present(?)

→ pressure gradient microphones tend to boost low-frequency components when held close to the mouth
(i.e. when the distance r from the sound source is approximately equal to the length of the sound wave).

The low frequencies boost can be expressed by:

$$\frac{\text{fig 8}}{\text{omni}}$$

$$\frac{e_8}{e_0} = \frac{1}{\cos\alpha}\ , where\ \tan\alpha = \frac{\lambda}{2\pi r} = \frac{54.14}{f \cdot r}$$

$$\frac{e_8}{e_0} = \sqrt{1 + \left(\frac{54.14}{f \cdot r}\right)^2}$$ almost 0 if f or r are high

e_8 = output voltage of a pressure gradient mic with figure-8 characteristic

e_0 = output voltage of an omnidirectional mic with the same T_f at 0° in plane field

r = microphone distance from a point source of sound (in meters)

λ = wavelength (in meters)

f = frequency (in Hz)

→ At high frequencies or long distances the boost is negligible

→ At low frequencies AND short distances the boost is sensible

3 versions:

a. Two capsule (omnidirectional + figure-8) coupled together

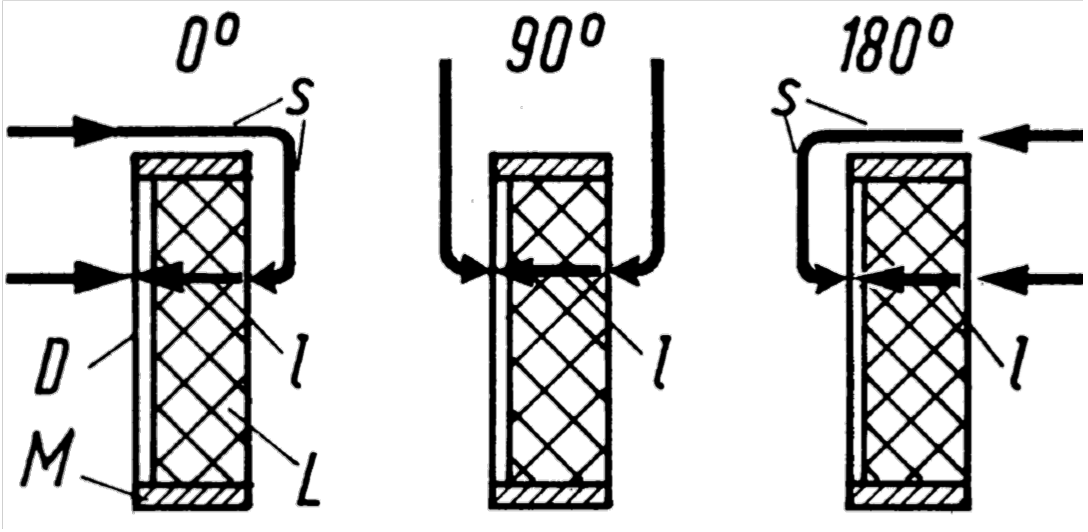
2 microphones in one

omnidirect figure8

b. One part of diaphragm has only its front face exposed to the sound field, while another part has both faces exposed to the sound field.

cardiod

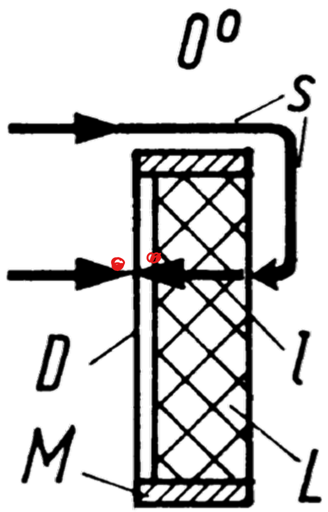
c. The sound arrives at the rear face of the diaphragm via an acoustic delay element (as an acoustic low-pass filter → delay & stop HF)

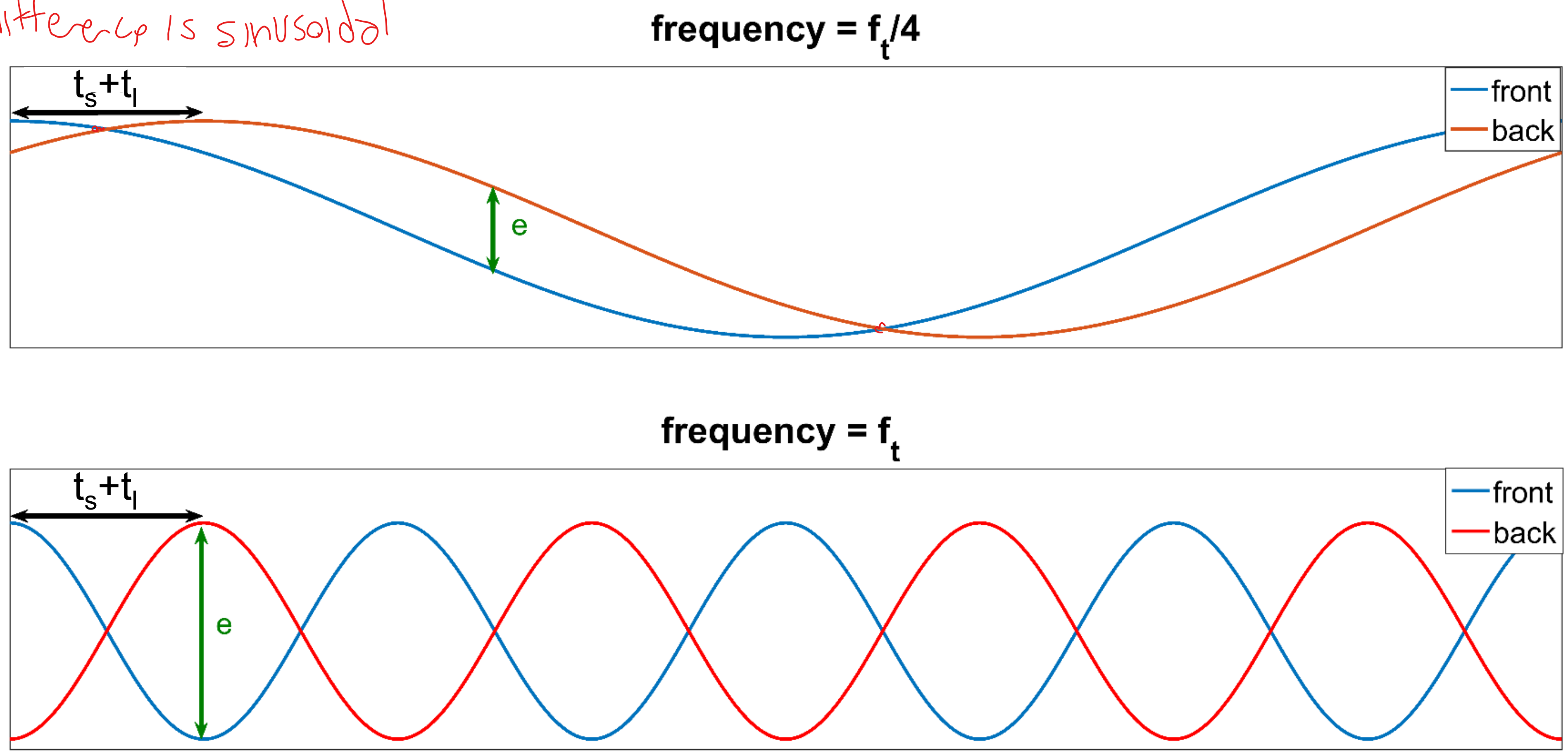


$t_s = t_l$

Sound from 0° → maximum T_f

difference is sinusoidal





$T = 2(t_{s}+t_{l})$

$$f_t = \frac{1}{2 \cdot (t_s + t_l)}$$

max sensitivity

Microphones with dimensions similar to or greater than the wavelengths being picked up present an obstacle for the sound waves

Frequency (Hz)	Wavelength (cm)
32	1050
320	105
3200	10.5
16,000	2.1

20Hz

up to

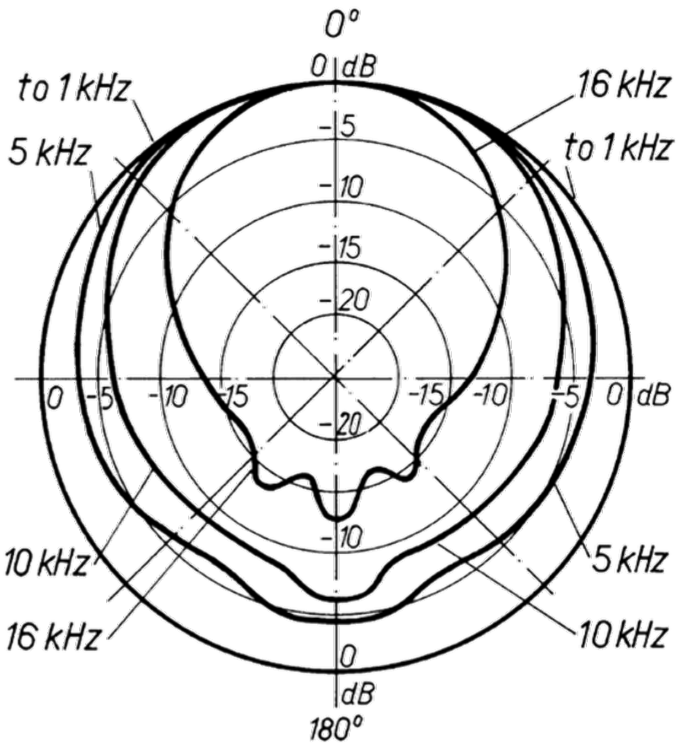
audible 20 MHz

All effects caused by the dimensions of the microphone are frequency-dependent.

→ Mic no larger than 6 mm in all three dimensions for a limit frequency of 16 kHz

- sound arriving perpendicularly to the diaphragm exerts more force on the diaphragm as the result of pressure build-up
- sound waves impinging diagonally do not strike all parts of the diaphragm simultaneously, giving rise to interference cancellations that are dependent on both direction and frequency (interference transducers)

up to 1kHz → ideal characteristic, for 5kHz hypercardiodic



at high frequencies omnidirectional characteristic gradually changes to a unidirectional polar pattern

↓

distortions in diffuse field

Type of capsules

course for MEMS

Capsule	Description
Condenser **Electrect**	Capacitive sensor with vibrating diaphragm
MEMS nope	Capacitive sensor integrated in MEMS technology
Dynamic – Moving coil	Electromagnetic induction (moving coil fastened to a diaphragm)
Dynamic – Ribbon	Electromagnetic induction (metal ribbon suspended in a magnetic field)
for ultrasound yes **Piezoelectric** nope	Piezoelectricity phenomena for measuring pressure
Carbon nope	Resistance variations

ξ displacement

inductance law → velocity

transfer function:
- mecanics (how's put in vibration)
- type microphone
  - pressure
  - difference of pressure
- measuring pressure or velocity? (captured
  - ξ
  - Velocity

pressure

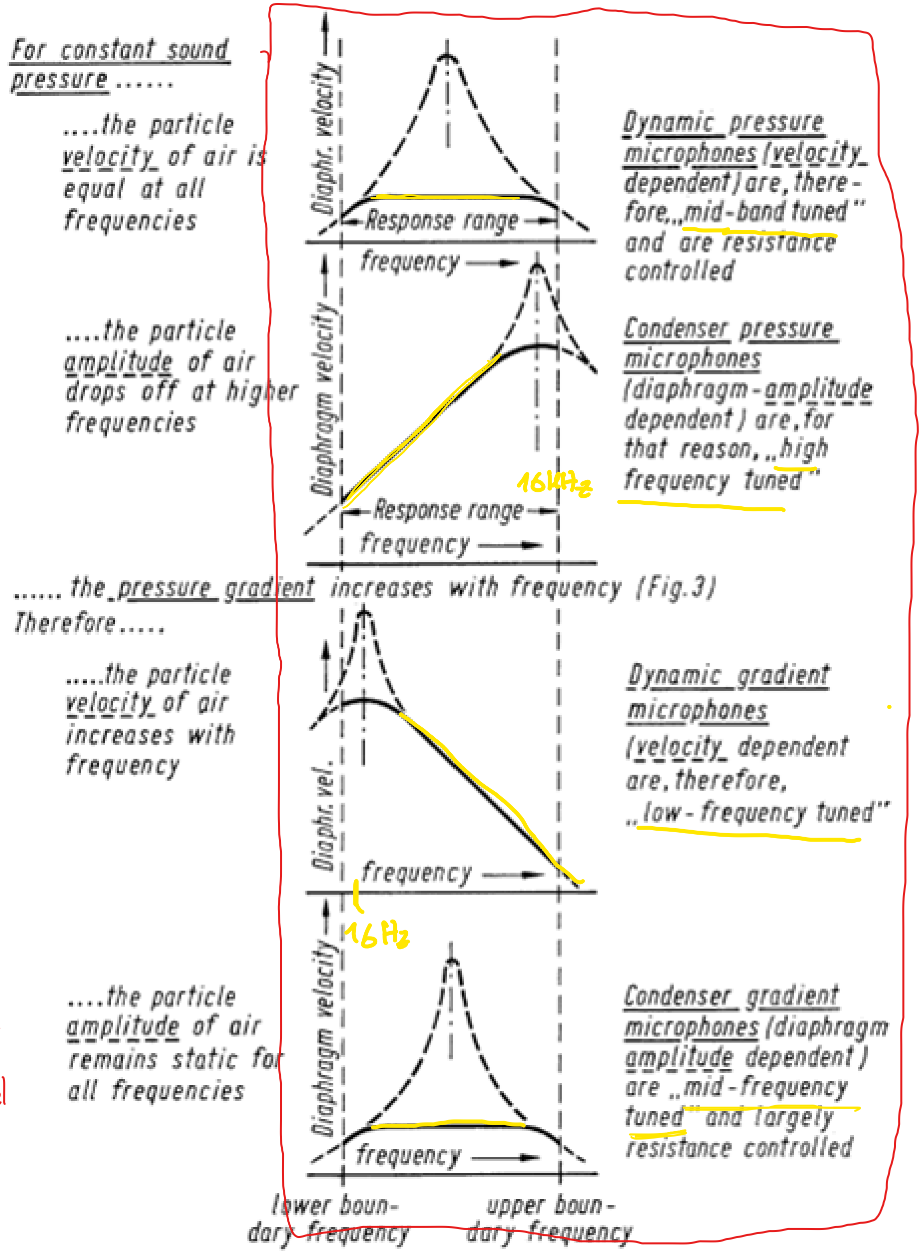
independent on frequency

from type of mic and capture we can understand how to want the mechanical:

→ Pag 11

pressure gradient

two transfer functions almost cancel each other



capture

Dynamic

$p = z \cdot v$ indip on freq

Condenser

$p = \underline{\omega} z \xi$

Dynamic

$p = z v$ indip on freq

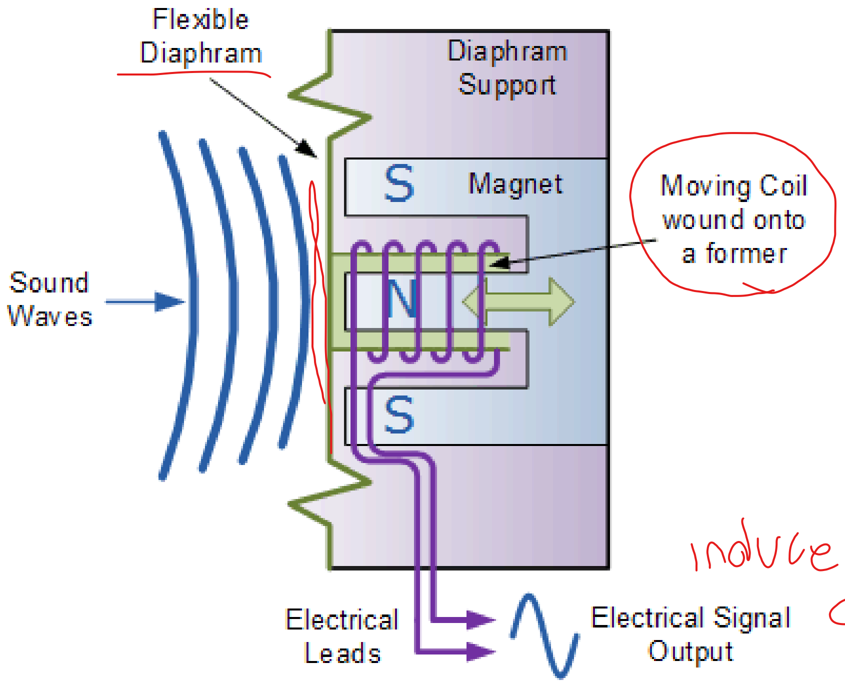
Condenser

$p = \underline{\omega} z \xi$

Dynamic microphones – Moving coil

Moving coil microphones have a small self-supporting coil that is fastened to a lightweight plastic diaphragm and moves in the air gap of a powerful permanent magnet.

→ A voltage proportional to the sound particle speed is induced at the coil terminals.



induce voltage across coil

particle velocity transducer:

$$v = \frac{p}{z}$$

derivative of the movement of coil

2 types of moving coils:

- pressure transducers (only front diaphragm)
- pressure gradient transducers (front and back diaphragm)

dinamic characteristic

mechanical → as flat as possible

For constant sound pressure the particle velocity is equal at all frequencies

→ «mid band tuned» with dumped resonance

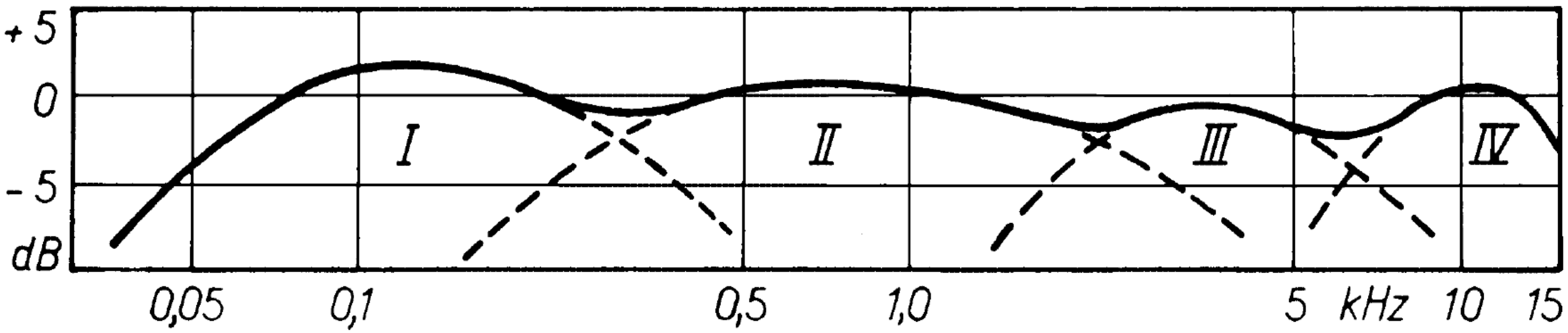
mass of diaphragm + coil
many times greater than diaphragm mass

↓

hard to dump resonance

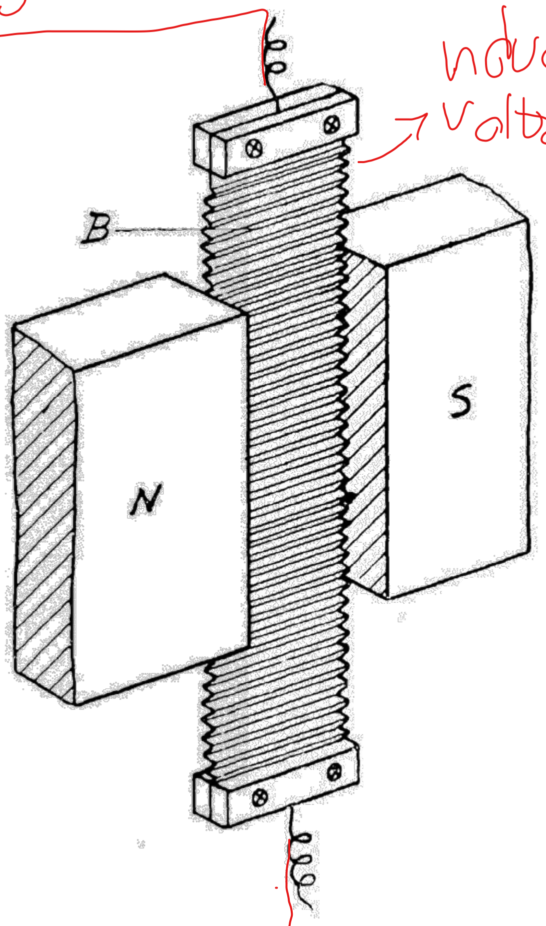
↓

additional resonances
with air cavities



In ribbon microphones, the sound field acts directly on the conductor, a strip of aluminum foil a few µm thick that is suspended so that it vibrates between the poles of a permanent magnet.
The foil is usually 2 to 4 mm wide and a few centimeters long.

no heavy coil

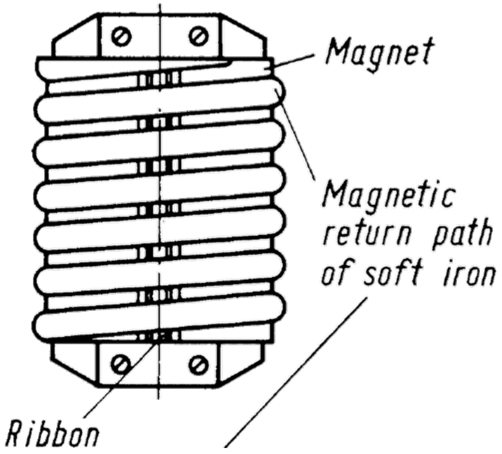


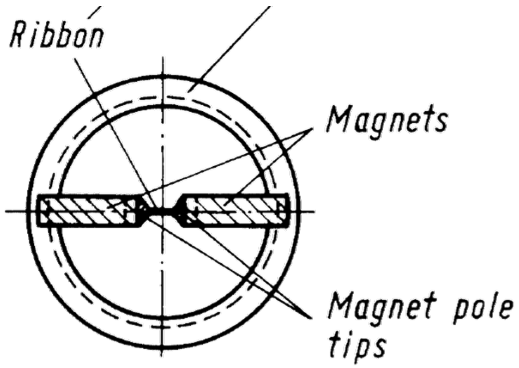
induced voltage

Just one coil!

Signal very low

- flat and resonance-free frequency response
- very low sensitivity → step-up transformer



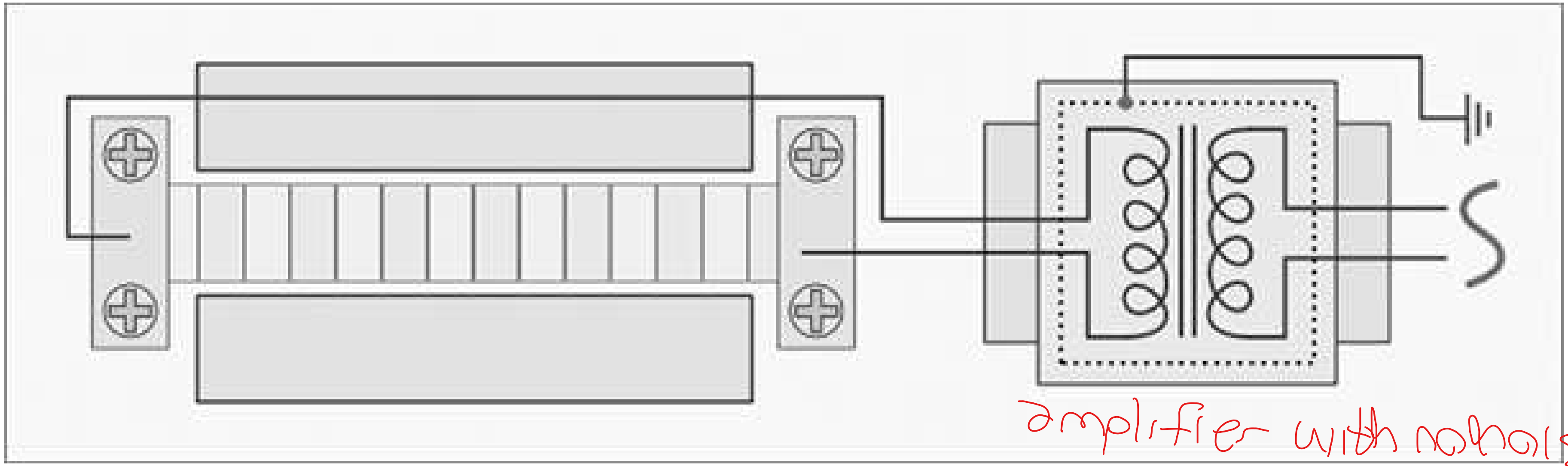


Dynamic microphones – Ribbon mic

Pro

Con

- flat and resonance-free frequency response
- very low sensitivity → step-up transformer



amplifier with no noise

Very low noise amplifier

Standard ratio → 1:37

- Figure-8
  → both front and rear sides of the ribbon exposed to sound

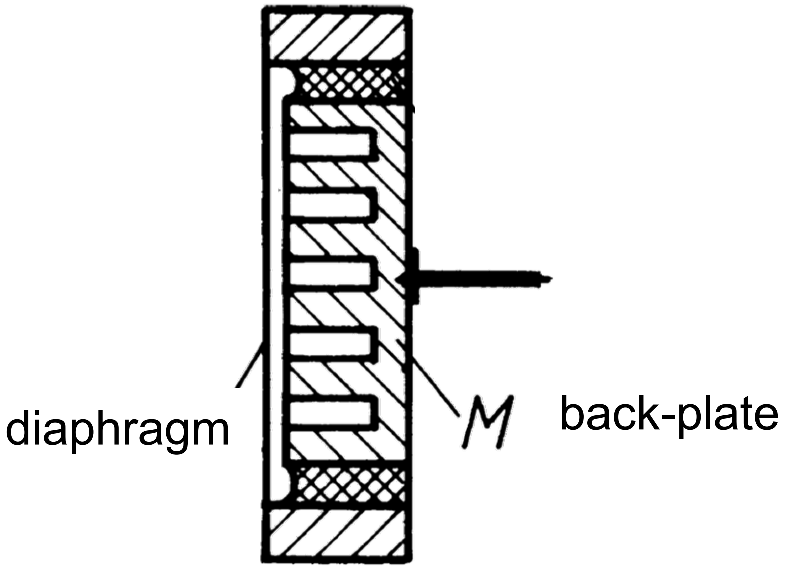
- Omnidirectional
  → only front side of the ribbon exposed to sound
  (rear portion terminated with acoustically absorptive material)

- Cardioid
  → only a portion of the ribbon is terminated at the rear,
  the remaining portion is exposed o sound on both sides

Basic construction:

- diaphragm with a thickness of 1÷10 µm made of metal or metallized plastic
- perforated, electrically conductive oppositely-charged electrode (backplate)

→ Impinging sound waves move the diaphragm and change its distance from the back-plate and thus the capacitance of the air-dielectric capacitor formed by the diaphragm and the back-plate.



particle displacement transducer:

$$\xi = \frac{v}{\omega} = \frac{p}{\omega \cdot z}$$

- Omnidirectional
  → only front side exposed to sound (pressure transducer)
  "high-tuned": diaphragm resonance at mic's upper cut-off frequency
  (in order to operate in the rising portion of the resonance curve)

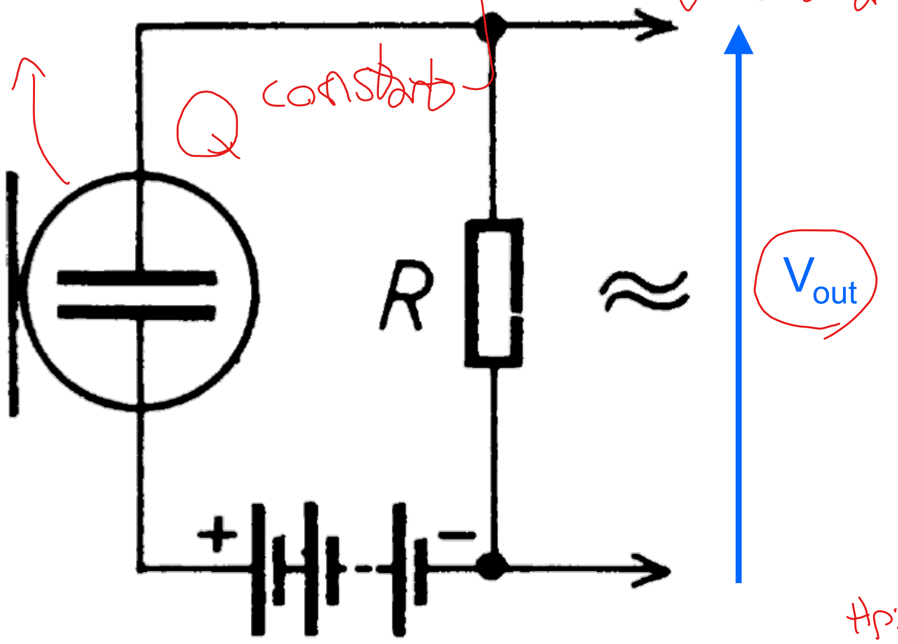
- Figure-8
  → both front and rear sides exposed to sound (pressure gradient)
  (back-plate is drilled all the way through)
  "mid-band tuned": pressure gradient and displacement relationship with pressure compensate each other

- Cardioid
  → a- only a portion of the back-plate is provided with through holes
  b- back-plate introduces time delay and low pass filter

capture of the microphone.

distance among plates varies with sound

if working with frequency higher than the pole (C_0R)



E_0 = 40 – 200 V

electrical biasing

C_0R

Capsule biased with constant Q in the frequency band:

$$f > \frac{1}{2\pi C_0 R}$$

C_0 = capsule capacitance (20pF-100pF)

R = typically > 100 MΩ (to have f^{min}=20Hz)

So capacitance doesn't have the time to charge/discharge

With sound pressure:

$$C = C_0 + c(t)$$

variation around C_0

Hp: $V_{out} << E_0$

$$V_{out}(t) = E_0 \frac{c(t)}{C_0}$$

with sound pressure → C changes

indeed: $Q_0 = C_0 E_0$ $\quad Q = C(E_0 - V_{out}(t))$

Hp: $Q_0 = Q \rightarrow C_0 E_0 = (C_0 + c(t))(E_0 - V_{out}(t))$

Electret mic – DC bias

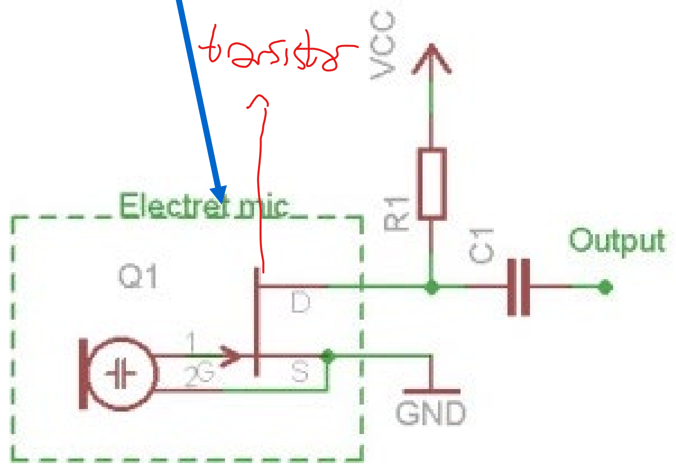
Permanently polarized foil membranes, using materials that can accept and maintain electrical charges (e.g., Teflon). Permanently polarized material

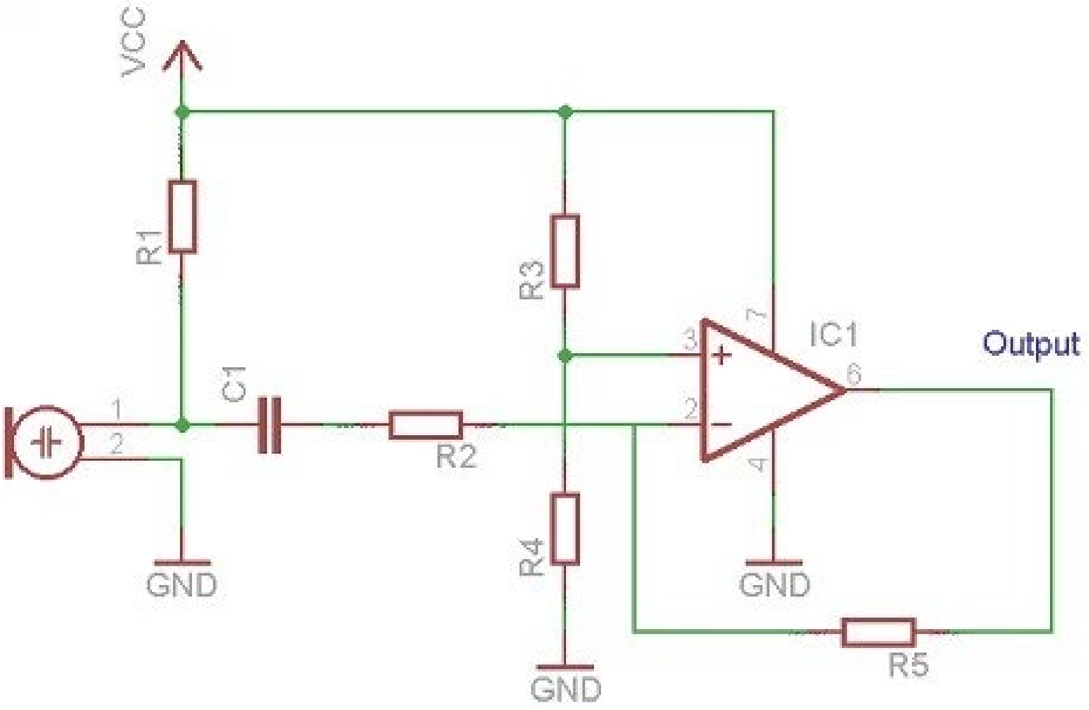
+ + + - + + +

To incorporate the negative charge carriers, the film is subjected to electron bombardment.

The foil is mounted on the surface of the back electrode, and the diaphragm can thus be realized using the standard materials

embedded preamplifier





Phantom power

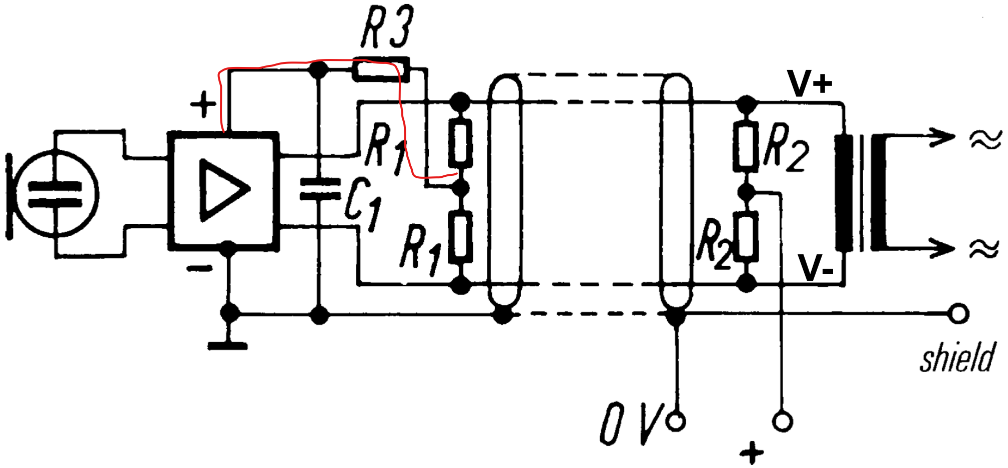
not in detail

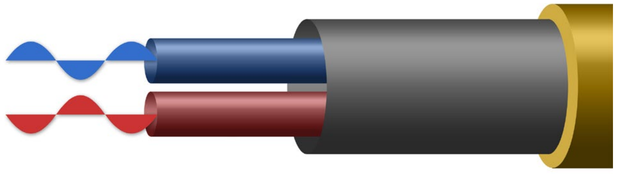
- used to bias condenser microphones
- it doesn't disturbs dynamic microphones
- typical voltages: 12V, 24V, 48V
- balanced cables

changing type of mic doesn't change

to bias condenser mics

XLR connectors





Balanced cables:

identical input and output impedances

Phantom power

- used to bias condenser microphones
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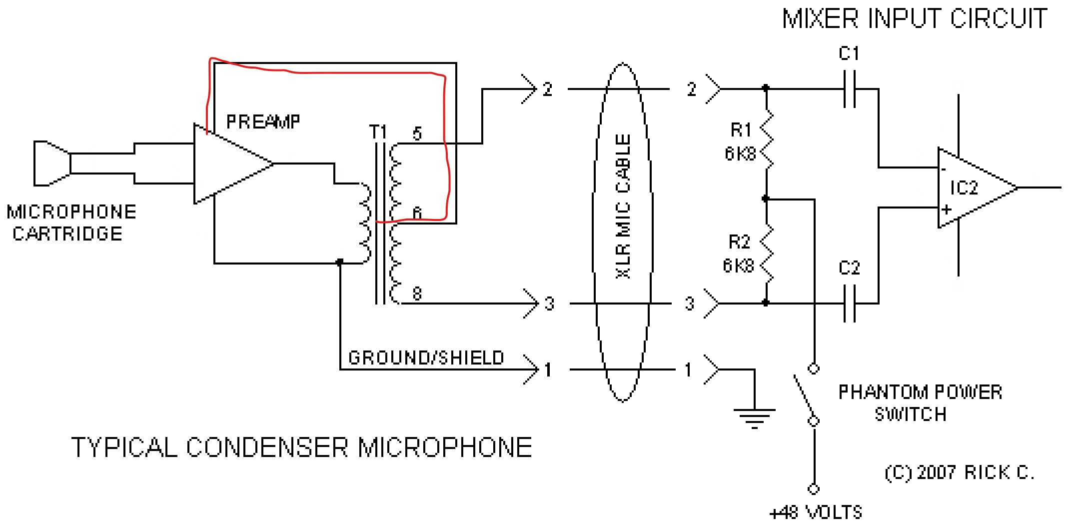
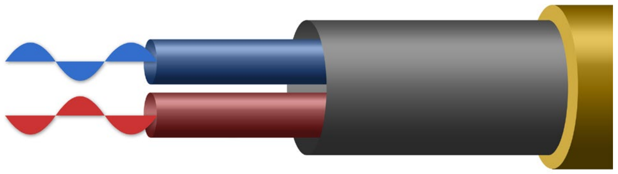
XLR connectors





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