ENGR 305 Lab #7: NPN at DC

Sean Balbale

October 16, 2025

Part 1: NPN in Active Mode

This section requires designing the circuit such that the NPN transistor is biased in the active region, meeting the specified operating conditions.

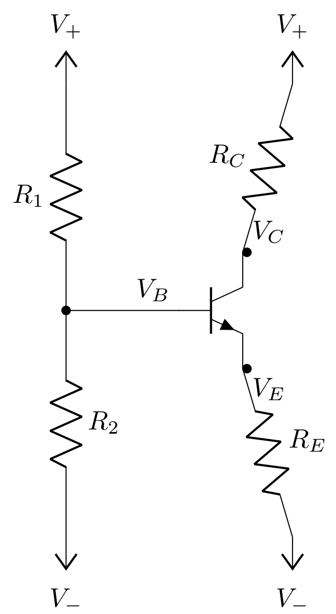
Given Parameters

- Collector Current (I_C): 1 mA
- Base Voltage (V_B): 0 V
- Collector Voltage (V_C): +5 V
- Supply Voltages: $V_+ = +15$ V, $V_- = -15$ V
- DC Current Gain (β): 100

Circuit Diagram

The circuit is a standard four-resistor biasing network for an NPN BJT.

Part 1 & 2: NPN Biasing Circuit



1. Calculate Base and Emitter Currents (I_B and I_E)

The base current (I_B) is found by dividing the collector current by the DC current gain, β.

$$I_B = \frac{I_C}{\beta} = \frac{1 \text{ mA}}{100} = 0.01 \text{ mA} = \mathbf{10}\ \boldsymbol{\mu}\mathbf{A}$$

The emitter current (I_E) is the sum of the collector and base currents.

$$I_E = I_C + I_B = 1 \text{ mA} + 0.01 \text{ mA} = \mathbf{1.01 \ mA}$$

2. Calculate Emitter Voltage (V_E)

Assuming the transistor is in the active region, the voltage drop from base to emitter (V_{BE}) is approximately 0.7 V.

$$V_{BE} = V_B - V_E \approx 0.7 \text{ V}$$

$$V_E = V_B - 0.7 \text{ V} = 0 \text{ V} - 0.7 \text{ V} = \mathbf{-0.7 \ V}$$

3. Calculate Resistor Values (R_E and R_C)

Using Ohm's law, we can find the required resistance for the emitter and collector resistors.

$$R_E = \frac{V_E - V_-}{I_E} = \frac{-0.7 \text{ V} - (-15 \text{ V})}{1.01 \text{ mA}} = \frac{14.3 \text{ V}}{1.01 \text{ mA}} \approx \mathbf{14.16 \ k\Omega}$$

$$R_C = \frac{V_+ - V_C}{I_C} = \frac{15 \text{ V} - 5 \text{ V}}{1 \text{ mA}} = \frac{10 \text{ V}}{1 \text{ mA}} = \mathbf{10 \ k\Omega}$$

4. Calculate Voltage Divider Resistors (R_1 and R_2)

The base voltage is set by the voltage divider. Since we need $V_B = 0$ V with symmetric supply rails (± 15 V), the resistors must be equal.

$$V_B = \frac{R_2 V_+ + R_1 V_-}{R_1 + R_2} \implies 0 = \frac{15R_2 - 15R_1}{R_1 + R_2} \implies \mathbf{R_1 = R_2}$$

The problem is not fully specified. To proceed, we make the divider "stiff" by setting the current through it to be about 10 times the base current ($10 \times 10\mu\text{A} = 0.1$ mA).

$$I_{divider} = \frac{V_+ - V_-}{R_1 + R_2} = \frac{30 \text{ V}}{R_1 + R_2} = 0.1 \text{ mA}$$

$$R_1 + R_2 = \frac{30 \text{ V}}{0.1 \text{ mA}} = 300 \text{ k}\Omega$$

Since $R_1 = R_2$, the values are:

$$R_1 = R_2 = \mathbf{150 \ k\Omega}$$

Part 2: NPN in Saturation Mode

In this part, the circuit is redesigned to bias the NPN transistor in the saturation region.

Given Parameters

- Collector Current (I_C): 1 mA
- Emitter Current (I_E): 1.2 mA
- Collector Voltage (V_C): +2 V
- Collector-Emitter Saturation Voltage ($V_{CE(sat)}$): 0.2 V
- Supply Voltages: $V_+ = +15$ V, $V_- = -15$ V

1. Calculate Emitter and Base Voltages (V_E and V_B)

The emitter voltage (V_E) is found using the given V_C and V_{CE}.

$$V_{CE} = V_C - V_E \implies V_E = V_C - V_{CE}$$
$$V_E = 2\text{ V} - 0.2\text{ V} = \mathbf{1.8\ V}$$

For a saturated transistor, the base-emitter voltage drop ($V_{BE(sat)}$) is typically assumed to be 0.8 V.

$$V_{BE(sat)} = V_B - V_E \approx 0.8\text{ V}$$
$$V_B = V_E + 0.8\text{ V} = 1.8\text{ V} + 0.8\text{ V} = \mathbf{2.6\ V}$$

2. Calculate Resistor Values (R_C and R_E)

The resistor values are found using Ohm's law with the given specifications.

$$R_C = \frac{V_+ - V_C}{I_C} = \frac{15\text{ V} - 2\text{ V}}{1\text{ mA}} = \frac{13\text{ V}}{1\text{ mA}} = \mathbf{13\ k\Omega}$$
$$R_E = \frac{V_E - V_-}{I_E} = \frac{1.8\text{ V} - (-15\text{ V})}{1.2\text{ mA}} = \frac{16.8\text{ V}}{1.2\text{ mA}} = \mathbf{14\ k\Omega}$$

3. Calculate Forced Beta (β_{forced})

First, calculate the base current (I_B) required to satisfy the given emitter and collector currents.

$$I_B = I_E - I_C = 1.2\text{ mA} - 1\text{ mA} = \mathbf{0.2\ mA}$$

The forced beta is the ratio of I_C to I_B when the transistor is in saturation.

$$\beta_{forced} = \frac{I_C}{I_B} = \frac{1\text{ mA}}{0.2\text{ mA}} = \mathbf{5}$$

Since $\beta_{forced} \ll \beta_{active}$, the design will successfully drive the transistor into saturation.

4. Calculate Voltage Divider Resistors (R_1 and R_2)

The voltage divider must provide $V_B = 2.6$ V.

$$V_B = \frac{R_2 V_+ + R_1 V_-}{R_1 + R_2} \implies 2.6 = \frac{15R_2 - 15R_1}{R_1 + R_2}$$
$$2.6(R_1 + R_2) = 15(R_2 - R_1) \implies 17.6R_1 = 12.4R_2 \implies R_2 \approx 1.42R_1$$

Using the stiff divider rule (divider current $\approx 10 \times I_B = 10 \times 0.2$ mA $= 2$ mA):

$$R_1 + R_2 = \frac{V_+ - V_-}{I_{divider}} = \frac{30\text{ V}}{2\text{ mA}} = 15\text{ k}\Omega$$

Solving the system of equations:

$$R_1 + (1.42R_1) = 15\text{ k}\Omega \implies 2.42R_1 = 15\text{ k}\Omega \implies R_1 \approx \mathbf{6.2\ k\Omega}$$
$$R_2 = 15\text{ k}\Omega - 6.2\text{ k}\Omega = \mathbf{8.8\ k\Omega}$$