Kurt Heutschi, Acoustics II, 2012-01-03

Exercise A2-4: Microphones

1. A microphone is constructed as a pressure sensor. The cavity on the rear side of the membrane has a volume of 1 cm^3. The thickness of the microphone tube is 1 mm. Calculate the diameter of the pressure equalization vent (its length is 1 mm) for a lower limiting frequency of 2 Hz. Note: the acoustical mass of the vent can be neglected compared to the acoustical resistance.

2. A 1-inch (1 inch = 2.5 cm) condenser microphone with omnidirectional directivity is operated with a polarization voltage of 200 V. The distance between the membrane and the back-plate at rest is 20 μm. The volume of the cavity behind the membrane is 3 cm^3, the sensitivity is 50 mV/Pa. Calculate the stiffness s of the membrane and the displacement of the membrane for a sound pressure level of 40 dB (0 dB = 2E-5 Pa).

3. A possible realization of a figure-of-eight directivity is the ribbon microphone. Hereby an electrically conducting foil is installed between the two poles of a magnet. The foil acts at the same time as membrane and coil. The conversion principle is electrodynamic. The figure shows a section through the microphone with the elements that have to be considered.

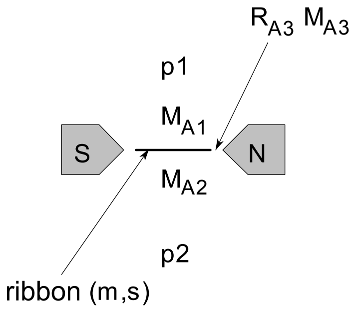

Figure 1: $p1$ and $p2$ are sound pressures, M_{A1} and M_{A2} describe the extra loading of the membrane by the acoustical mass of the oscillating air on both sides of the membrane. R_{A3} and M_{A3} stand for the acoustical resistance and the acoustical mass of the gap between the membrane and the magnet.

Draw the equivalent electrical network and get rid of the gyrators by appropriate dual conversion.

Solutions to Exercise A2-4: Microphones

1.
The relation between the sound pressure outside of the microphone p_{outside} and the sound pressure inside p_{inside} can be described by the equivalent network shown below. The volume of the cavity in the microphone corresponds to an acoustical compliance (capacitor C), the vent corresponds to an acoustical resistance (resistor R).

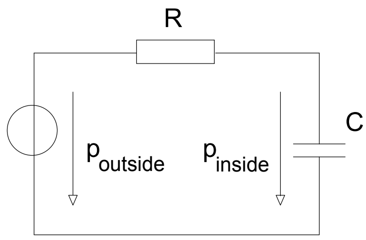

Figure 2: Equivalent electrical network for the equalization vent in a pressure microphone.

The transfer function $p_{\mathsf{inside}}/p_{\mathsf{outside}}$ is thus

$$\frac{p_{\mathsf{inside}}}{p_{\mathsf{outside}}} = \frac{1}{1 + j\omega RC} \tag{1}$$

The membrane is driven by the pressure difference outside and inside. Therefore the -3 dB point is reached for:

$$\frac{|p_{\mathsf{outside}} - p_{\mathsf{inside}}|}{|p_{\mathsf{outside}}|} = 0.71 \tag{2}$$

This condition is fulfilled, if p_{inside} has an amplitude of 0.71 p_{outside} and a phase turn of -45° relative to p_{outside}. This is the case at the -3 dB point in the transfer function $p_{\mathsf{inside}}/p_{\mathsf{outside}}$ and thus for $\omega RC = 1$.

A lower limiting frequency of 2 Hz is obtained for $2\pi 2RC = 1 \rightarrow RC = 0.0796$. With an acoustical compliance of $C = \frac{V}{\rho c^2} = 7.2$E-12 it follows for the resistance $R = 1.1E10 = \frac{l \times 8 \times 1.82E-5}{\pi r^4} \rightarrow$ radius of the vent $r = 4.5$E-5 m.

2.

The microphone output voltage U_c depends on membrane displacement Δx, membrane spacing at rest x_0 and polarization voltage U_0 according to:

$$U_c = U_0 \frac{\Delta x}{x_0} \tag{3}$$

40 dB = 2E-3 Pa $\rightarrow U_c =$ 1E-4 V $\rightarrow \Delta x =$ 1E-11 m.

With

$$U_c = p \frac{C_{A2}}{C_{A2} + \frac{A^2}{s}} \frac{-AU_0}{sx_0} \tag{4}$$

follows

$$s = \frac{C_{A2} A U_0 - \frac{U_c}{p} A^2 x_0}{x_0 C_{A2} \frac{U_c}{p}} \tag{5}$$

With $C_{A2} = \frac{V}{c^2 \rho} = 2.16$E-11 the stiffness becomes $s = 8.9$E4 N/m.

3.

The equivalent network is found as

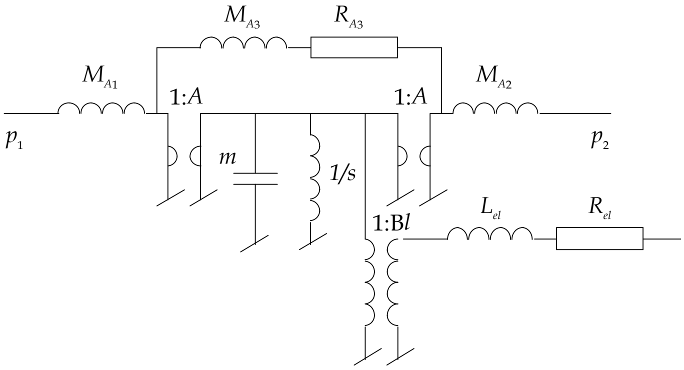

Figure 3:

Suitable dual conversion removes the gyrators

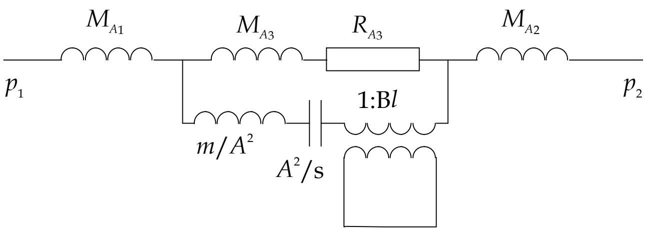

Figure 4: