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CENTRAL EUROPE SECTION

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UNIDIRECTIONALLY RADIATING LOUDSPEAKERS

Unidirectionally radiating loudspeakers

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ABSTRACT.

The maximum sound reinforcement attainable in large reverberant halls is highly dependent on the directional properties of the loudspeakers used, particularly in the lower frequency range.
A method of designing loudspeakers for unidirectional sound radiation will be presented.
Frequency response curves for such loudspeakers will be compared to those for conventional enclosures and applications will be considered.

1. Introduction:

It is a well-known fact, that the radiation of a vibrating circular diafragm shows no directivity at wavelengths much larger than its diameter.
Significant directivity occurs at wavelengths shorter than its circumference.
The lower limiting frequency for significant directivity is defined by an upperlimiting wavelength, approximately given by

$$\lambda = 3\,d \qquad (1)$$

in which λ = wavelength of sound
d = diameter of diafragm

The electroacoustical analogue circuit of an unidirectionally radiating loudspeaker is given in fig. 1.

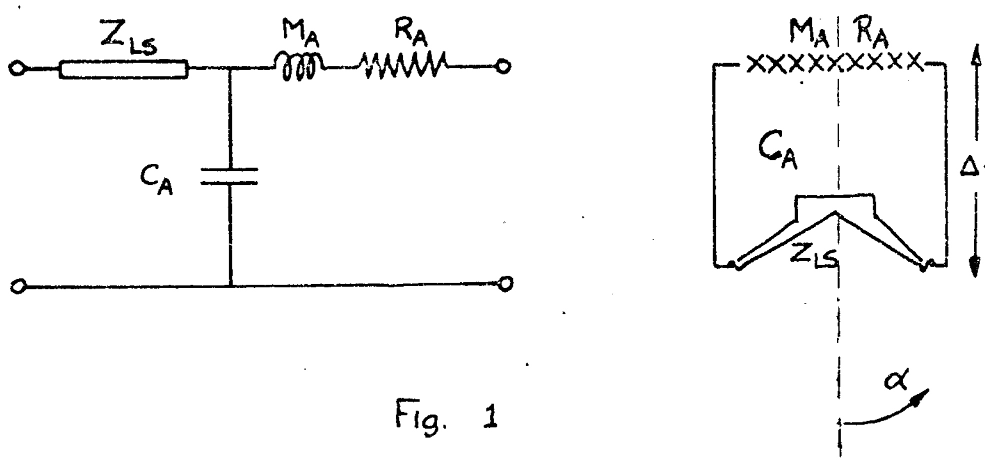


Fig. 1

The notations are: Z_{LS} = the acoustic impedance of the loudspeaker
C_A = the acoustic compliance of the enclosure
M_A, R_A = the acoustic mass and resistance of the opening on the rear side of the enclosure.

Δl = distance between front and rear side of the enclosure.
α = angle between direction of sound and loudspeakeraxis.
$\omega = 2\pi f$
f = frequency
c = velocity of sound

Considering fig. 1 we find the following expressions for the phase angle ϕ_1,
due to acoustic network $\phi_1 = \arctan\left(\frac{-\omega R_A C_A}{1-\omega^2 M_A C_A}\right)$ (2)
and the phase angle ϕ_2, due to delay by $\Delta l \cos\alpha$: $\phi_2 = \frac{\omega \Delta l}{c}\cos\alpha$ (3)

Expression (2) can be written

$$\phi_1 = \arctan \frac{1}{Q} \frac{-\frac{\omega}{\omega_0}}{1-\left(\frac{\omega}{\omega_0}\right)^2} \quad (4)$$

The best linear relationship between ϕ_1 and $\frac{\omega}{\omega_0}$ is obtained for a value of Q

$$Q = \frac{2}{\pi}$$

giving an approximation

$$\phi_1 = \frac{\pi}{2} \frac{\omega}{\omega_0} \quad (5)$$

valid up to $\frac{\omega}{\omega_0} = 1$ within 8%

The expression (3) may be written in the form

$$\phi_2 = \frac{\omega_0 \Delta l}{c} \cos\alpha \frac{\omega}{\omega_0} \quad (6)$$

Radiation for the angle $\alpha = 180°$ will be suppressed up to $\frac{\omega}{\omega_0} = 1$ if

$$\frac{\omega_0 \Delta l}{c} = \frac{\pi}{2} \longrightarrow \omega_0 = \frac{\pi}{2} \cdot \frac{c}{\Delta l} \quad (7)$$

The deviation between ϕ_1 and ϕ_2 will remain within 25% (10%) for all frequencies up to an upper limiting frequency corresponding to

$$\omega = \frac{4}{3}\omega_0 = \frac{2\pi}{3} \frac{c}{\Delta l} \quad (8)$$

The corresponding lower limiting wavelength $\lambda = 3\Delta l$ (9)

Formula (9) expresses that the unidirectional radiation of the loudspeaker in its enclosure, due to the front- and rear openings is limited to a lower limiting wavelength, whereas formule (1) expresses that the directivity of the radiation of the loudspeaker diafragm due to its dimensions is limited to an upperlimiting wavelength.

Proper take-over of both directivity effects will occur if

$$d = \Delta l \quad (10)$$

i.e. if the distance between the front- and rear-openings of the enclosure is equal to the diameter of the loudspeakerdiafragm.

Fig. 2 shows in a vector diagram for the angles 0°, 90° and 180° the origin of the directivity from the collaboration of the contributions of the radiation of front and rearopenings.

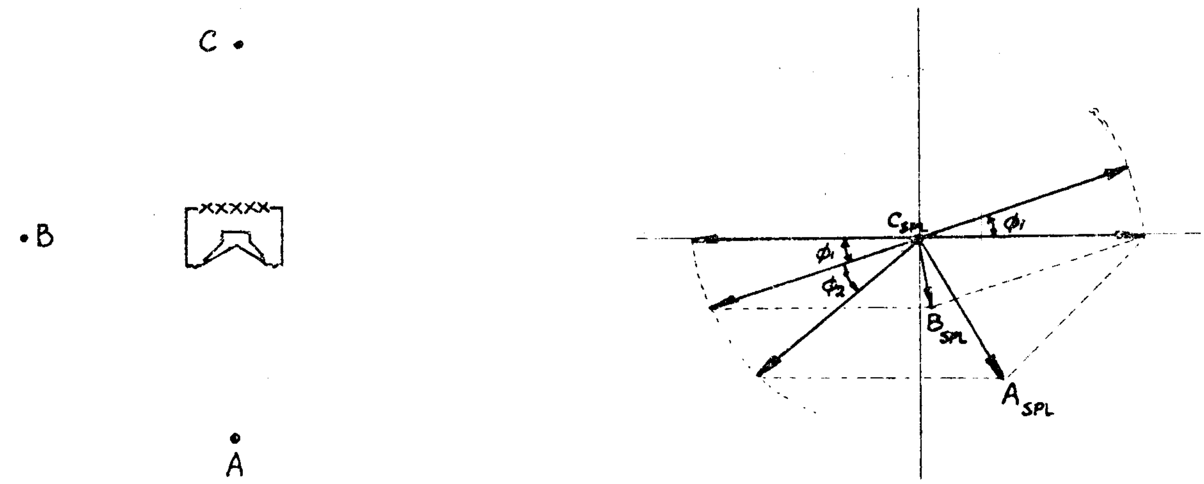


Fig. 2

2. Designing an unidirectionally radiating soundcolumn

The considerations mentioned above have been applied to the design of an unidirectionally radiating loudspeakercolumn.
The acoustic mass and resistance are located on the sides of the column and are realized by two long slits, one on each side of the column, covered with a copper gauze.
Fig. 3 shows the frequency response curves for different angles for the unidirectional column (a) and the corresponding curves for the conventional column (b).

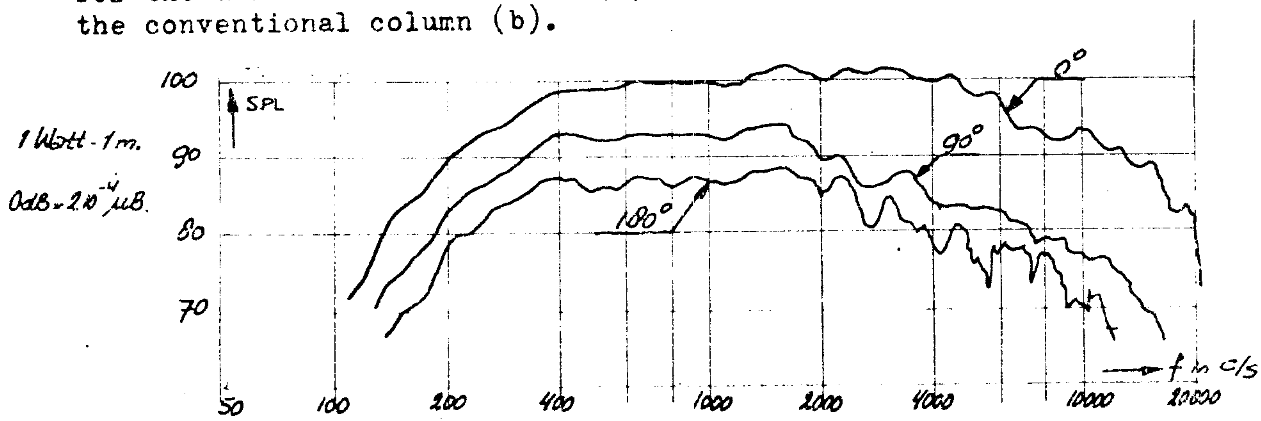


Fig 3a.

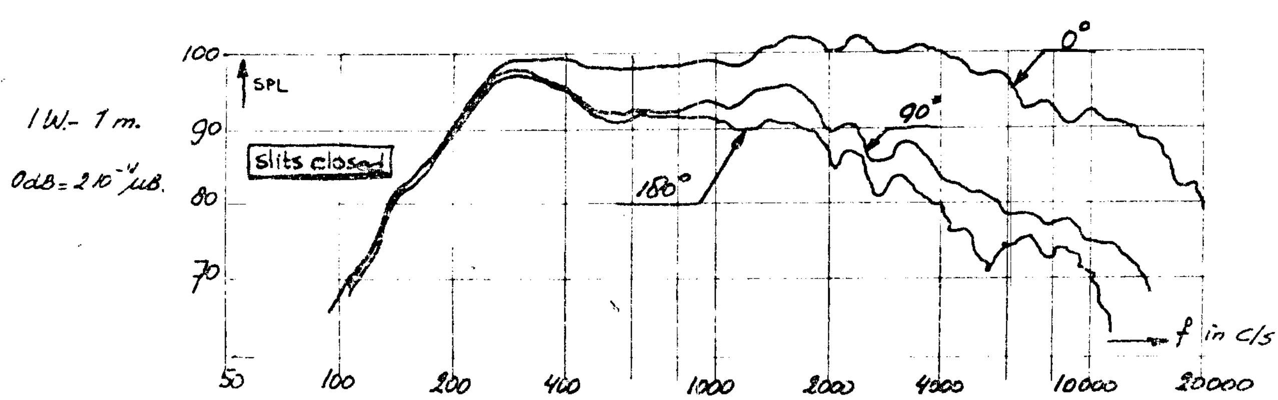


Fig 3b

3. Features of the unidirectionally radiating loudspeaker

a. For a unidirectional loudspeakercolumn the front-to-random index in the lower frequency range will be approximately 4,5 dB higher than for the conventional type with the same length. The unidirectional type, designed to produce the same direct sound level at zero degrees as a conventional type with the same length, will, therefore produce an approximately 4,5 dB lower level of diffuse, reverberant sound, resulting in a significantly better speech intelligibility (less masking).
For public-address systems, for which the maximum attainable sound reinforcement is limited by acoustical feed-back in the lower frequency range the unidirectionally loudspeakercolumn will allow an approximately 4,5 dB higher gain or can produce the same soundlevel for an approximately 65% larger speaking distance from the microphone.
No low-frequency roll-off is necessary to avoid acoustical feed-back so that the naturalness of speech will not be impaired.

b. Because the directivity is maintained in the low-frequency range the balance between low and high frequency components will be maintained in a horizontal opening angle up to approximately 180°.

c. The critical distance for <u>direct</u> coupling between microphone and loudspeaker will be much shorter, accomodating for positioning of the loudspeaker nearer to the speaker, resulting in a better localization.

d. The frequency response of an unidirectional loudspeaker is less affected by obstacles such as walls, pilars e.o.: see fig. 4 (distance between front of soundcolumn and wall is approximately 40 cm.).

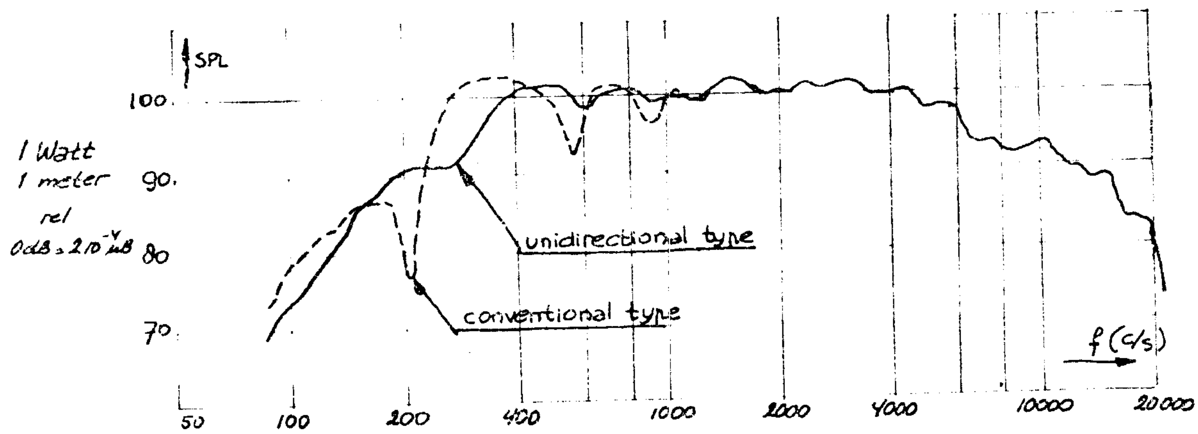
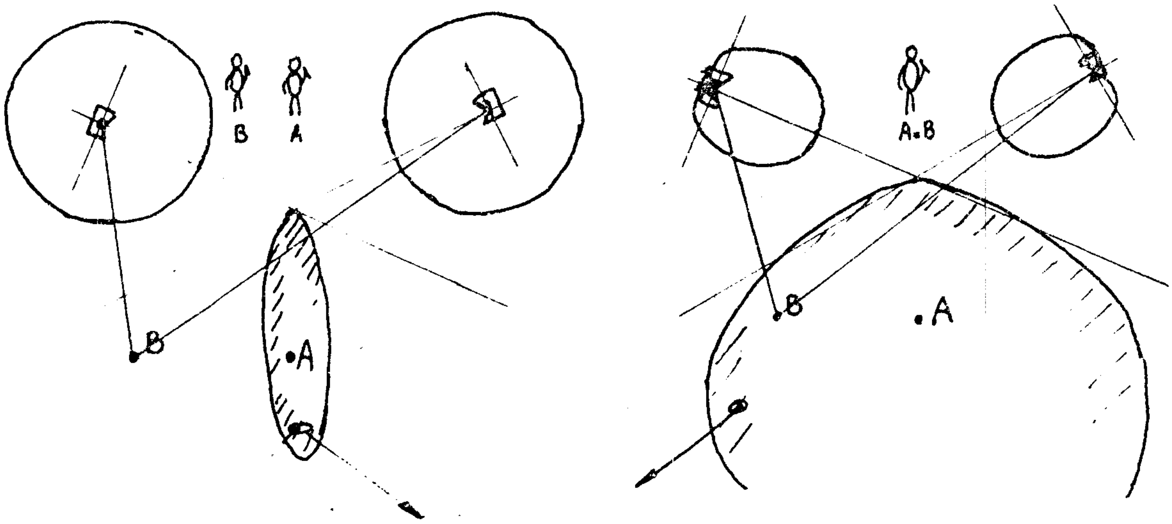


Fig 4.

e. The range, covered by an (unidirectional-)loudspeaker is enlarged, so in a public-address-system less loudspeakers will be needed to cover a pre-determined area.

f. The frequency independant directional properties of the unidirectional loudspeaker is a particular feature for application in stereo-systems.
It allows the time-error for off-center listeners to be compensated by a matched difference in level for both loudspeakers so

that a proper localization is maintained over a large area (fig.5). Furthermore the stereo reproduction when using unidirectional loud-speakers is much less influenced by reflections coming from side walls.



proper localization

Fig. 5

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