Basic theory of sound, piezomaterials and vibrations

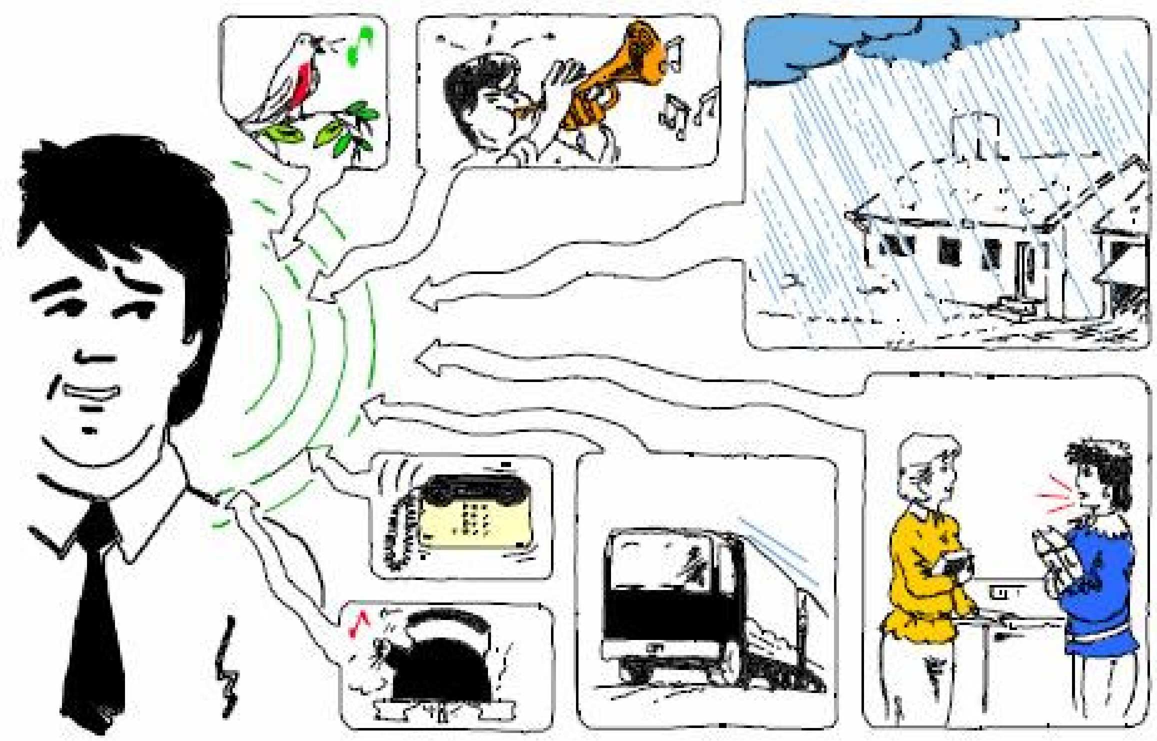
Content of presentation

- Theory of sound
- Piezomaterials and the piezoelectric effect
- Basic principles of the Sonitron products

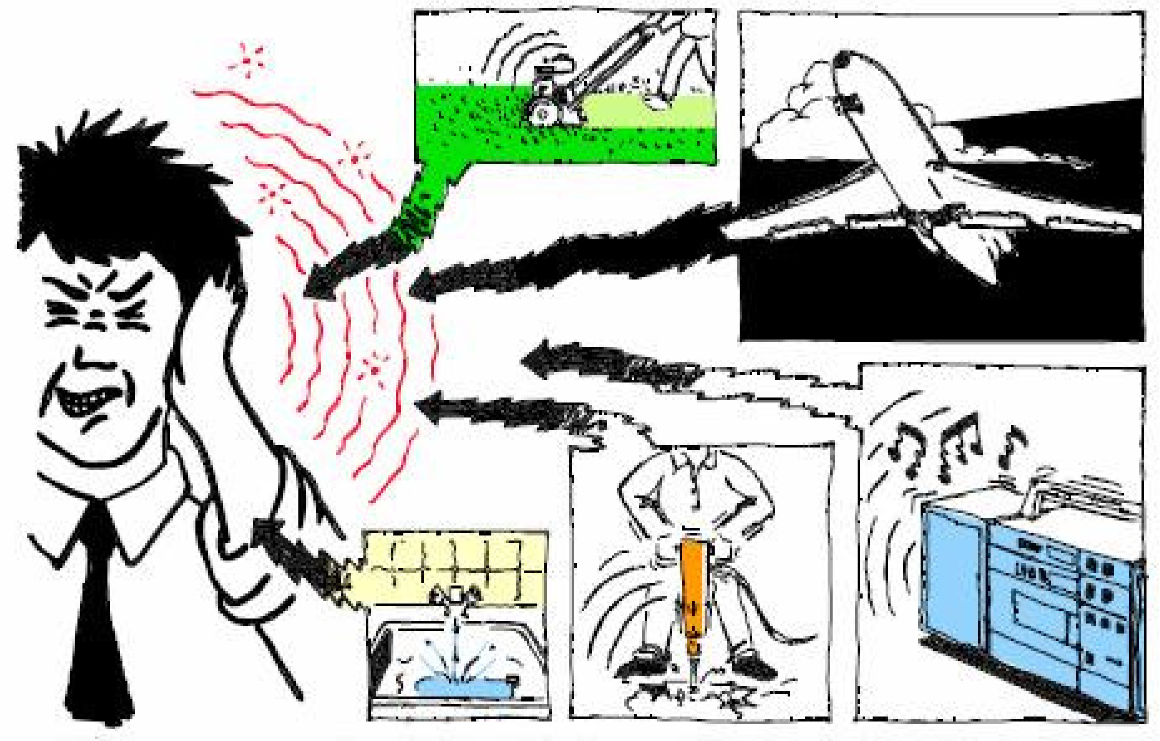
Theory of sound

Excellence in physical acoustics

Sound



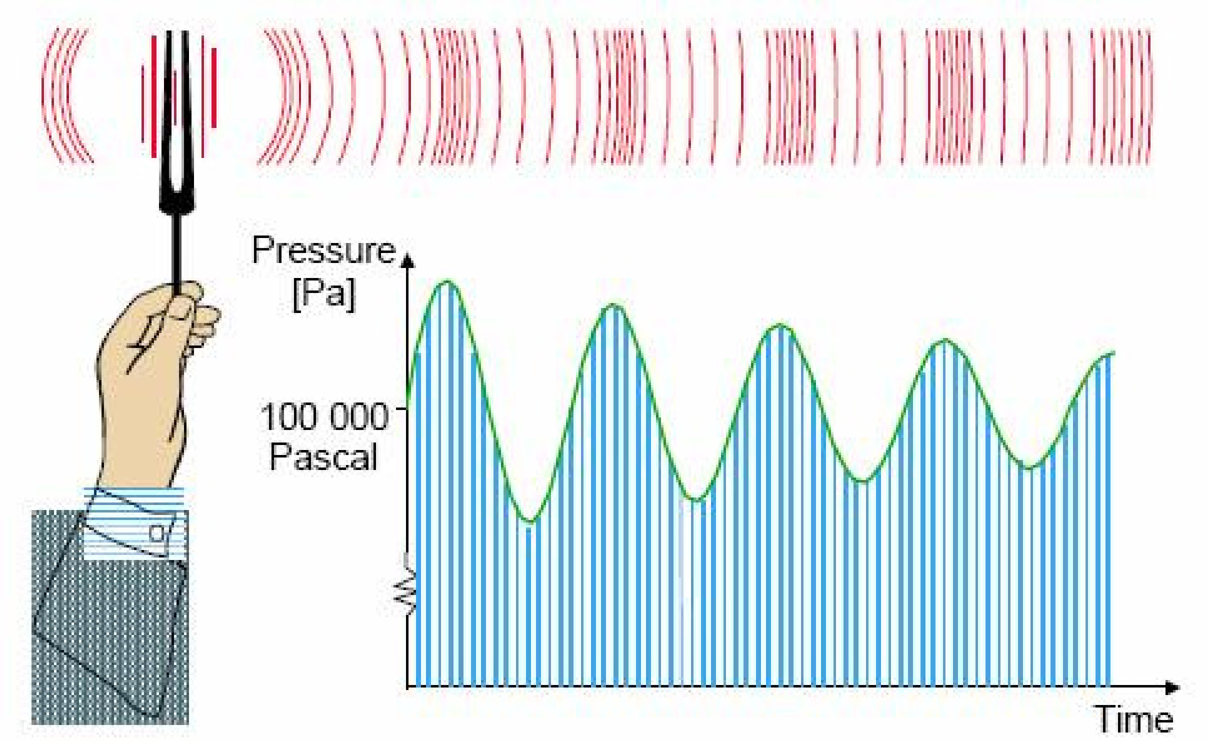
Noise



Definition

- **Sound** = the vibration of molecules around their balance position that can be detected by the human ear
- The vibrations cause variations in air pressure around the atmospheric pressure $\rightarrow$ sound propagates as a pressure wave

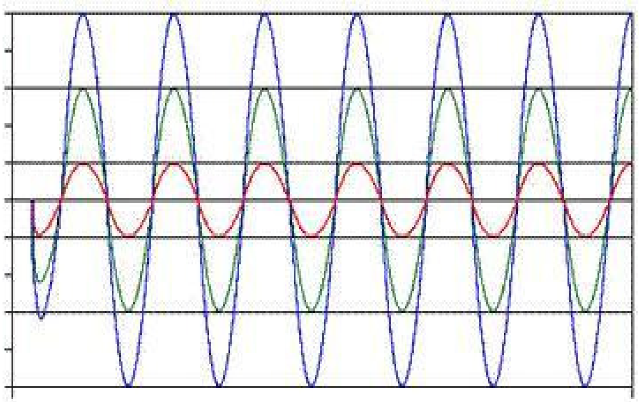
Definition

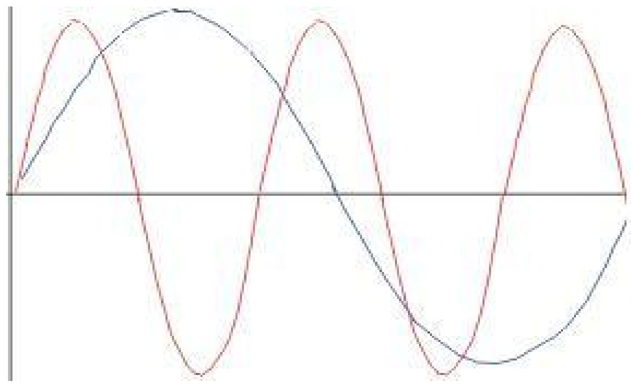


Theoretical aspects

- Pressure wave is characterized by:

  1. Amplitude
  2. Frequency

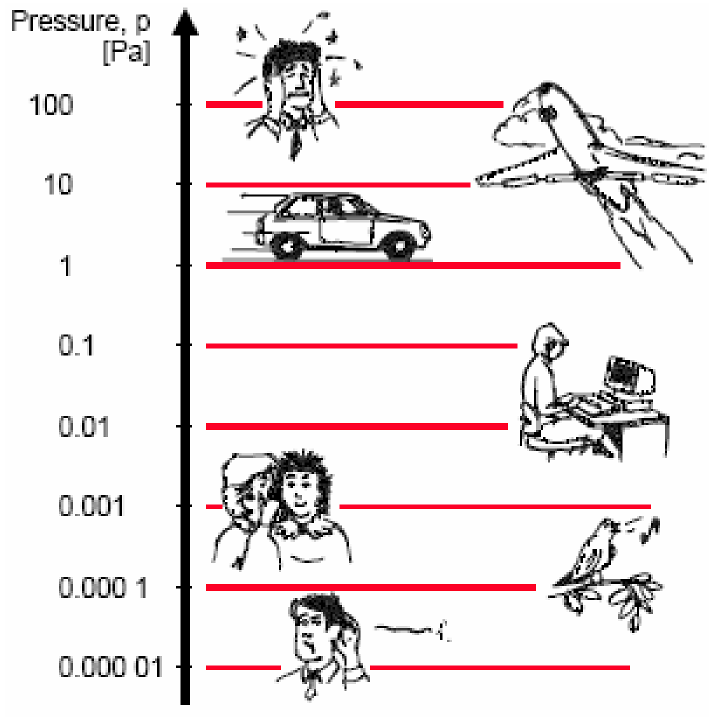




Amplitude

- Human ear:
  - Minimum pressure variation: 20 μPa
  - Maximum pressure variation: 200 Pa

    → **range = 10^7!!**
- Atmospheric pressure = 100 000Pa!!



Amplitude

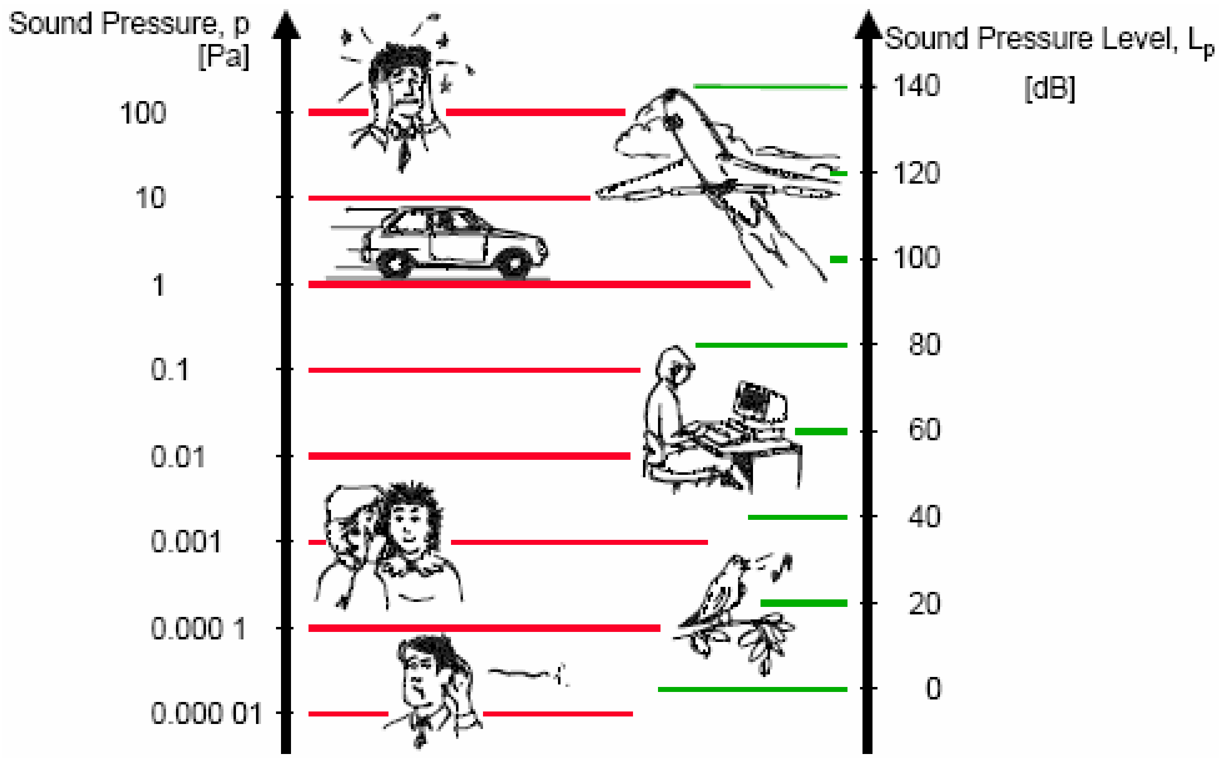
- Sound Pressure level (SPL):

$$SPL = 20 \log (p/p_0)$$ (expressed in **decibels = dB**)

with p_0 = 20 µPa (= threshold of hearing)

- Examples:
  - p = 20 µPa → SPL = 0 dB
  - p = 1 Pa → SPL = 94 dB
  - p = 200 Pa → SPL = 140 dB

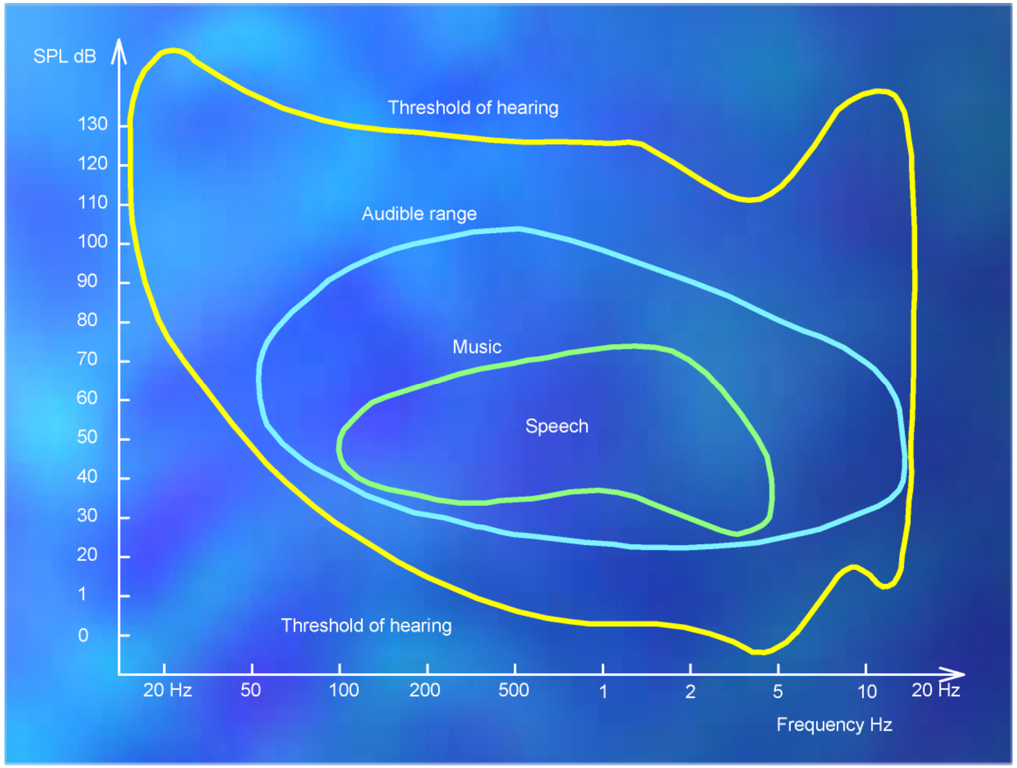
Amplitude (SPL)



Frequency

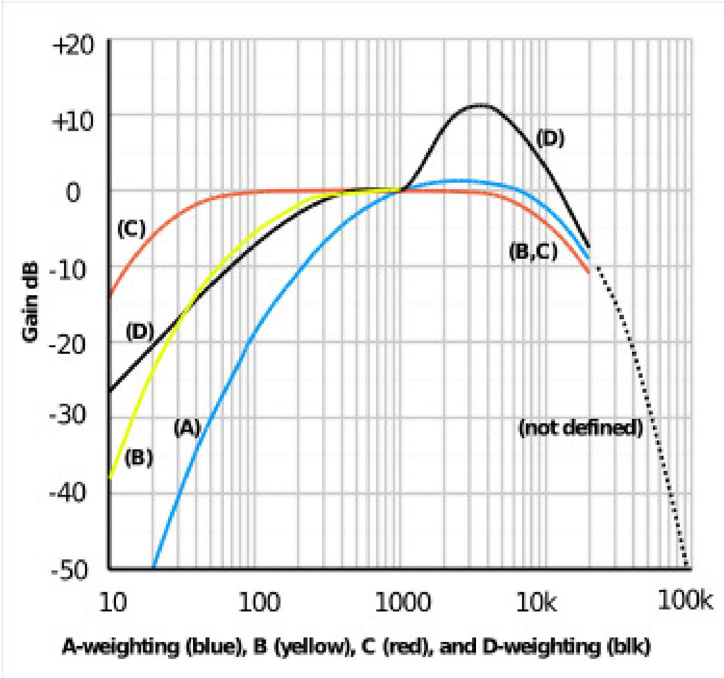
- Human ear:
  - Minimum frequency: 20 Hz
  - Maximum frequency: 20 000 Hz
- Sensitivity of the human ear is not constant:
  - Low sensitivity for the very low and high frequencies
  - Highest sensitivity between 2000Hz – 5000Hz (speech!)

Frequency


SPL dB
130
120
110
100
90
80
70
60
50
40
30
20
1
0
Threshold of hearing
Audible range
Music
Speech
Threshold of hearing
20 Hz
50
100
200
500
1
2
5
10
20 Hz
Frequency Hz

Frequency

- Weighting curves are used to evaluate the SPL like it is perceived by the human ear.
- 4 weighting curves exist (A, B, C and D filter)
- Most commonly used: A-filter. Measurements are given in dB(A) to indicate the weighting.



Perception of sound

Change in Sound Level (dB)	Change in Perceived Loudness
3	Just perceptible
5	Noticeable difference
10	Twice (or 1/2) as loud
15	Large change
20	Four times (or 1/4) as loud

Calculating with SPL

- Addition of SPL's

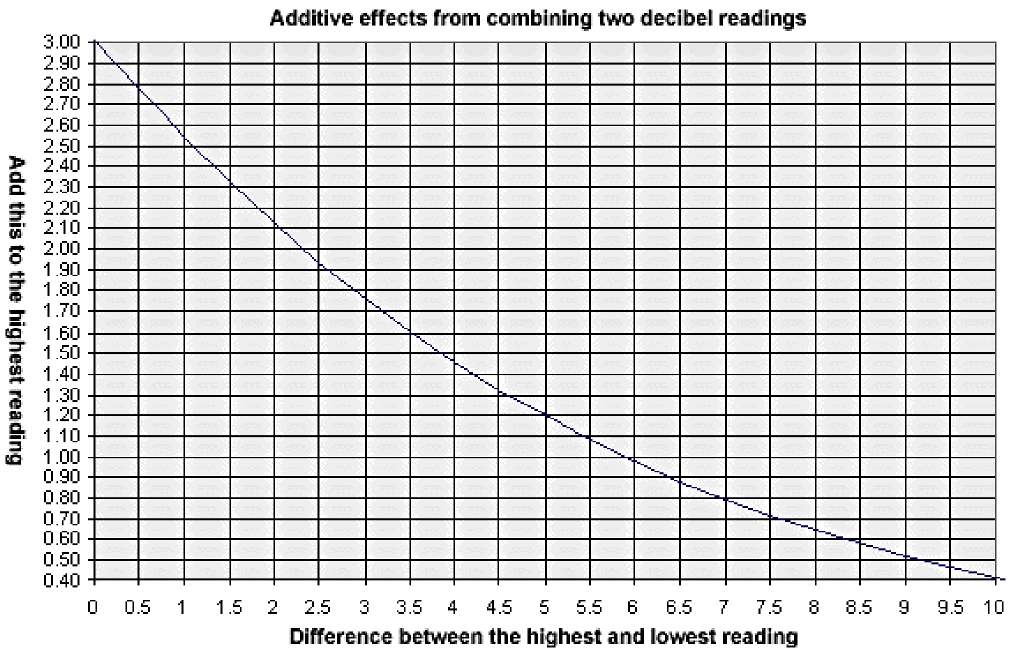
  Logarithmic values can NOT be added like linear values. Two methods can be applied for the addition of SPL's:

  1. Converting the dB values to linear values (Pa):

$$SPL_{total} = 10.\log (10^{SPL1/10} + 10^{SPL2/10} + \ldots)$$

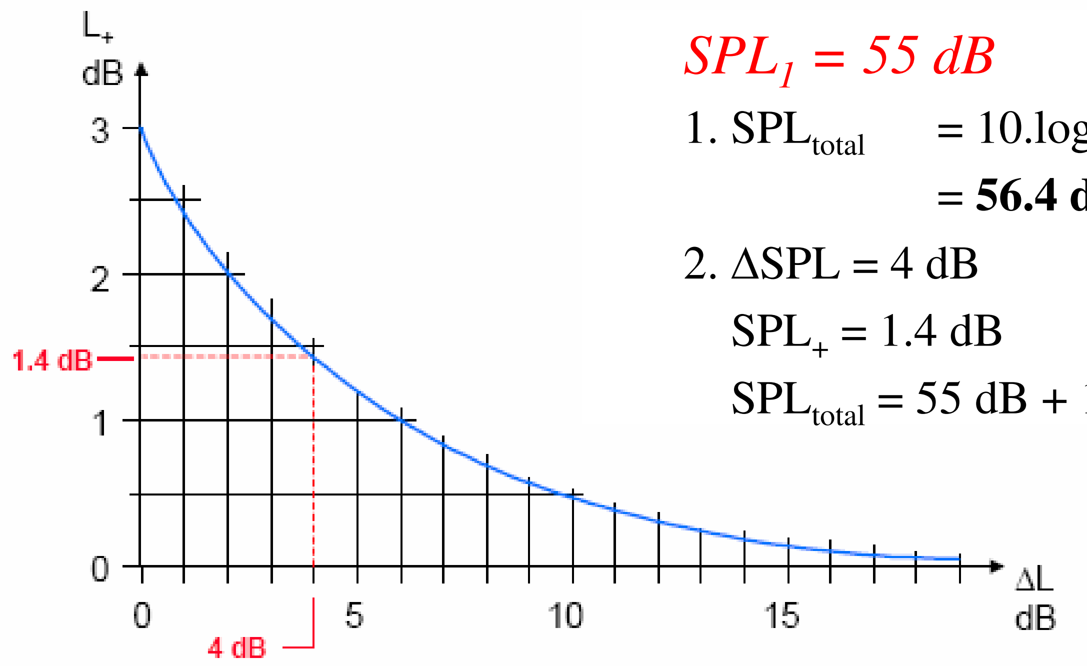
Calculating with SPL

2. Using graphs



Calculating with SPL

3. Examples:



$SPL_1 = 55\ dB$ *$SPL_2 = 51\ dB$*

1. $SPL_{total} = 10.\log(10^{55/10} + 10^{51/10})$
   $= \mathbf{56.4\ dB}$
2. $\Delta SPL = 4$ dB
   $SPL_{+} = 1.4$ dB
   $SPL_{total} = 55$ dB + 1.4 dB = **56.4 dB**

Calculating with SPL

- Conversions of specified SPL's:
  - Converting the specified distance:

$$\Delta SPL = 20.\log (r_1 / r_2)$$

with: r_1 = distance at which the SPL is given

r_2 = distance at which you want to know the SPL

Calculating with SPL

– Converting the specified voltage:

$$\Delta SPL = 20.\log (V_2 / V_1)$$

with: V_1 = voltage at which the SPL is given

V_2 = voltage at which you want to know the SPL

Calculating with SPL

– Example: SPL = **90 dB** @ 24V @ 1m

$\rightarrow$ *SPL @ 12V @ 0.3m ?*

$\Delta SPL_{distance} = 20.\log(1 / 0.3) = +\ 10.45\ dB$

$\Delta SPL_{voltage} = 20.\log(12 / 24) = -\ 6\ dB$

$\rightarrow$ *SPL @ 12V @ 0.3m:*

90 dB + 10.45 dB – 6 dB = **94.45 dB**

Piezomaterials and the piezoelectric effect

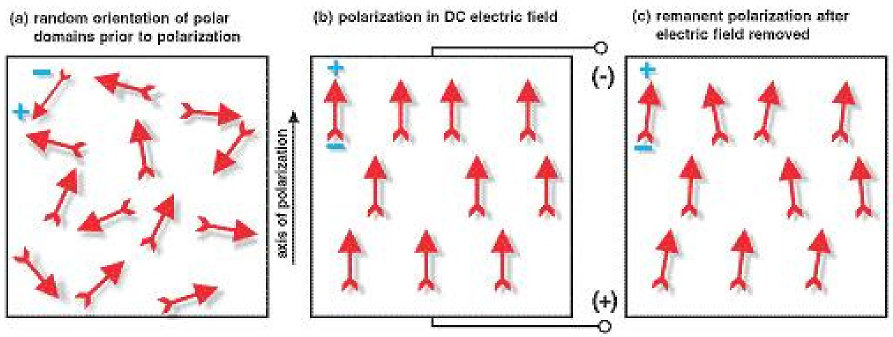
Definition

- Discovered in 1880 by Jacques and Pierre Curie

- **Piezoelectricity** is the phenomenon in which materials develop an electric field when subjected to pressure/force, or conversely, exhibit a mechanical deformation when subjected to an electric field.

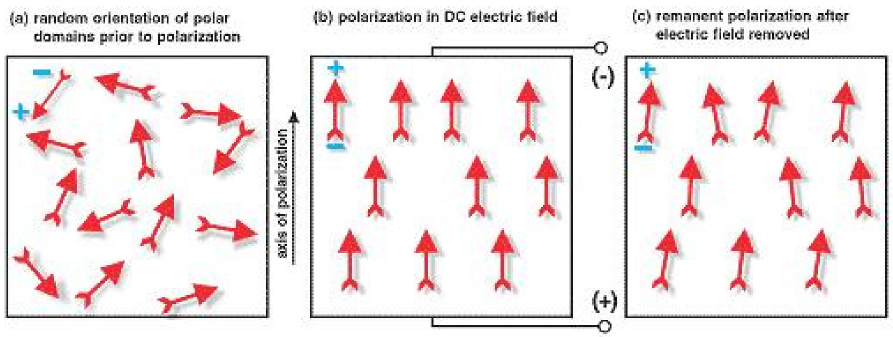
Piezomaterial

- Piezoceramic = mass of perovskite crystals
- Each crystal has a dipole moment (polarization) randomly oriented so the ceramic element has no overall polarization → NO PIEZOELECTRIC EFFECT



Piezomaterial

- Apply a strong DC field (> 2000V/mm) to induce piezoelectric properties
- The crystals will align and roughly stay in alignment → remanent polarisation



Piezomaterial

- Natural piezoelectric materials:
  - Quartz
  - Tourmaline
  - …

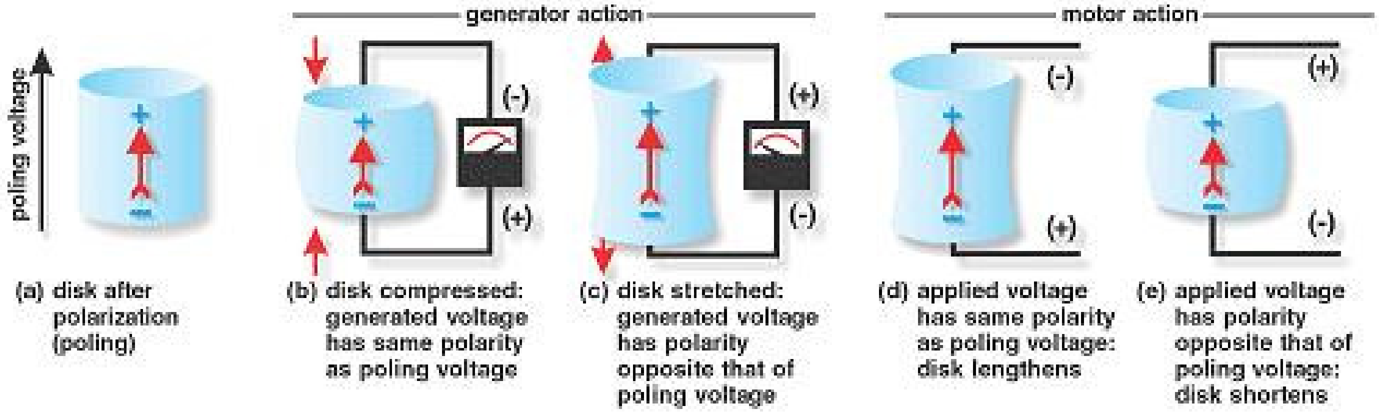
  → **Small piezoelectric effect!**

- Synthetic piezoelectric materials:
  - $BaTiO_3$
  - Lead Zirconate Titanate (PZT)
  - …

  (General formula ABO_3 where A and B are metals and O stands for oxigen)

  → **Large piezoelectric effect!**

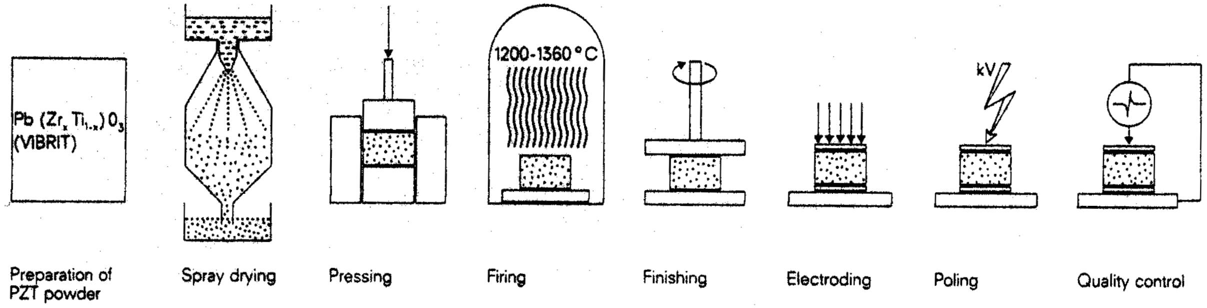
Piezoelectric effect



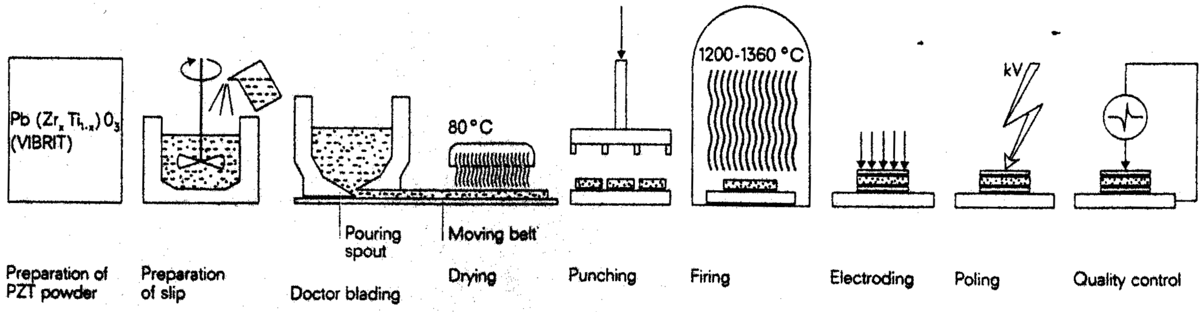
- Direct effect: sensors (pressure/crash/accelaration), gas lighter, power supply (shoe-mounted piezoelectrics), …
- Converse effect: acoustic components, micro engine, actuator (inkjet printer/ diesel injection system), micropump, positioning system, …

Manufacturing technology

1. Pressing



2. Tape casting



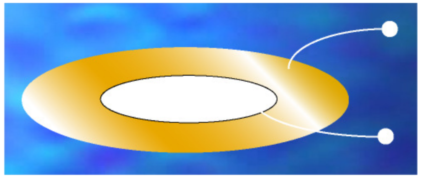
Problems during manufacturing

- Purity and particle size of the oxide powders
- Weight ratio of the oxide powders
- Type and quantity of the binder
- Firing method
- Cooling method after sintering
- Pitfalls
- Poling of the ceramic
- …

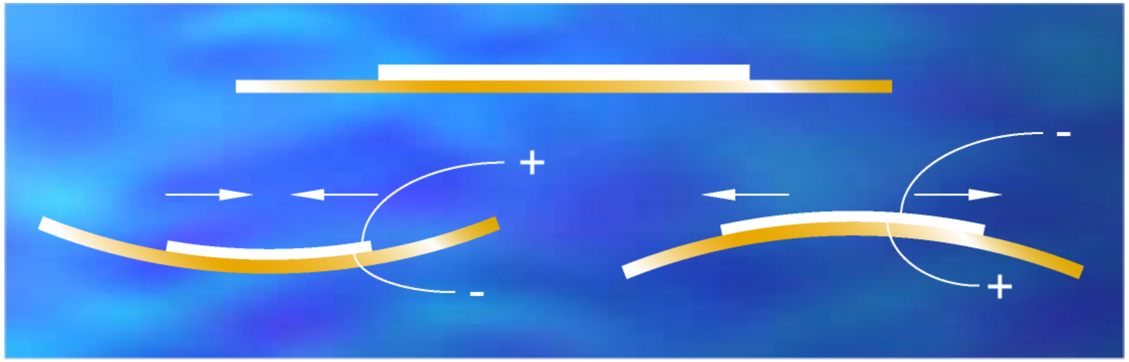
Basic principles of the Sonitron products

Piezoelectric acoustic components

- Piezoceramic disc glued onto metal or composite membrane:



- Alternating electric field: membrane vibrates = variations in air pressure → sound



Mounting methods and mechanical vibrations

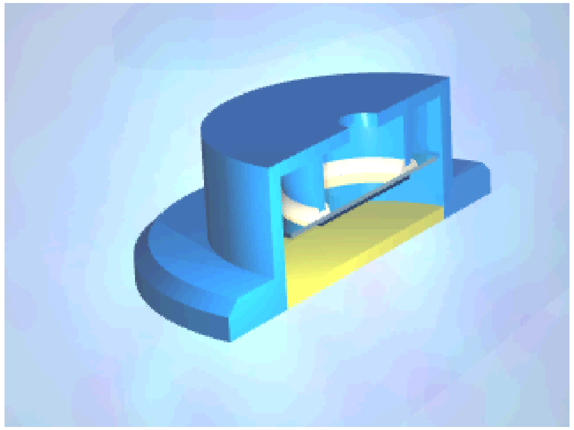
- Nodal support:
  - Vibration of a free strip is a standing wave in which the maximum amplitude (belts) occurs at both ends and in the middle.
  - The position of these nodes is governed by the energy balance, the total energy inside the nodes is at each moment equal to the total energy outside the nodes.
  - In this case, displacements are at maximum because the strip is in a free natural resonance, without extern boundary conditions that can limit this movement.

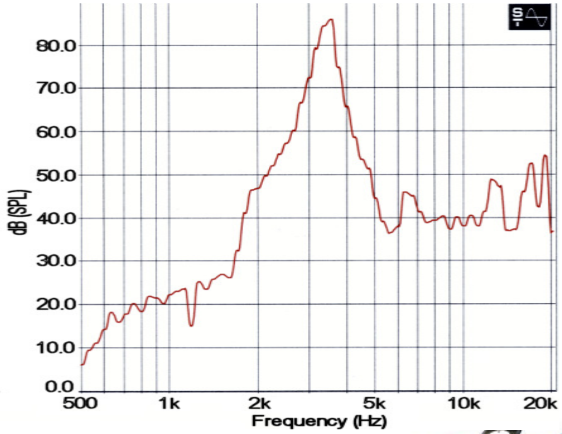
Mounting methods and mechanical vibrations

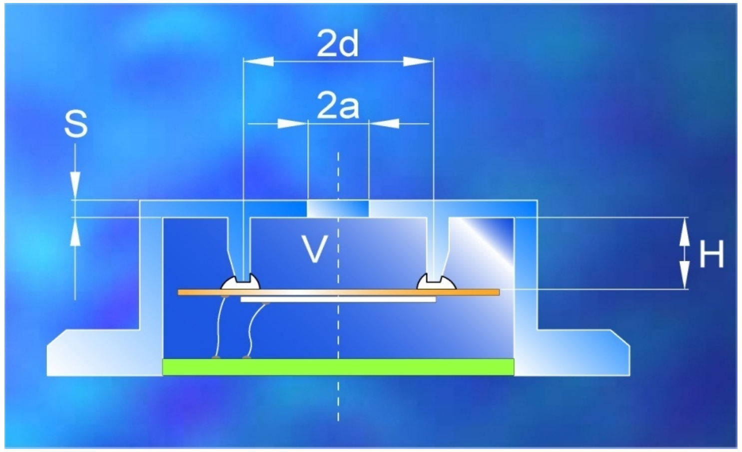
- Edge support:
  - Vibration of a free strip is a standing wave in which maximum amplitude (belts) occurs in the middle of the strip.
  - Energy balance → energy lost in the points of support
  - Suppresses the fundamental frequency by moving the node to the boundary of the membrane/plate (smaller displacements).
  - The whole surface of the membrane vibrates in phase resulting in a lower resonance frequency.

Construction of Sonitron products

- Nodal support:
  - Most efficient mounting method
  - Higher resonance frequency
  - Higher movement of the membrane
  - Smaller surface to produce sound
  - Very clear resonance peak.





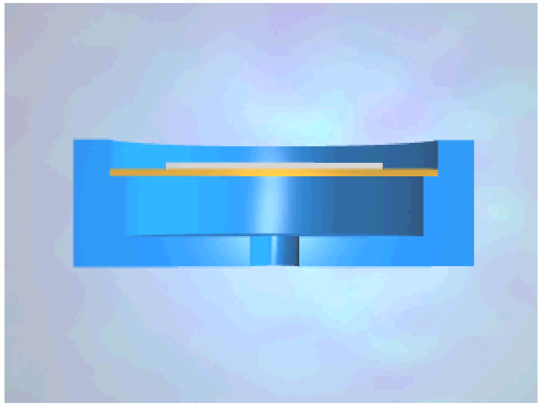


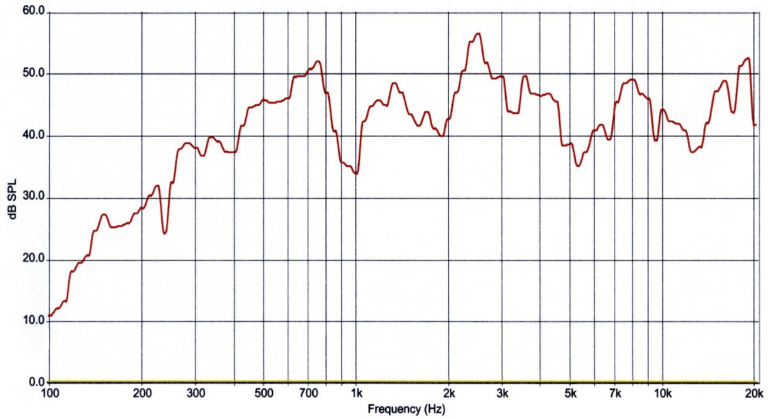
Construction of Sonitron products

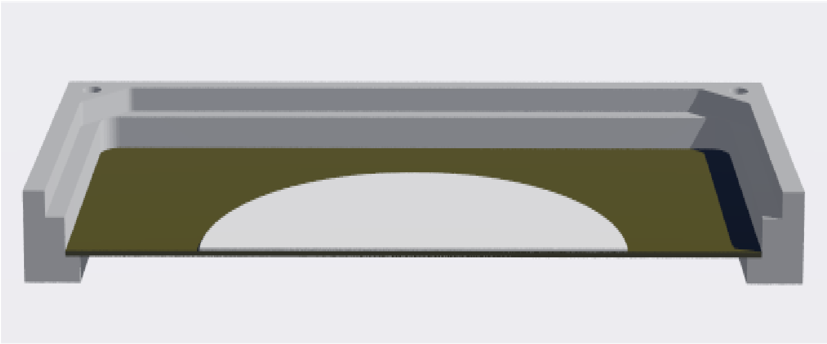
- Information about mounting method:
  - Soft glue (silicones) → needs 2 - 3 days to dry
  - Not waterproof
  - Membrane has to be mounted precisely in the centre :
    - Not easily to achieve: wires connected to the membrane and dry time 2 - 3 days
    - If not mounted precisely in the centre, resonance frequency and sound pressure changes.
  - Only for buzzers and transducers that generate a single working frequency

Construction of Sonitron products

- Edge support:
  - More surface area to produce sound
  - Less vibration of the membrane
  - Wider bandwidth
  - Lower resonance frequency
  - No distinctive resonance peak







Construction of Sonitron products

- Information about mounting method:
  - Hard (epoxy) or soft (silicones) glue
  - Membrane is easily to place in the housing (always centred)
  - SPL is very consistent
  - Waterproof
  - For speakers, multifunctional buzzers and alarms (products in which different frequencies are used)

Comparison with electro-dynamic speaker

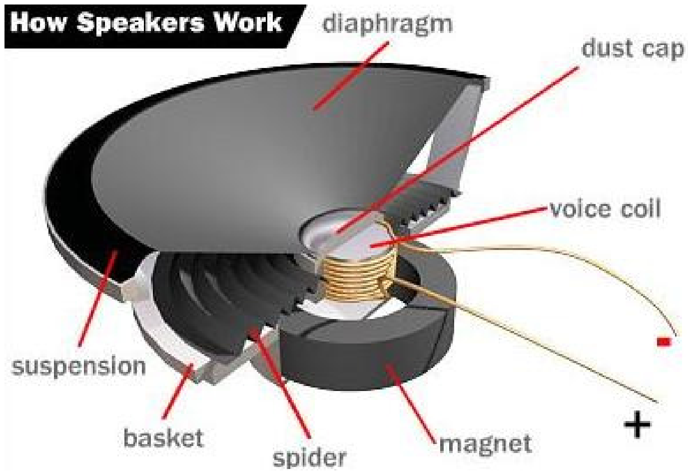
- Electrodynamic speaker:

  Alternating current through voice coil

  → Alternating magnetic field

  → Interacts with magnetic field of permanent magnet

  → Movement of cone



Comparison with electro-dynamic speaker

- Piezoelectric speaker:

  Alternating voltage on piezoceramic

  → Alternating contraction and expansion of piezoceramic

  → Movement of membrane