ELECTRONICS

Physics 226 - Spring Quarter, 2009 - University of Chicago

REVIEW EXERCISES DUE TUESDAY, MAY 5

1. Calculate f_{3dB} and sketch the behavior of $|V_{out}/V_{in}|$ and the phase of V_{out}/V_{in} for the two circuits:

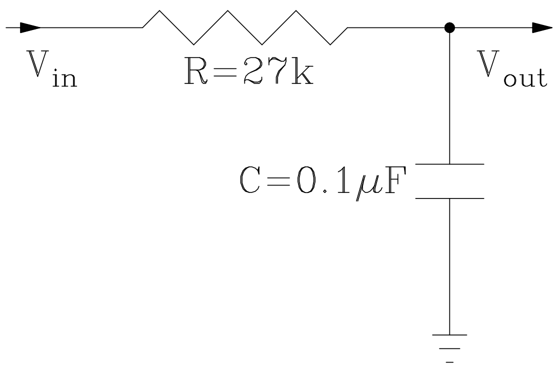

Figure 1: Low-pass filter

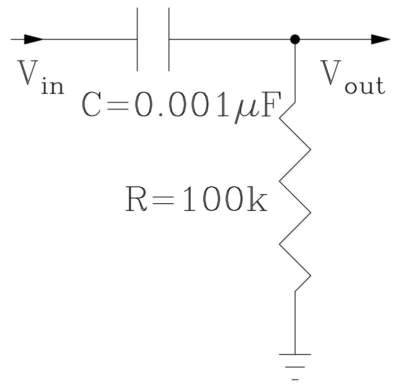

Figure 2: High-pass filter

Answers: For the low-pass filter, $f_{3dB} = (2\pi RC)^{-1} = (2\pi[27 \times 10^3][0.1 \times 10^{-6}])^{-1} =$ 58.95 Hz. The ratio of output to input voltage is

$$\frac{V_{out}}{V_{in}} = \frac{-j/\omega C}{R - j/\omega C} = \frac{-j}{\omega RC - j} = \frac{1 - j\omega RC}{(\omega RC)^2 + 1} \quad . \tag{1}$$

The ratio of $|V_{out}/V_{in}|$ is then $1/\sqrt{(\omega RC)^2 + 1}$, which goes to 1 as $\omega \to 0$ and falls off as $1/(\omega RC)$ for large ω. The phase of V_{out}/V_{in} is

$$\mathrm{Arg}(V_{out}/V_{in}) = -\arctan(\omega RC) \tag{2}$$

which goes to zero for $\omega \to 0$, is $-45°$ for $\omega RC = 1$, and goes to $-90°$ for large ω. Equivalently: At high frequencies the capacitor becomes a short. Therefore V_{in} sees a resistive load, while V_{out} sees a capacitive load. So the current in C is in phase with V_{in}, and leads V_{out} by 90°.

For the high-pass filter, $f_{3dB} = (2\pi RC)^{-1} = (2\pi[100 \times 10^3][0.001 \times 10^{-6}])^{-1} = 1.592$ kHz. Here the ratio of output to input voltage is

$$\frac{V_{out}}{V_{in}} = \frac{R}{R - j/\omega C} = \frac{\omega RC}{\omega RC - j} = \frac{(\omega RC)(\omega RC + j)}{(\omega RC)^2 + 1} \quad . \tag{3}$$

The ratio of $|V_{out}/V_{in}|$ is then $(\omega RC)/\sqrt{(\omega RC)^2 + 1}$, which behaves for small ω as ωRC and goes to 1 for large ω. The phase of V_{out}/V_{in} is

$$\mathrm{Arg}(V_{out}/V_{in}) = \arctan(1/\omega RC) \tag{4}$$

which goes to 90° for $\omega \to 0$, is 45° for $\omega RC = 1$, and falls to 0 for $\omega \to \infty$. The same behavior can be seen by noting that at low frequencies the capacitor dominates the series impedance, while its effect is negligible at high frequencies.

2. Consider the emitter-follower circuit depicted in Figure L.4.4 of the laboratory manual. Change the input capacitance to 0.1μF and the emitter resistance to 15k. Discuss the gain, $f_{3\mathrm{dB}}$, and input and output impedances for this circuit.

Answer: Since the emitter and base voltage difference is approximately constant, the gain will be unity. The input impedance far above $f_{3\mathrm{dB}}$ is

$$Z_{\mathrm{in}} = 130k \parallel 150k \parallel \beta R_E \simeq 130k \parallel 150k \parallel 1.5M \simeq 67k \quad , \tag{5}$$

where we took $\beta \simeq 100$. Hence the circuit acts like a high-pass filter with $C = 0.1\mu$F and $R \simeq 67k$, and $f_{3\mathrm{dB}} = (2\pi RC)^{-1} = (2\pi[67 \times 10^3][0.1 \times 10^{-6}])^{-1} \simeq 24$ Hz. The output impedance is $\{(Z_{\mathrm{FG}}[= 50] \parallel 130k \parallel 150k)/\beta + r_e\} \parallel 15k \simeq r_e \simeq 50\Omega$, where Z_{FG} is the output impedance of the function generator. (See the bottom of p. 103, lab manual. For a high-impedance input one would get instead about 711Ω for the circuit's output impedance.) The emitter resistance is 50 Ω because the quiescent emitter current is about 0.5 mA.

3. Consider the grounded-emitter circuit depicted in Figure L.5.4 of the laboratory manual. Omit (for now) the input capacitance, change the bias network to 100k (upper resistor) and 12k (lower resistor), and the collector resistor to 6.8 k. Discuss the gain, input and output impedances, quiescent current, and quiescent voltages for this circuit. How would you go about measuring the input and output impedances?

Answer: The (AC signal) gain is determined by the intrinsic emitter resistance r_e since the 15μF capacitance bypasses the 1 k emitter resistance for AC signals of sufficiently high frequency. Thus one must first calculate the quiescent voltages and emitter current. The bias network sets the base voltage at about 1.6 V, so the emitter voltage is roughly 1 V and the quiescent emitter current is 1 mA. Then $r_e \simeq 25\Omega$ for small signals which do not change the current appreciably. Approximately the same currents flow in the emitter and the collector. The change in emitter voltage is approximately the same as the change in the base (input) voltage, so $G = V_{\mathrm{out}}/V_{\mathrm{in}} = -R_C/r_e = -6.8k/25 \simeq -272$.

Several methods are suitable for measuring the input and output impedances. For input impedance, one could connect a large blocking capacitor (with negligible reactance at the signal frequency) in series with a resistor R_{test} between the function generator and the input to the circuit. The input impedance would be that value of R_{test} which cuts the signal in half. Another way would be to use a blocking capacitor of known value C between the function generator and the circuit and to measure $f_{3\mathrm{dB}}$. The system would be behaving like a high-pass filter. Assuming the input impedance is resistive, it would be $R_{\mathrm{in}} = (2\pi f_{3\mathrm{dB}} C)^{-1}$. One should find $Z_{\mathrm{in}} = 100\mathrm{k} \parallel 12\mathrm{k} \parallel \beta r_e \simeq 100\mathrm{k} \parallel 12\mathrm{k} \parallel 2.5\mathrm{k} \simeq 2\mathrm{k}$.

Similarly, for output impedance, one could connect a large bypass capacitor in series with a resistor R_{test} from the output to ground. The output impedance would be that value of R_{test} which cuts the signal in half. Or, one could use a bypass capacitor of known value C to ground. The system would be behaving like a low-pass filter. Assuming the output impedance is resistive, it would be $R_{\mathrm{out}} = (2\pi f_{3\mathrm{dB}} C)^{-1}$. One should find $Z_{\mathrm{out}} \simeq 6.8\mathrm{k}$. A simple way to visualize this is to think of the amplifier as providing a fixed current swing applied to the collector resistor.