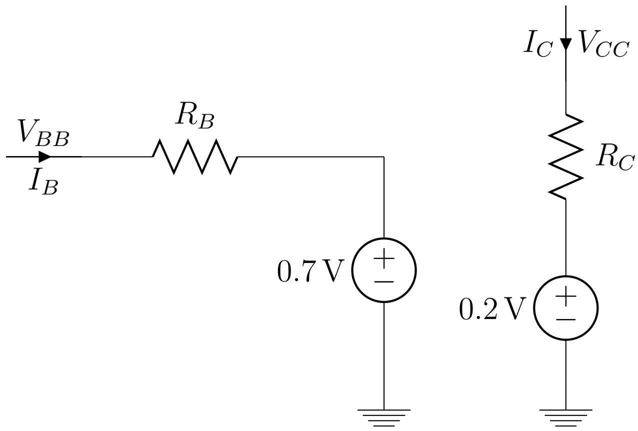
Task 1



(a) Basic Circuit A (b) Basic Circuit B

Figure 1: Basic circuits

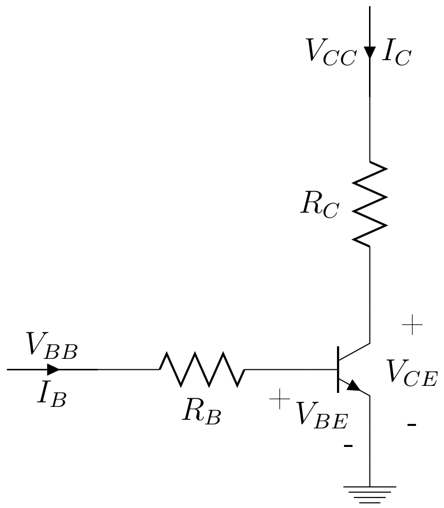


Figure 2: Transistor circuit

Task 1.a

Figure 1 shows two basic circuits. Find an expression for I_B and I_C.

In saturation the transistor in Figure 2 has the following characteristics:

$$I_B \geq \frac{I_C}{\beta}$$
$$V_{BE} = 0.7\,\text{V}, \qquad V_{CE} = 0.2\,\text{V}$$
$$\beta = 100$$

Task 1.b

Find the expression for I_B and I_C.

Hint: $V_{RX} = \text{V}_{XX} - V_{XE}$

Task 1.c

Show that the following equation ensures saturation

$$R_B \leq \beta R_C \frac{V_{BB} - 0.7}{V_{CC} - 0.2}$$

Task 1.d

Given the component values in Table 1, find I_B, I_C and an appropriate value for R_B

Component	Value
V_{CC}	5 V
V_{BB}	5 V
R_C	10 kΩ

Table 1: Component values

Task 1 Solution

Task 1.a Solution

$$V_{R_B} = V_{BB} - 0.7\,\text{V}$$
$$I_B = \frac{V_{R_B}}{R_B} = \underline{\underline{\frac{V_{BB} - 0.7\,\text{V}}{R_B}}}$$

$$V_{R_C} = V_{CC} - 0.2\,\text{V}$$
$$I_C = \frac{V_{R_C}}{R_C} = \underline{\underline{\frac{V_{CC} - 0.2\,\text{V}}{R_C}}}$$

Task 1.b Solution

$$V_{R_B} = V_{BB} - V_{BE}$$
$$I_B = \frac{V_{R_B}}{R_B} = \underline{\underline{\frac{V_{BB} - 0.7\,\text{V}}{R_B}}}$$

$$V_{R_C} = V_{CC} - V_{BE}$$
$$I_C = \frac{V_{R_C}}{R_C} = \underline{\underline{\frac{V_{CC} - 0.2\,\text{V}}{R_C}}}$$

Task 1.c Solution

$$I_B \geq \frac{I_C}{\beta}$$
$$\frac{V_{BB} - 0.7\,\text{V}}{R_B} \geq \frac{\frac{V_{CC}-0.2\,\text{V}}{R_C}}{\beta}$$
$$\underline{\underline{R_B \leq \frac{V_{BB} - 0.7\,\text{V}}{V_{CC} - 0.2\,\text{V}}\beta R_C}}$$

Task 1.d Solution

$$I_C = \frac{5\,\text{V} - 0.2\,\text{V}}{10\,\text{k}\Omega} = \underline{\underline{480\,\mu\text{A}}}$$
$$R_B \leq \frac{5\,\text{V} - 0.7\,\text{V}}{5\,\text{V} - 0.2\,\text{V}} 100 \cdot 10\,\text{k}\Omega = 89\,503\,\Omega$$
$$\Rightarrow R_B = \underline{\underline{80\,\text{k}\Omega}}$$
$$I_B = \frac{5\,\text{V} - 0.7\,\text{V}}{80\,\text{k}\Omega} = \underline{\underline{53.75\,\mu\text{A}}}$$

Task 2

Task 2.a

Consider the circuit in Figure 3. What is V_{OUT} if V_{IN} is a DC power supply?

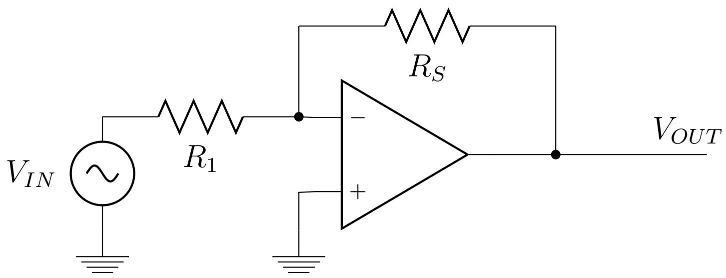


Figure 3: Inverted amplifier

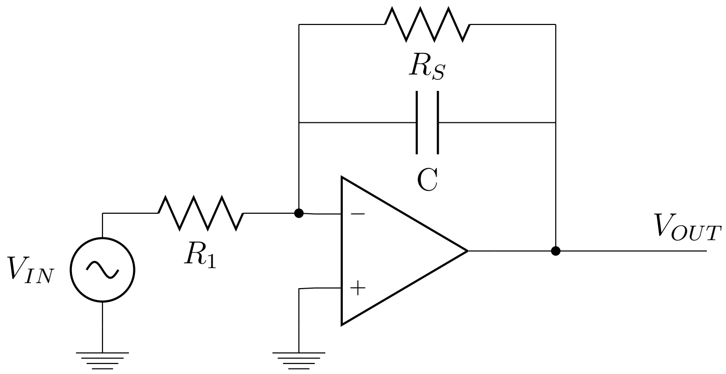


Figure 4: Active low-pass filter

Task 2.b

Consider the circuit in Figure 4. If R_S is removed, then

$$\frac{d}{dt}V_{OUT} = -\frac{1}{R_1 C}V_{IN}$$

What is the equivalent equation if R_S is added?

Task 2.c

Using $V_{IN} = V_0 e^{j\omega t}$, show that

$$V_{OUT} = -\frac{R_S}{R_1}\frac{V_0}{1 + j\omega C R_S}e^{j\omega t}$$

Task 2.d

Using $R_S = R_1 = 1\,\mathrm{k\Omega}$, $C = 1\,\mu\mathrm{F}$ and $V_0 = 10\,\mathrm{V}$, calculate V_{OUT} for each ω as shown in Table 2.

ω	V_{OUT}
$10\,\mathrm{rad\,s^{-1}}$	
$100\,\mathrm{rad\,s^{-1}}$	
$1000\,\mathrm{rad\,s^{-1}}$	
$10\,000\,\mathrm{rad\,s^{-1}}$	
$100\,000\,\mathrm{rad\,s^{-1}}$	

Table 2: Result table for V_{OUT}

Task 2 Solution

Task 2.a Solution

On the amplifier we have that $V_{AMP.IN-} = V_{AMP.IN+} = 0V$. This means that:

$$I_{IN} = -I_{OUT}$$
$$\Rightarrow \frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{R_S}$$
$$\Rightarrow V_{OUT} = -\frac{R_S}{R_1}V_{IN}$$

Task 2.b Solution

$$I_C + I_{R_S} + I_{R_1} = 0$$
$$\frac{d}{dt}CV_{OUT} + \frac{V_{R_S}}{R_S} + \frac{V_{R_1}}{R_1} = 0$$
$$\frac{d}{dt}V_{OUT} = -\frac{V_{R_S}}{CR_S} - \frac{V_{R_1}}{CR_1}$$

Task 2.c Solution

$$I_{IN} + I_{OUT} = 0$$
$$\frac{V_{IN}}{Z_{IN}} = -\frac{V_{OUT}}{Z_{OUT}}$$
$$\frac{1}{Z_{OUT}} = \frac{1}{Z_{R_C}} + \frac{1}{Z_C} = \frac{1}{R_S} + \frac{1}{\frac{1}{j\omega C}} = \frac{R_S}{1 + j\omega C R_S}$$
$$V_{OUT} = \frac{R_S}{R_1}\frac{V_{IN}}{1 + j\omega C R_S}$$
$$\Rightarrow \frac{R_S}{R_1}\frac{V_0}{1 + j\omega C R_S}e^{j\omega t}$$

Task 3

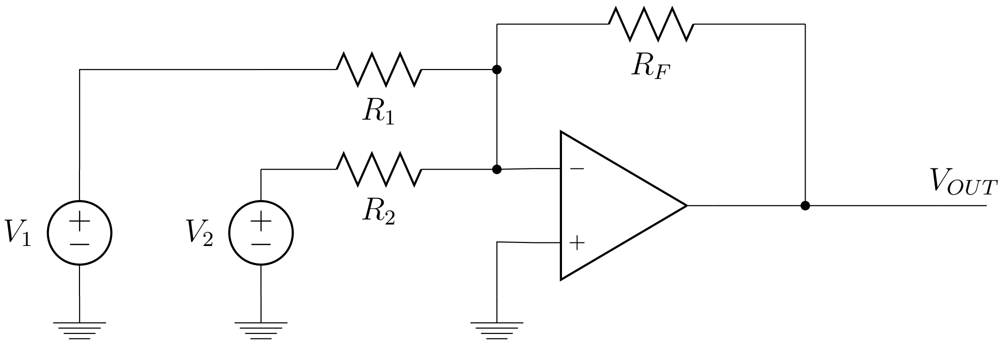


Figure 5: Inverting summer circuit

Task 3.a

Determine an equation for the output voltage V_{OUT} in Figure 5 given that $R_1 = R_2 = R_F = R$. Is the name of the circuit appropriate?

Task 3.b

Calculate the voltage on the negative and positive pin on the op amp, and the output voltage V_{OUT}, given that $V_1 = 6\,\text{V}$, $V_2 = 7\,\text{V}$ and $R_1 = R_2 = R_F = R = 1\,\text{k}\Omega$.

Task 3.c

What happens to the output voltage if $R_F = 2R_1 = 2R_2$

Task 3 Solution

Task 3.a Solution

$$I_1 + I_2 + I_F = 0$$
$$\frac{V_1}{R} + \frac{V_2}{R} = -\frac{V_{OUT}}{R}$$
$$\underline{\underline{V_{OUT} = -(V_1 + V_2)}}$$

Task 3.b Solution

Since the positive pin on the amplifier is connected to ground, then the voltage is $0\,\text{V}$. Since there is a connection between the out pin and the negative pin, then the negative pin will also be the same as the positive pin. The negative pin is therefore $0\,\text{V}$

V_{OUT} is calculated from the previous formula, and is $-13\,\text{V}$.

Task 3.c Solution

Setting $R_f = R$ and $R_1 = R_2 = 2R$.

$$
\begin{gathered}
I_1 + I_2 + I_F = 0 \\
\frac{V_1}{2R} + \frac{V_2}{2R} = -\frac{V_{OUT}}{R} \\
\underline{\underline{V_{OUT} = -\frac{V_1 + V_2}{2}}}
\end{gathered}
$$