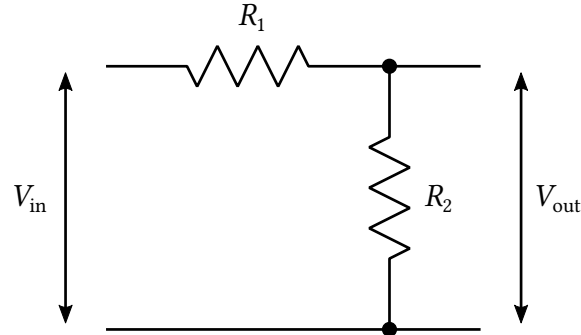


# THE SCIENCE OF MUSIC

## EXERCISES FOR CHAPTER 7

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7.1 In this circuit  $V_{\text{in}} = 5$  volts,  $R_1 = 600\Omega$ , and  $R_2 = 400\Omega$ :



- What is  $V_{\text{out}}$ ?
- If I want  $V_{\text{out}} = 1$  volt with  $R_1$  still being  $600\Omega$ , what should  $R_2$  be?

7.2 We send a pure sine-wave signal into a 6 dB-per-octave filter like the one in Fig. 7.8.

- If the frequency of the sine wave is exactly equal to the cutoff frequency  $f_c$  of the filter, by how many decibels is the intensity of the corresponding sound decreased?
- What about if the frequency is  $2f_c$ ?
- If the filter is a 12 dB-per-octave one, as in Fig. 7.12, how much is the intensity cut by at  $f_c$ ?

7.3 Consider a band-pass filter like the one in Fig. 7.15, built out of a low-pass filter and a high-pass filter one after the other, and let us denote the cutoff frequencies of the two filters by

$$f_L = \frac{1}{2\pi R_1 C_1}, \quad f_H = \frac{1}{2\pi R_2 C_2}.$$

Show that the center frequency  $f_C$  of the band-pass filter, which is the frequency at which the filter passes the largest fraction of the input signal—the center of the peak in Fig. 7.16—is  $f_C = \sqrt{f_L f_H}$ .

7.4 Microphones come in two main types: pressure microphones and pressure-gradient microphones.

- How do the two types differ in terms of the direction in which they pick up sound?

If you have a choice between these two microphone types, which would be better in each of the following applications?

- The microphone on a laptop used for videoconference calls.
- A microphone used on a guitar amplifier for live performance.

- d) A microphone used for recording vocals in the studio.
- e) A headset microphone for an operator in a call center.
- f) A microphone used for recording a full symphony orchestra in a concert hall.

**7.5** A cardioid microphone picks up sound most strongly from the direction directly in front of the diaphragm—the  $0^\circ$  point in a polar plot like Fig. 7.25. By how many decibels will the sound level drop off at (a)  $45^\circ$ , (b)  $90^\circ$ , and (c)  $135^\circ$ ?

**7.6** A hypercardioid microphone has an open-backed capsule like a cardioid microphone, but the diaphragm is not right at the front, but instead is  $\frac{1}{3}$  of the way back inside the capsule.

- a) Show that the net sound pressure felt by a hypercardioid mic for sound coming from an angle  $\theta$  off-axis is proportional to  $\frac{1}{3} + \cos \theta$ .
- b) Hence show that the microphone picks up no sound at all from an angle of approximately  $109.5^\circ$  off-axis.

**7.7** Either by hand or using a plotting program, make polar plots of the directional response of a cardioid microphone in the high-frequency region where Eq. (7.54) applies and (a)  $fd/c = \frac{1}{2}$ , (b)  $fd/c = 1$ .

**7.8** Consider a condenser microphone of the kind discussed in Section 7.3.5.

- a) What is the normal voltage of the electricity that such a microphone runs on?
- b) How large is the typical separation between the diaphragm and backplate of such a microphone?
- c) The typical voltage output by a condenser microphone (before amplification) is about a tenth of a volt. Hence, about how far does the diaphragm move back and forth as sound hits it?

**7.9** For a condenser microphone it is important, as discussed in Section 7.3.5, that the capacitor formed by the diaphragm and backplate charge up only slowly—more slowly than the rate at which the diaphragm vibrates. In practice, this means that the time constant  $RC$  of the resistor-microphone combination in the circuit of Fig. 7.30a must be longer than the period of the lowest-frequency sound waves. A typical capacitance for a condenser microphone is 50 picofarads. Hence what value should one use for the resistor?

**7.10** A professional analog tape recorder, of the kind widely used in recording studios in the mid 20th century, has a gap of  $3 \mu\text{m}$  between the poles of the tape head. At what speed should the tape move in order to fully capture the entire frequency range of audible sound?

**7.11** The earliest commercial vinyl records were 10 inches in diameter and rotated at 78 revolutions per minute. The playing area extended from the rim of the record inward about 2.5 inches, which is about 6.4 cm. If the recording is to have a dynamic range of 50 dB, approximately what would be the maximum playing time of such a record?

**7.12** A portable radio contains only one loudspeaker, which is 10 cm across. A listener listens to music on the radio from a point not directly in front of the speaker but  $45^\circ$  off axis.

- a) Up to about what frequency will they hear the sound clearly?
- b) Will this matter from a musical point of view?

**7.13** As we have seen, loudspeakers come in a range of sizes.

- a) Explain briefly the advantages and disadvantages of large loudspeakers versus small ones, paying particular attention to the relative merits of each for reproducing high and low frequencies.

With these issues in mind, approximately what size speakers should one use for the following?

- b) A “tweeter” intended for frequencies above 5000 Hz.
- c) A speaker for a bass amplifier that needs to capture frequencies up to 500 Hz.
- d) The “driver” speaker in a set of over-the-ear headphones.

**7.14** A line array speaker projects most of its sound into a narrow horizontal angle, with little sound going up or down. If a particular line array is 2.5 meters high, about how wide will that angle be in degrees?