Kurt Heutschi, Acoustics II, 2011-12-30

Exercise A2-2: Electro-mechanical-acoustical analogies

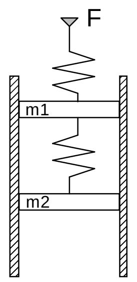
1. In a recording studio, a speaker cabin with a total weight of 1000 kg shall be installed. The cabin is put on a very heavy ground plate. To protect the cabin from possible structure-borne noise, it shall be mounted vibration-isolated using four springs.

a Draw the equivalent electrical network.

b What is the qualitative frequency response of the transfer function *cabin velocity / ground plate velocity*?

c Calculate the stiffness of each of the four springs to attenuate the velocity level of the cabin compared to the velocity of the ground plate by at least 10 dB above 50 Hz. Discuss the position of the resonance frequency with respect to 50 Hz.

2. A mechanical system is given according to the Figure below. The system consists of a tube with two moving masses $m1$ and $m2$ that are coupled by a spring. At the tube walls, velocity proportional friction is assumed. As external excitation, a force F acts in series to a spring on mass $m1$.



Draw the equivalent electrical network of the system.

3. The equivalent electrical network of a violin shall be developed. As simplifications the following assumptions are made:

- the violin body is a cavity with two f-holes.
- the top plate of the violin vibrates in its fundamental mode (piston movement) only.
- the violin is excited by a force acting on the top plate.

The gyrators shall be eliminated by dual conversion of the network.

Solutions to Exercise A2-2: Electro-mechanical-acoustical analogies

1.

The springs dampen the velocity, the force remains constant. The ground plate vibrates with velocity v_B, the velocity of the cabin is v_K. The corresponding electrical network is shown in the figure below.

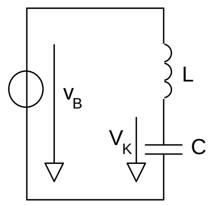


Figure 1: Equivalent electrical network of the mechanical system of the speaker cabin mounted on springs on a heavy ground plate with velocity excitation.

The ratio of the velocities or the transfer function G is given by the L-C voltage divider:

$$G = \frac{v_K}{v_B} = \frac{1}{1 - \omega^2 LC} \tag{1}$$

The requirement of a velocity damping of 10 dB at 50 Hz corresponds to the condition $v_K = v_B/3$. This is fulfilled for $\omega^2 LC = 4$ or $LC =$ 4.05E-5. It should be noted that the phase is 180°. One spring has to carry 1/4 of the total weight of the cabin. With $C = m/4$ and $L = 1/s$ follows for the stiffness $s =$ 6.2E6 N/m. The resonance frequency follows from $\omega_{res}^2 \cdot LC = 1$ as 25 Hz.

2.

The force is the flow quantity, the velocity is the potential quantity. In the system, three different velocities can be identified:

$v1$ velocity of the end of the spring F1 with the force excitation

$v2$ velocity of mass m1

$v3$ velocity of mass m2

With these quantities, the equivalent network becomes

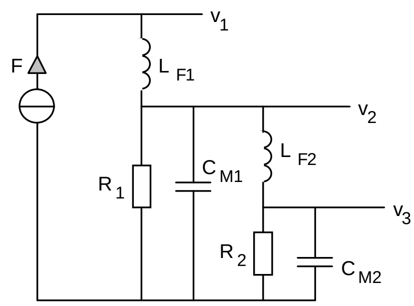


Figure 2: Equivalent network of the system from task 2.

3.

The excitation is a force source. The force acts on the top plate of the violin body. This plate corresponds to a membrane with mass, spring and damping properties. As all three elements have identical velocity v, they are arranged in parallel. If the plate vibrates, its rear side operates against the cavity of the violin body. The velocity v of the plate corresponds to the sound particle velocity and by scaling with the plate area this equals the volume flow. The conversion from the mechanical into the acoustical system is performed by a gyrator. The cavity corresponds to an acoustical compliance and is represented in the electrical network by a capacitance. The f-holes correspond to an acoustical mass and an acoustical resistance that includes the radiation losses as well. The mass and the resistance are arranged in series, as the volume flow of both elements is identical. With respect to the acoustical compliance they are in parallel, as the see they same sound pressure.

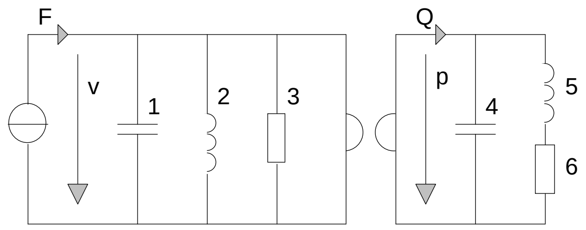


Figure 3: Equivalent electrical network of a simplified violin.

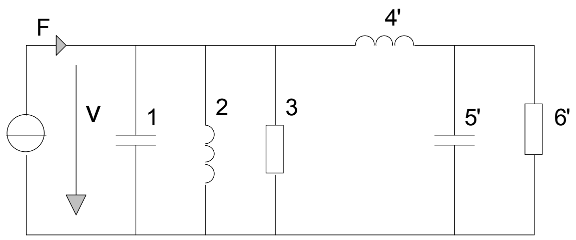


Figure 4: Equivalent electrical network of a simplified violin after dual conversion to get rid of the gyrators.

where:

F: exciting force
v: velocity of the top plate
Q: volume flow
p: sound pressure

1: mass of the top plate
2: mechanical stiffness of the top plate
3: internal losses and radiation losses of the top plate
4: acoustical compliance of the cavity
5: acoustical mass of the f-holes
6: acoustical resistance and radiation losses of the f-holes