Radiation impedance of cones at high frequencies

- Radiation into free space
- Boundary element method
- Mechanical model
- Sound pressure measurements
- Approximation of radiation impedance

AES 112

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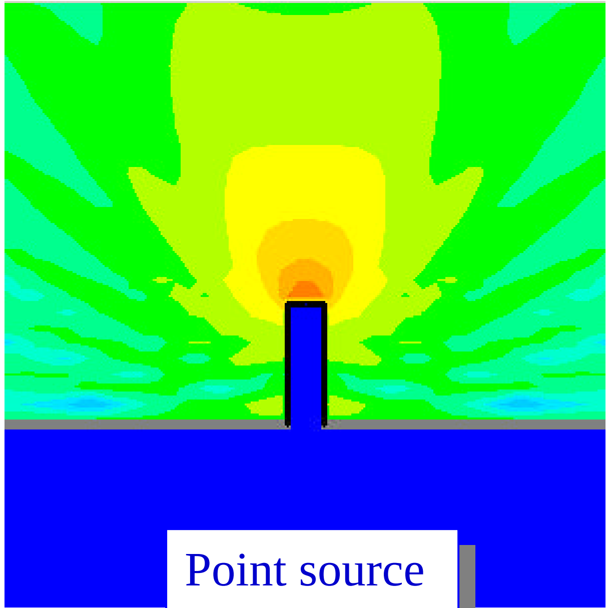
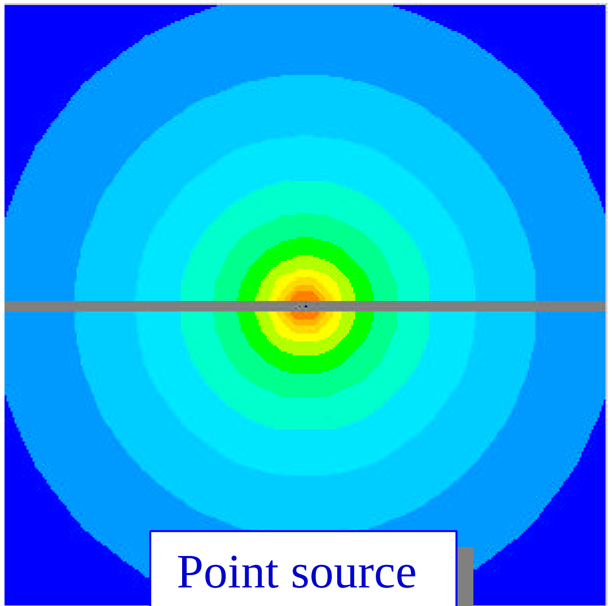
Radiation into free space



Point source
Finite baffle
1 kHz



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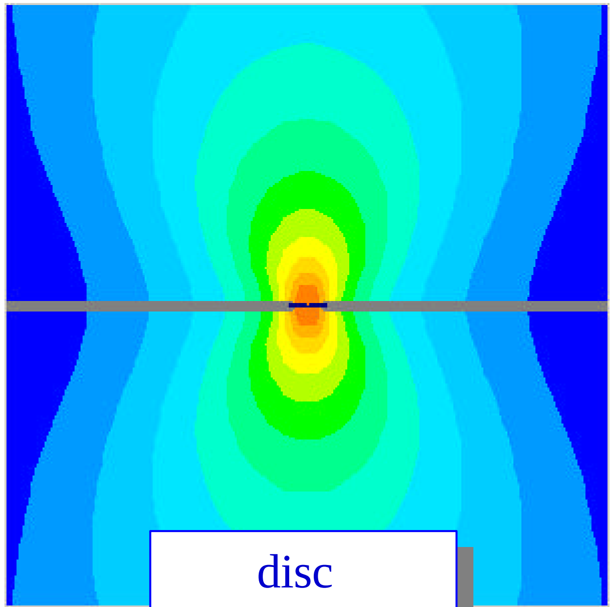


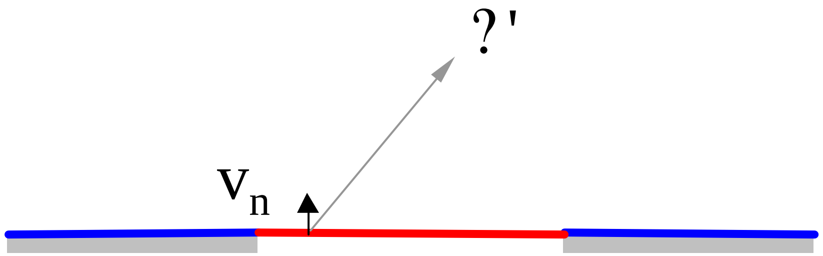
disc
Infinite baffle
1 kHz

Infinite baffle avoids interferences caused by the baffle

Boundary element method

Flat source:

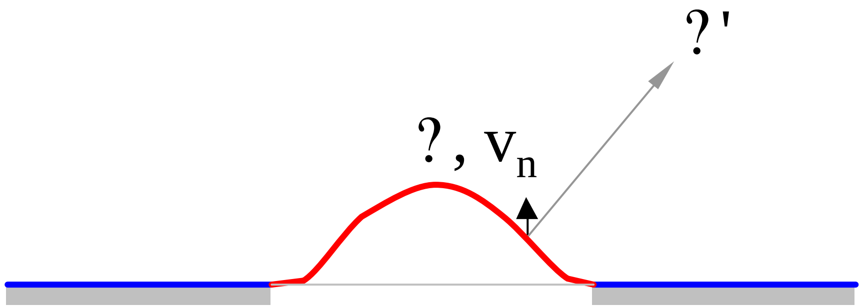
Rayleigh's formula



$$f\ '\ ?\ ?_{S}\, v_{n}\ ?G\ \ ds$$

Otherwise:

Helmholtz integral



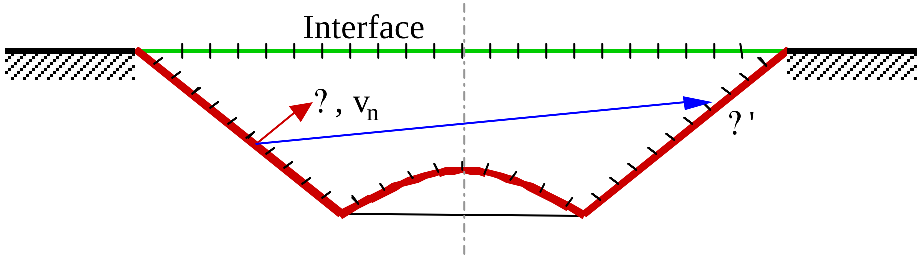
$$f\ '\ ?\ ?_{S}\, v_{n}\ ?G\ \ ds\ \ ?\ \ ?_{S}\, f\ \ ?G_{n}\ ds$$

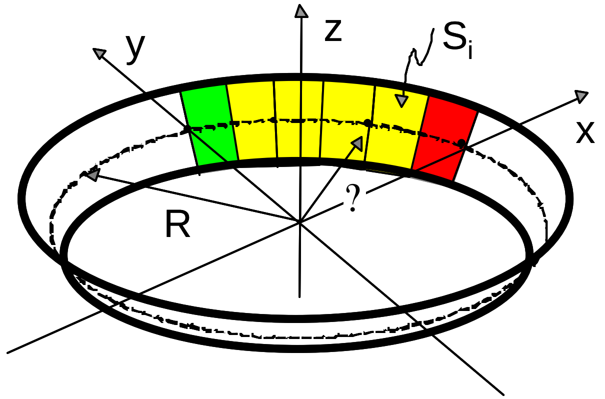
Unknown → f

Boundary element method

$$f\ '\ ?\ \underset{S}{?}\ v_n\ ?G\ \ ds\ \ ?\ \underset{S}{?}\ f\ \ ?G_n\ ds$$

Unknown





Solving Helmholtz Integral

1. Discretize surface into small segments (rings)
2. Lower receiving points of Helmholtz Integral onto surface segments
3. Assume constant potential across a segment
4. Integrate Green functions numerically for each ring
5. Solve linear equation system for surface potentials ?
6. Apply Helmholtz Integral again for any receiving point

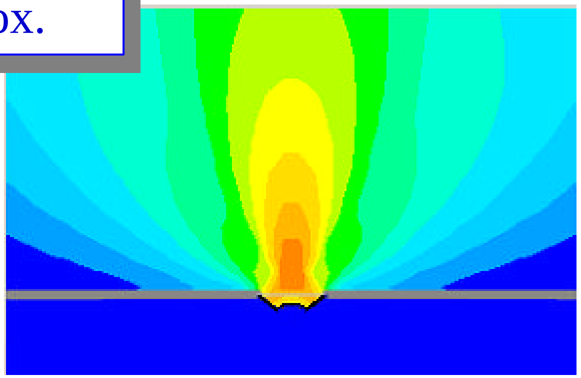
Boundary element method

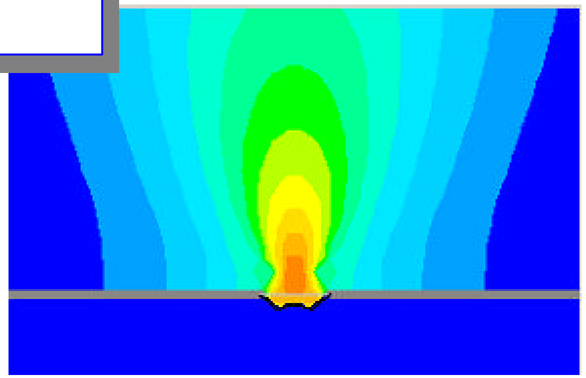
Rayleigh formula approx.

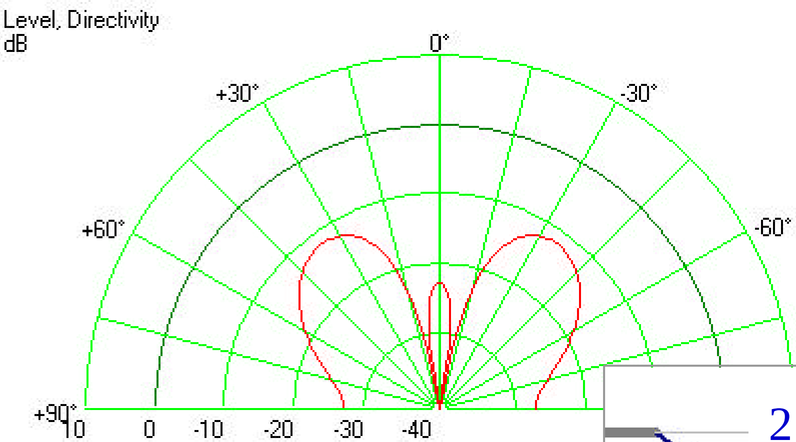
f ' ? ?v_n ?G ds
S

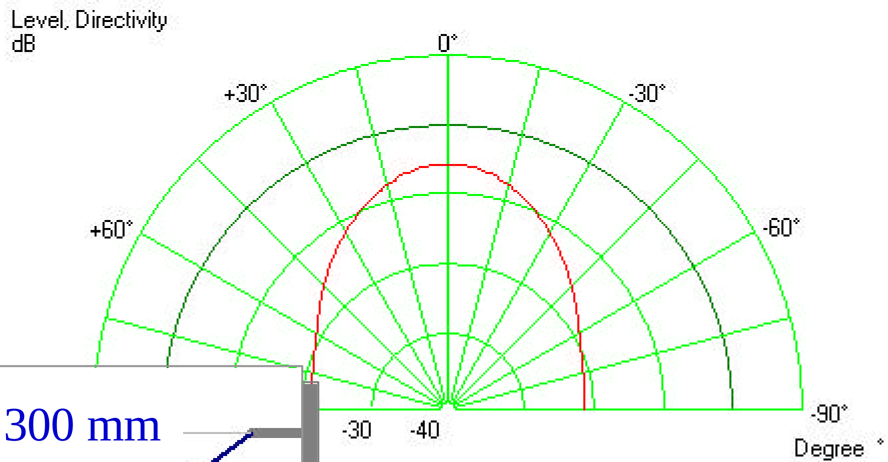
Helmholtz Integral

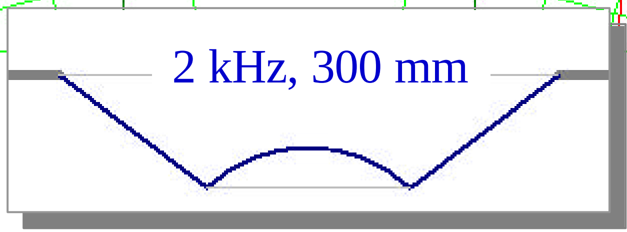
f ' ? ?v_n ?G ds ? ?f ?G_n ds
S S











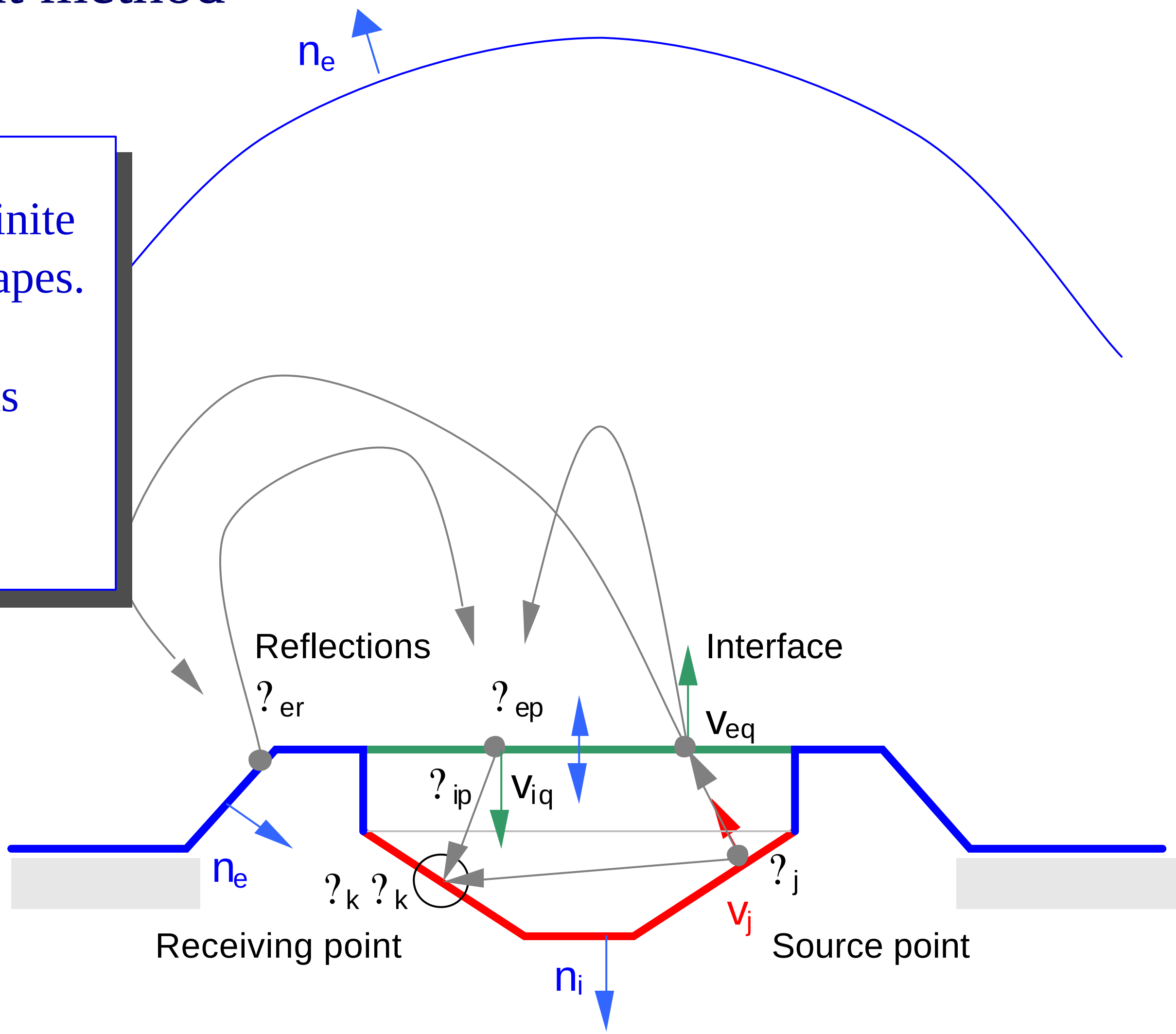
Boundary element method

Coupled BEM for infinite baffle and concave shapes.

Interface conditions

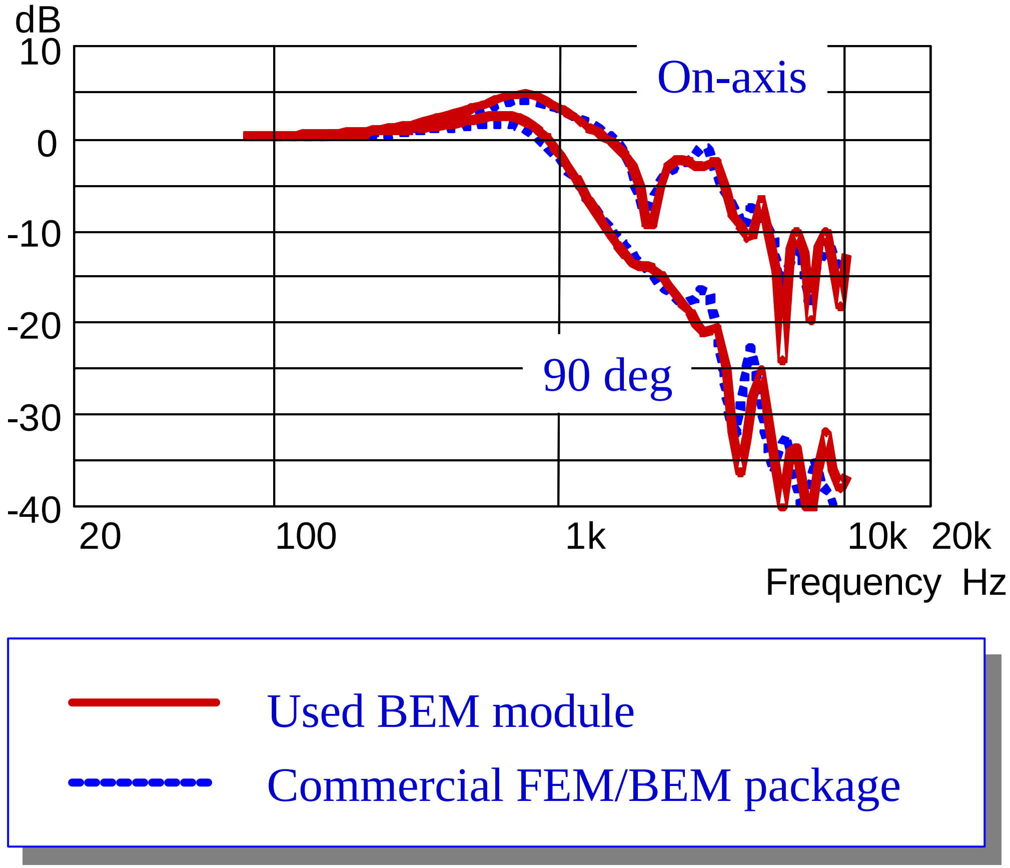
$?_i = ?_e$

$v_i = -v_e$



Boundary element method

Sound pressure comparison



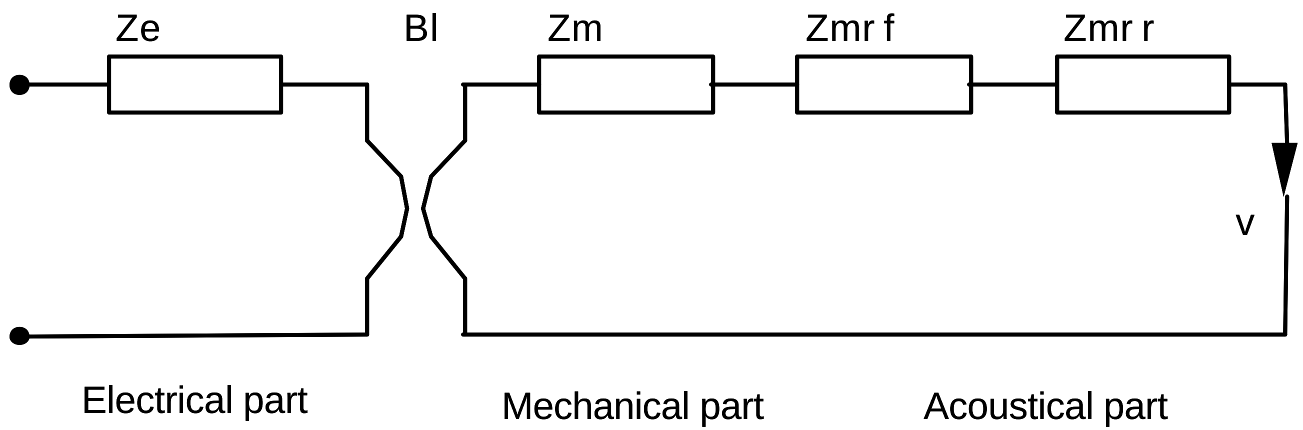
Mechanical Model

- BEM models radiation in great detail.
  Arbitrary properties of each segment.
- Dynamics of membrane would be next natural step.
  Bending wave radiation and coupling.
  Interesting studies have been done before.

- Rigid body mode is investigated here only.
- Simulation bandwidth restricted to low and mid bands,
  but BEM increases bandwidth by 1 ... 2 octaves against disc approximation.
- Only geometrical data are necessary, no material data

Mechanical Model

Rigid body model of electro-dynamical loudspeaker driver

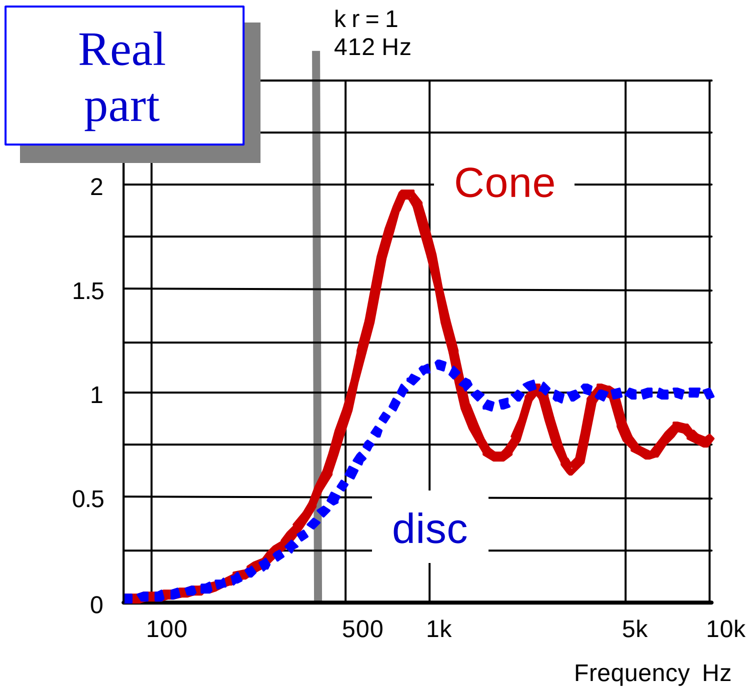


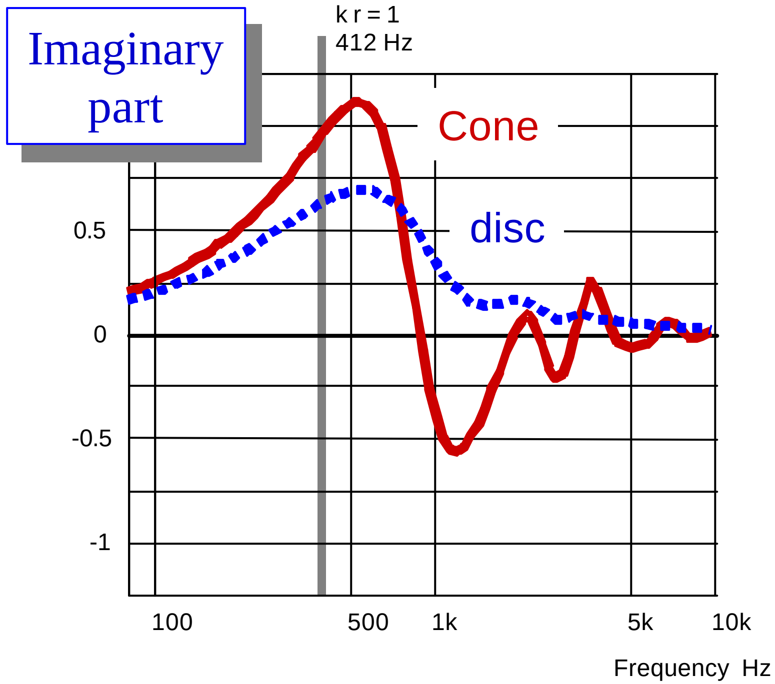
Radiation impedance

$$Z_{mr} = \frac{\sum_i p_i \cdot S_i \cdot \cos(a_i)}{v} \qquad Z_{mr} = \frac{F}{v}$$

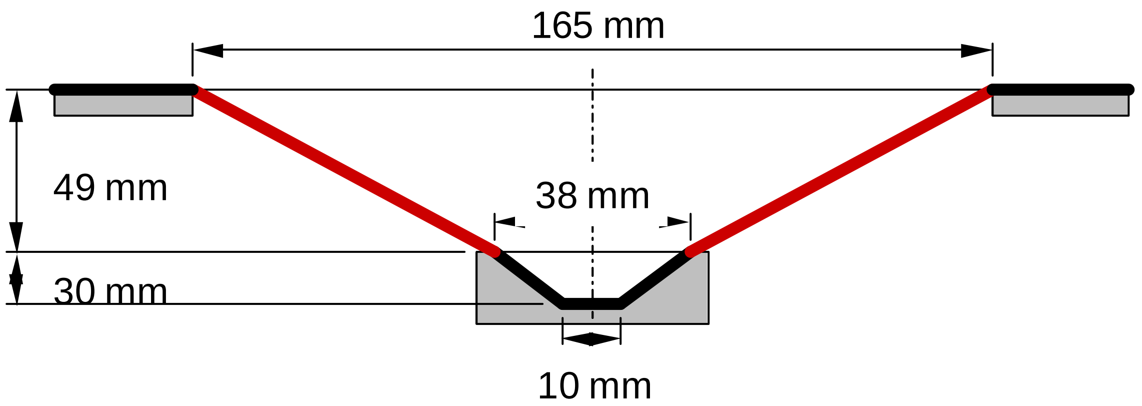
Mechanical Model

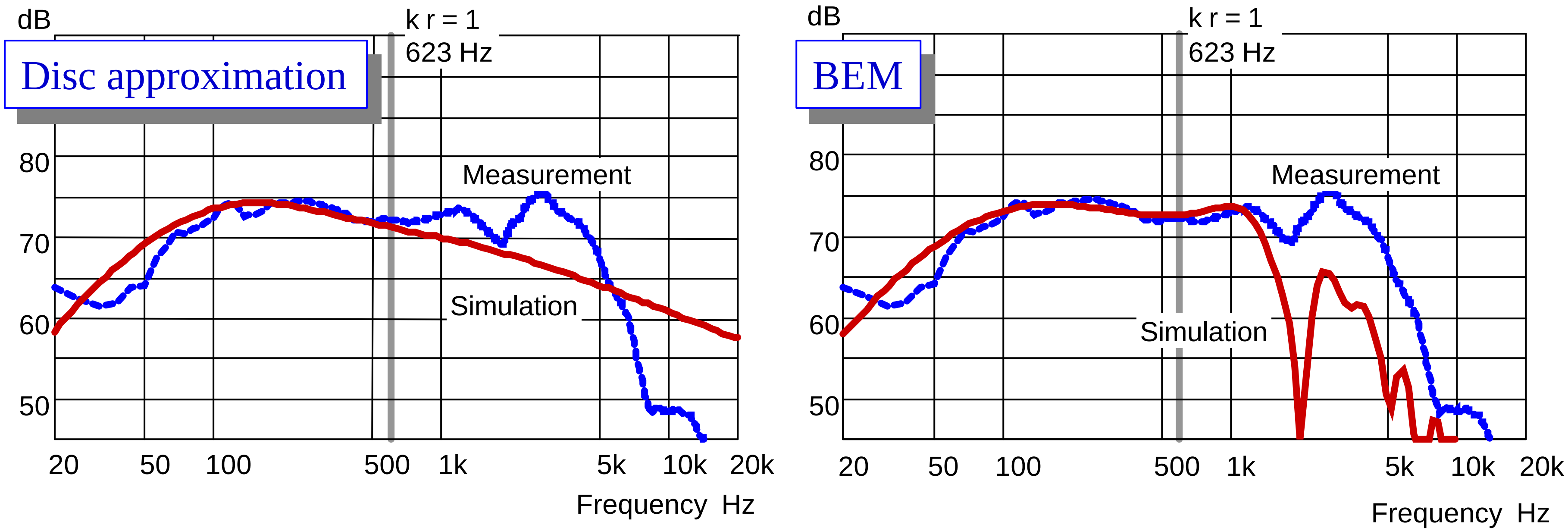
Radiation impedance





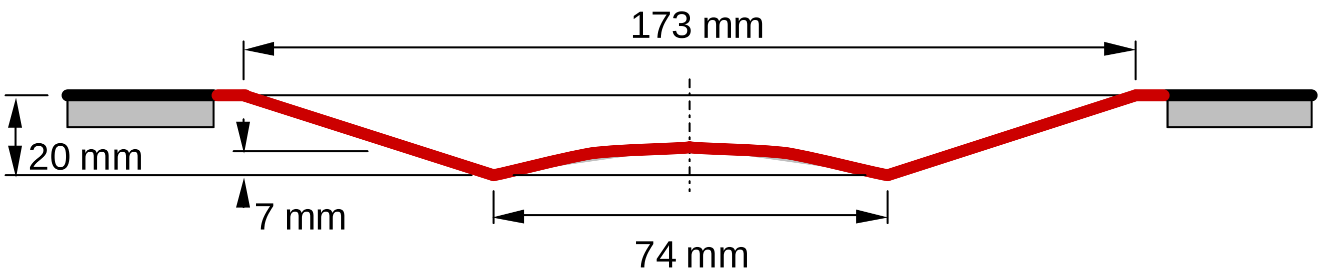
Sound Pressure Measurements

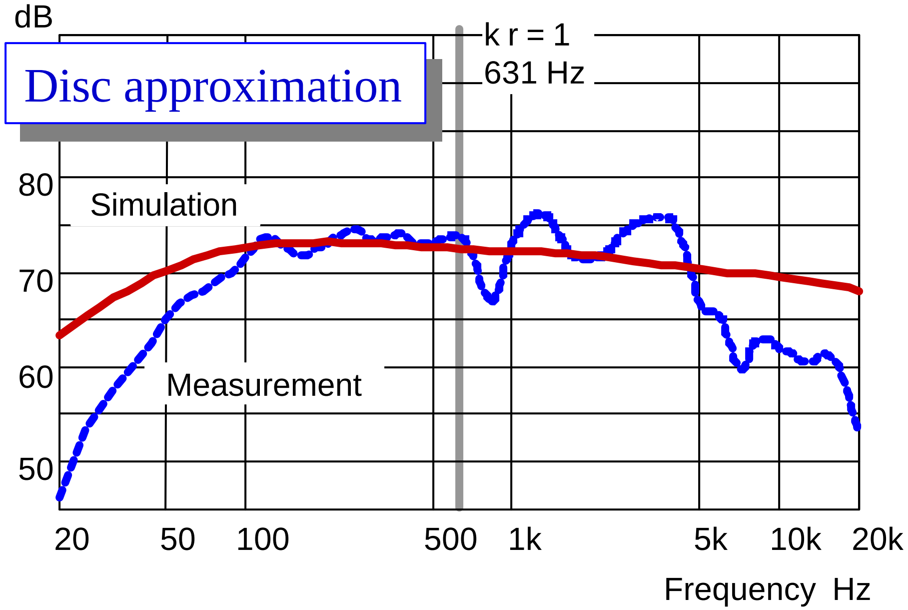


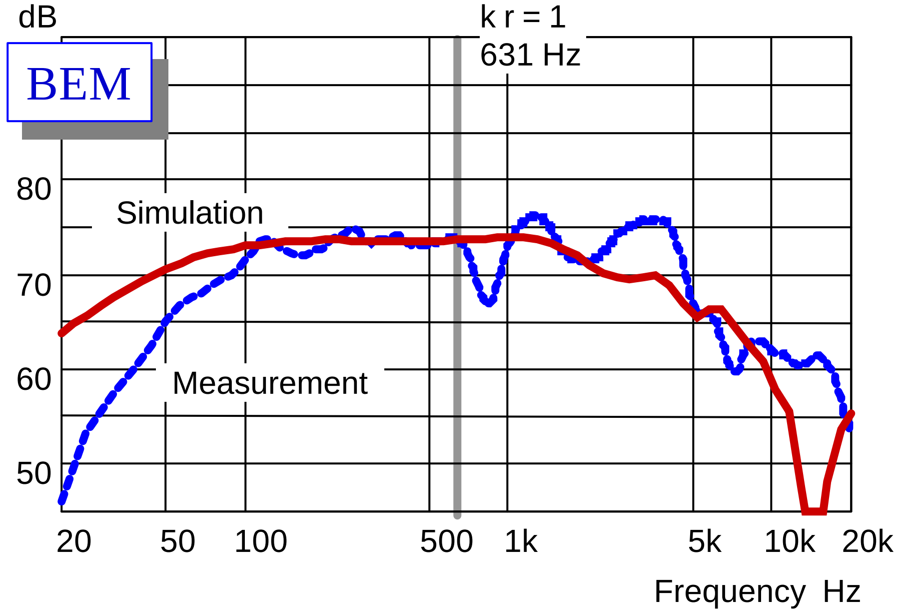


Far-field sound pressure on-axis

Sound Pressure Measurements







Far-field sound pressure on-axis

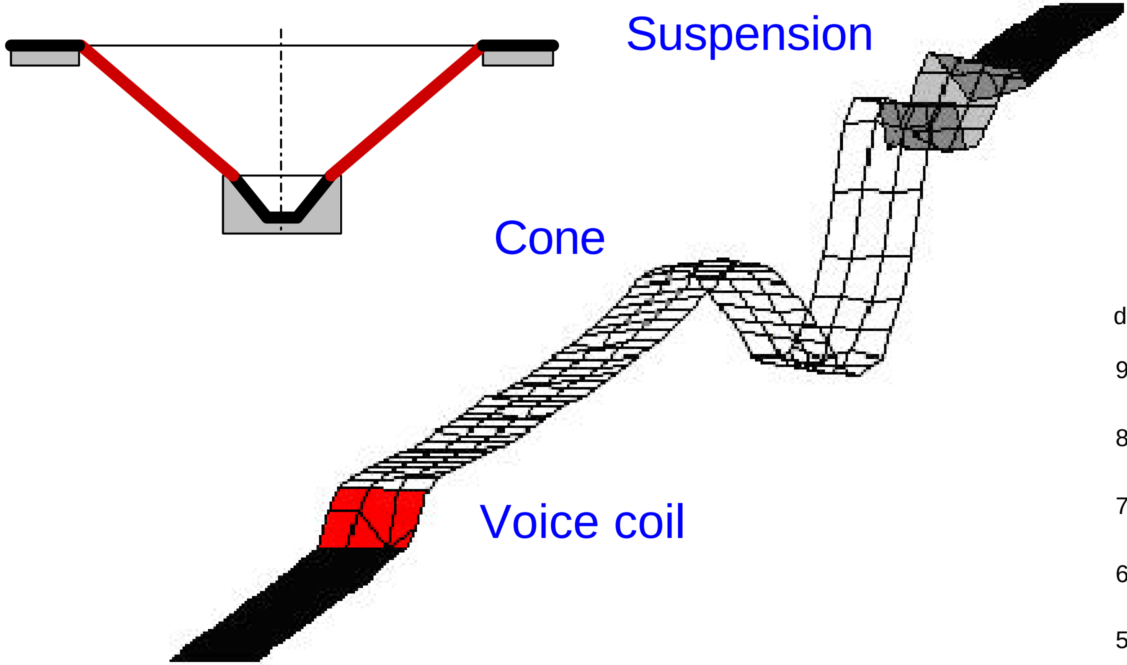
Sound Pressure Measurements

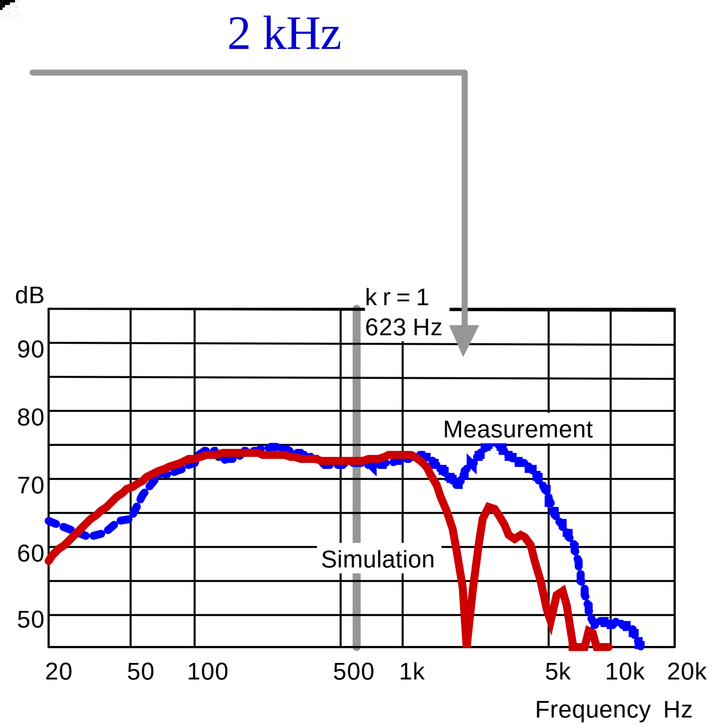
Rigid body model + BEM gives:

- One more octave of simulation bandwidth.
- Geometric data are needed additionally.
- Simulation bandwidth approx. kr = 2 ... 2.5

Sound Pressure Measurements

Membrane dynamics at 2 kHz



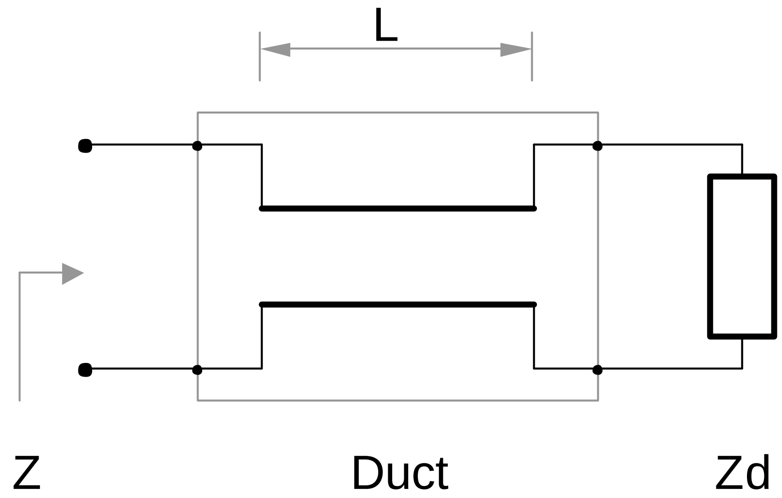


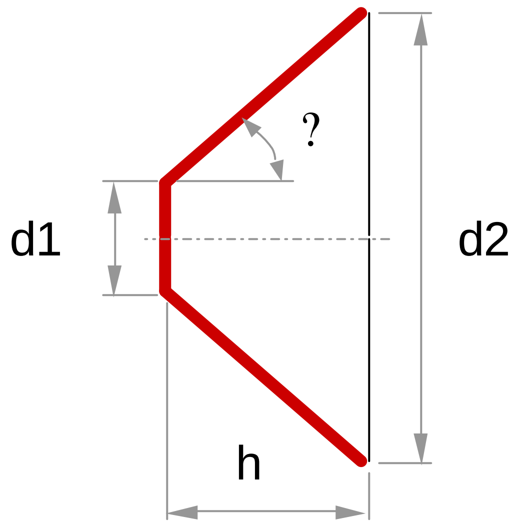
Approximation of Radiation Impedance

- Radiation impedance of rigid cone in infinite baffle.
- Approximation between disc model and BEM.
- Based on acoustic duct in fundamental mode.
- Duct loaded by radiation impedance Zd of a disc with diameter d2 in infinite baffle.

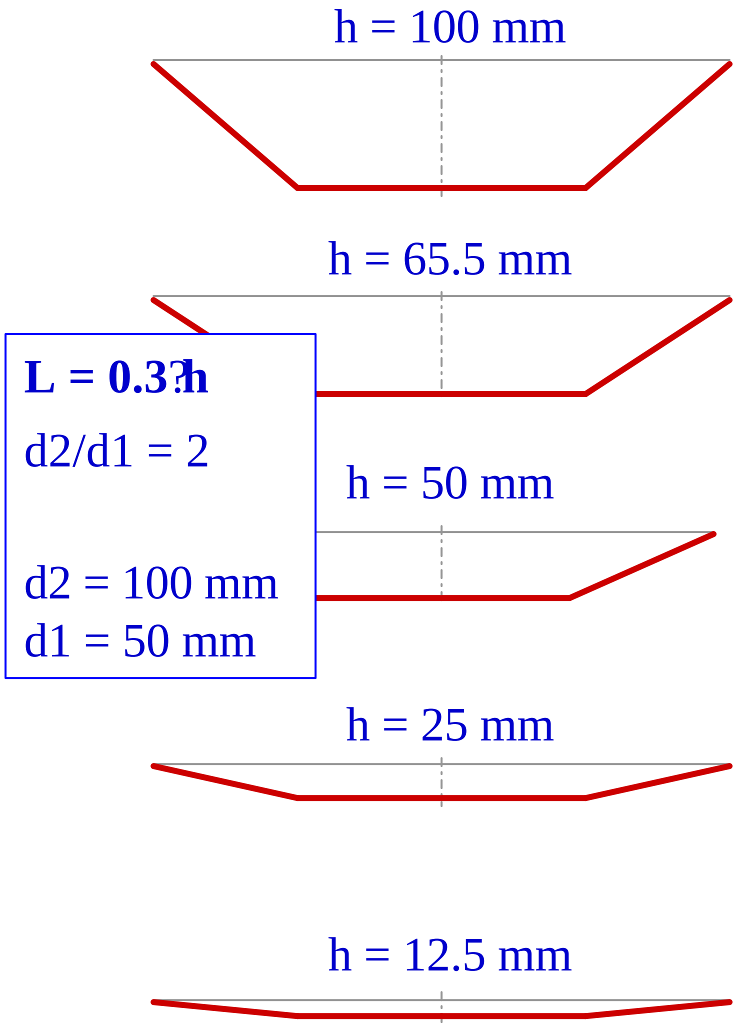
$$Z = \frac{Zd \cdot \cos(k \cdot L) + i \cdot \sin(k \cdot L)}{\cos(k \cdot L) + i \cdot Zd \cdot \sin(k \cdot L)}$$

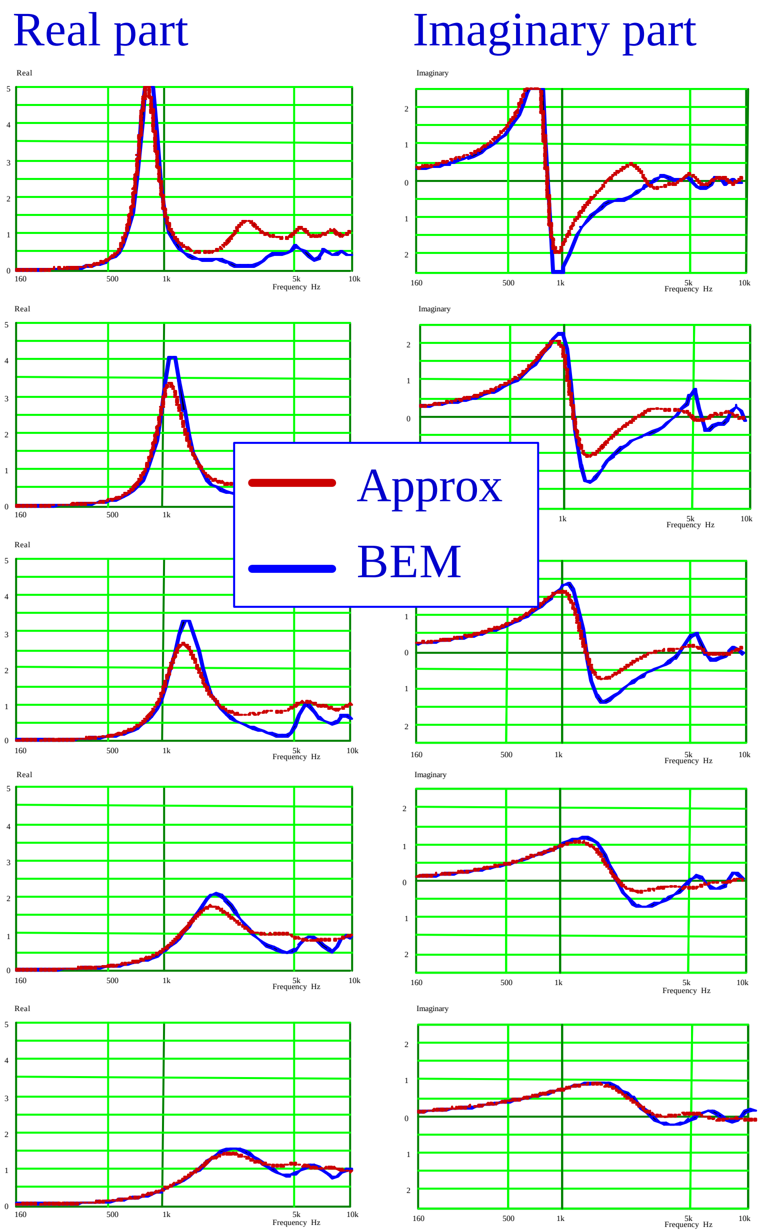
$$L = \mathrm{function}\left(h, \frac{d2}{d1}\right)$$



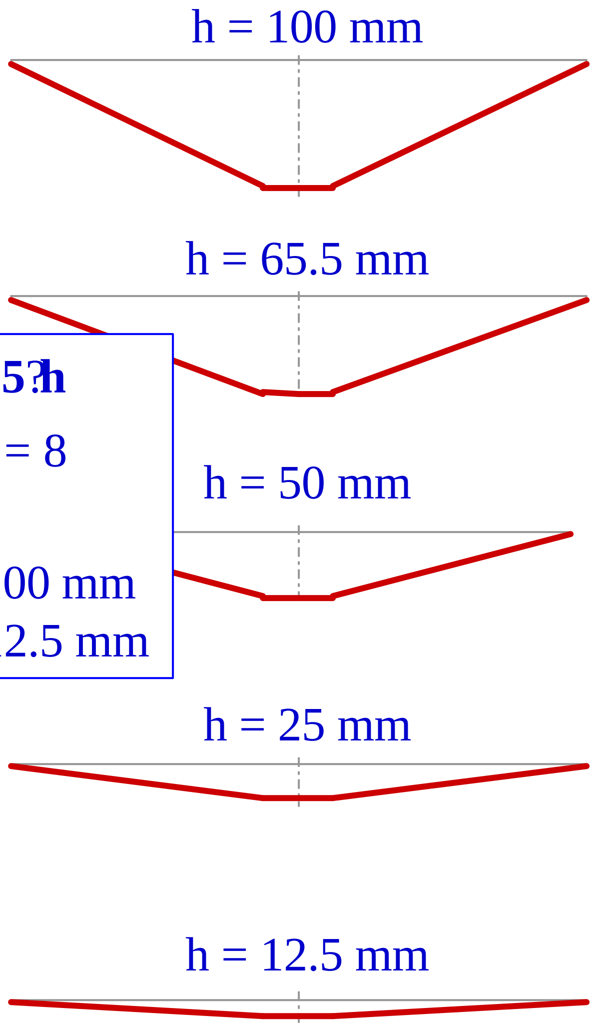


Approximation of Radiation Impedance





Approximation of Radiation Impedance

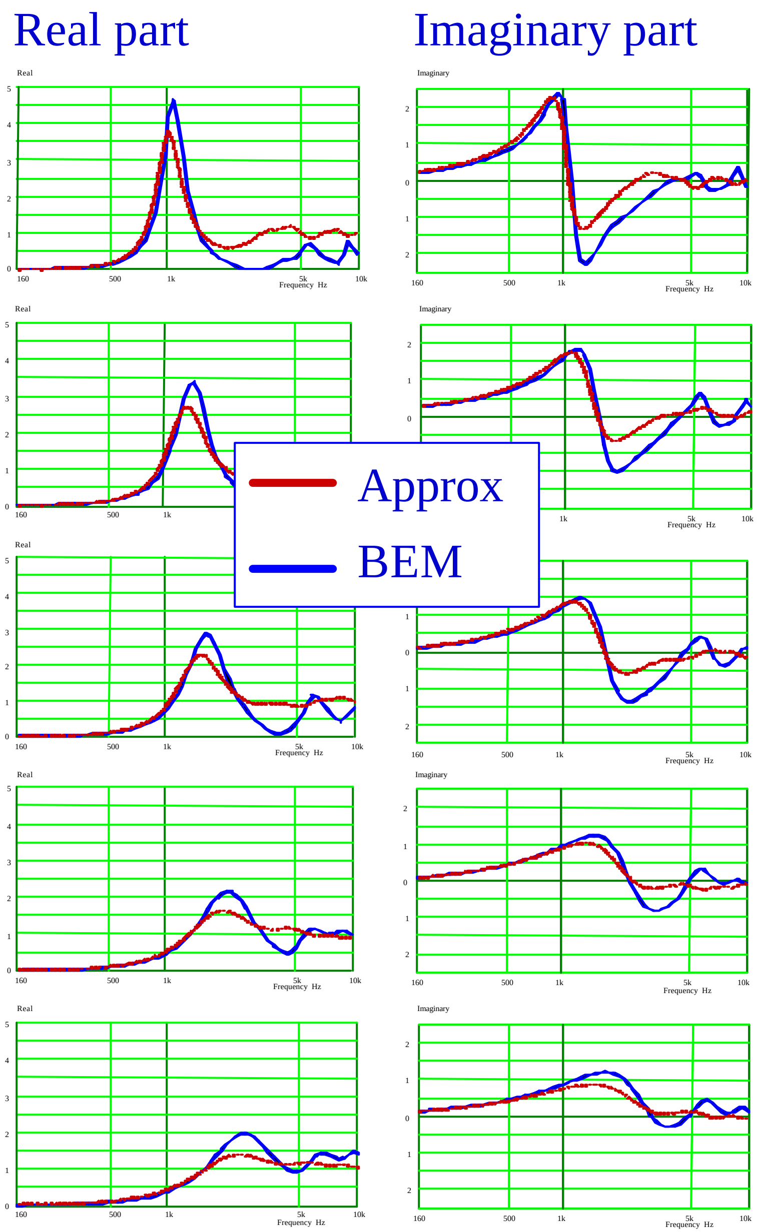


L = 0.5?h

d2/d1 = 8

d2 = 100 mm

d1 = 12.5 mm



Conclusions

- Application of BEM to radiation of cones
- Rigid body mode of mechanical system
- Confident model up to $k \cdot r = 2 \ldots 2.5$
- Only geometrical data are necessary additionally
- Interesting approximation for radiation impedance of cones.
- Future work: Linking BEM to dynamical vibration of the cone

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