Universidade do Vale do Itajaí
Computer Engineering
Basic Electronics

Tenth Assignment for Basic Electronics

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Teacher Advisor: Walter Antonio Gontijo

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Tenth Assignment for Basic Electronics presented for the class of the Twenty Ninth of October, 2021.

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Contents

1 Objective

The analysis of multiple circuits containing *NPN* transistors.

2 Introduction

This paper will demonstrate and explain multiple transistor uses in circuits, the analysis will consist of the calculations and possible simplifications as well as simulations.

3 Switches

If a supply, normally a signal, cannot provide enough current to turn on a certain component, a transistor may be used to amplify the source, allowing a separate higher power supply to activate the component based on the initial signal.

The following current is not the standard amplifier however, it only expects a high or low signal.

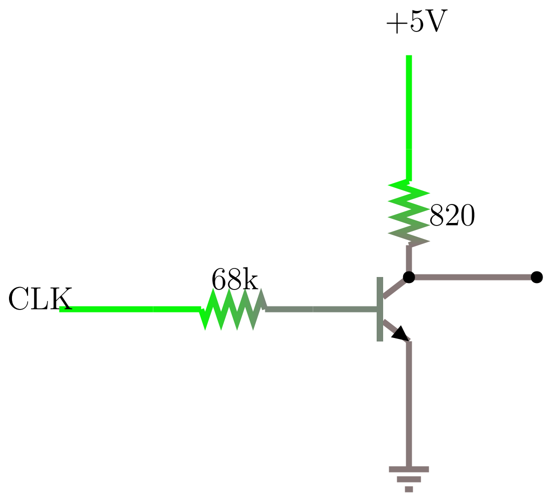

Figure 1: *NPN* transistor working as a switch, $hFe = 120$.

This circuit amplifies the signal to the corresponding voltage depending on the collector's resistor.

One can also notice the high gain, or hFe, it is in the interest of the transistor to switch at small variations of the input, since the signal might be very faint.

Although one could say that when the transistor is active and switching the voltage between the collector and emitter are zero, since it should be equivalent to a wire. That causes problems with the standard equations one uses.

When the transistor is working as a switch, one should consider.

$$0 < V_{CE} < 0.2V$$

In practice the output of the circuit should be as follows.

When the transistor is off, the current through the collector's resistor is zero, so the voltage at the output node is equal to the supply.

When the transistor is on there should be current through the transistor, since it is a switch, the maximum current should go through it and the voltage at the output node should be the expected drop based on the collector's resistor.

The behaviour should be visible in the equations as follows.

$$V_C = V_{CC} - (I_C \times R_C)$$

If the transistor is on and is switching.

$$I_C = \frac{V_{CC}}{R_C} = \frac{5V}{820} = 6.1mA$$

$$V_C = 5V - (6.1mA \times 680) = 0V$$

As one can see, when the transistor is on the voltage difference between collector and emitter is zero, which is expected since the transistor effectively became a wire.

If the transistor is off.

$$I_C = 0A$$

$$V_C = 5V - (0A \times 680) = 5V$$

The expected behaviour should be a open switch, so the voltage on the collector should be $5V$ and the emitter's $0V$.

3.1 Simulation

The simulator gives a small difference to the equations, since the equations used a simplified model where the transistor opens or closes with no resistance, the values calculated are not especially close to that of a real transistor.

The simulator does however consider voltage drops and gain on its calculations since it does not recognize a transistor as a simple switch.

$$I_{C_{on}} = 5.92mA$$

$$I_{C_{off}} = 10.2pA$$

$$V_{C_{on}} = 152mV$$

$$V_{C_{on}} = 5V$$

4 Transistor Emitter Polarization

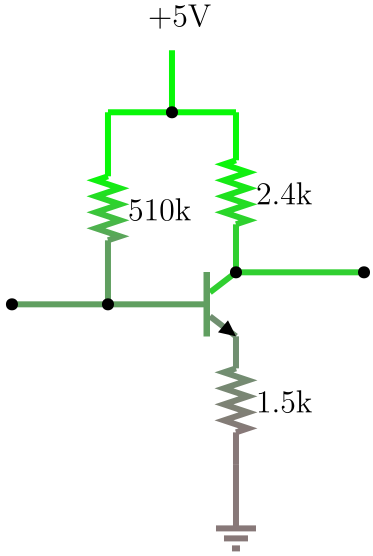

Figure 2: $hFe = 100$.

This type of amplifier circuit polarizes the emitter by placing a resistor series to ground. Since all currents pass through the emitter, this changes the standard equations slightly.

The final equations are deduced from the entry and exit loops, which are derived from the circuit above.

Entry Loop:

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

Exit Loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

Which generate the following equations

$$I_E = (\beta + 1) \times I_B$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E}$$

If $hFe \geq 100$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$V_B = V_{CC} - I_B R_B$$

$$V_E = V_B - V_{BE}$$

$$V_C = V_{CC} - I_C R_C$$

4.1 Analysis

The process to analyse the circuit however is the same as it normally would be, simply calculate the variables with the constants provided by separating the *Base Emitter* and *Collector Emitter* paths.

4.1.1 Constants

$$V_{BE} = 0.7V$$

$$R_B = 510k\Omega$$

$$R_C = 2.4k\Omega$$

$$R_E = 1.5k\Omega$$

$$\beta = 100$$

$$V_{CC} = 20V$$

4.1.2 Base Emitter

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} = \frac{20 - 0.7}{(510 \times 1000) + (100 + 1) \times (1.5 \times 1000)} = 29.18\mu A$$

Since $hFe \geq 100$

$$I_E = (\beta + 1) \times I_B = (100 + 1) \times 29.18 = 2.94mA$$

$$V_B = V_{CC} - I_B R_B = 20 - (29.18\mu \times (510 \times 1000)) = 5.12V$$

$$V_E = V_B - V_{BE} = 5.12 - 0.7 = 4.42V$$

4.1.3 Collector Emitter

$$I_E = I_B + I_C$$
$$I_C = I_E - I_B = 2.94m - 29.18\mu = 2.917mA$$

$$V_C = V_{CC} - I_C R_C = 20 - (2.917m \times (2.4 \times 1000)) = 13V$$
$$V_{CE} = V_C - V_E = 13 - 4.42 = 8.28V$$

4.2 Simulation

The simulator has a different V_{BE} constant than what was used in the analysis, so the values will be slightly different.

	Analysis ($V_{BE} = 0.7$)	Simulation ($V_{BE} = 0.623$)
I_B	$29.18\mu A$	$29.292\mu A$
I_E	$2.94mA$	$2.958mA$
I_C	$2.917mA$	$2.929mA$
V_B	$5.12V$	$5.061V$
V_E	$4.42V$	$4.438V$
V_C	$13V$	$12.97V$
V_{CE}	$8.28V$	$8.532V$

5 Base Polarization Through Voltage Dividers

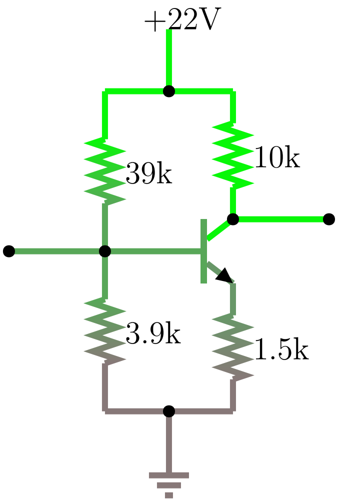

Figure 3: $hFe = 140$.

In essence, this circuit is similar to the before-mentioned circuit if the *Thevenin Theorem* is used.

Since this is a voltage divider at the base, the theorem will go as follows.

$$R_{Th} = R_1 | R_2$$

$$E_{Th} = \frac{R_2}{R_1 + R_2} V_{CC}$$

The same principles will apply with the input and output loops.

Input Loop

$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

Output Loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

The following equations can be gathered.

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1) R_E}$$

If $\beta \geq 100$

$$I_C \approx I_E$$

$$V_{CE} = V_{CC} - I_C\left(R_C + R_E\right)$$

$$V_B = E_{Th} - I_B R_{Th}$$

$$V_E = V_B - V_{BE}$$

$$V_C = V_{CC} - I_C R_C$$

5.1 Circuit Analysis

The analysis will be the same as the before-mentioned circuit except for the new *Thevenin Theorem* parameters.

5.1.1 Constants

$$R_1 = 39k\Omega$$
$$R_2 = 3.9k\Omega$$
$$R_C = 10k\Omega$$
$$R_E = 1.5k\Omega$$
$$\beta = 140$$
$$V_{CC} = 22V$$
$$V_{BE} = 0.7V$$

5.2 Thevenin Theorem

$$R_{Th} = R_1|R_2 = \frac{39k \times 3.9k}{39k + 3.9k} = 3545.45\Omega = 3.545k\Omega$$

$$E_{Th} = \frac{3.9k}{39k + 3.9k}22 = 2V$$

5.3 Base Emitter

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)\,R_E} = \frac{2 - 0.7}{3.54k + (140 + 1)\,1.5k} = 6.045\mu A$$

$$I_E = (\beta + 1) \times I_B = (140 + 1)\,6.045\mu = 0.852mA$$

$$V_B = E_{Th} - I_B R_{Th} = 2 - 6.045\mu 3.54k = 1.98V$$

$$V_E = V_B - V_{BE} = 1.98 - 0.7 = 1.28V$$

5.4 Collector Emitter

$$I_C = I_E - I_B = 0.852m - 6.045\mu = 0.852mA$$

$$V_C = V_{CC} - I_C R_C = 22 - (0.852m \times 10k) = 13.48V$$

$$V_{CE} = V_C - V_E = 13.48 - 1.28 = 12.2V$$

6 Base Polarization Simplification

Under the condition that:

$$\beta R_E \geq 10 R_2$$

A simplification can be assumed, and the following simplification equations can be used.

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$V_E = V_B - V_{BE}$$

$$I_E = \frac{V_E}{R_E}$$

$$I_{C_Q} \approx I_E$$

$$V_{CE_Q} = V_{CC} - I_C \left(R_C + R_E \right)$$

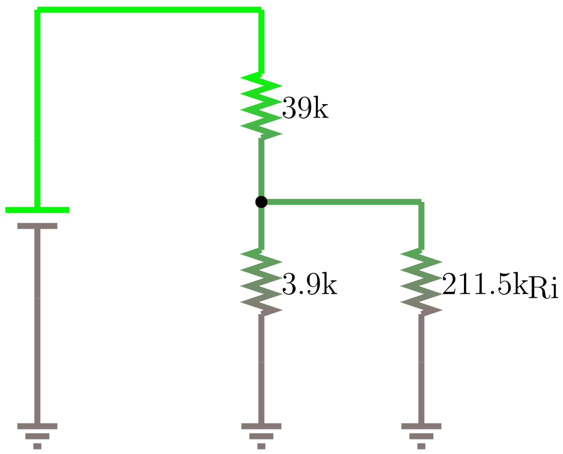

Figure 4: $hFe = 140$. $R_i = (\beta + 1) R_E$

6.1 Simplified Circuit Analysis

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{3.9k \times 22}{39k + 3.9k} = 2V$$

$$V_E = V_B - V_{BE} = 2 - 0.7 = 1.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{1.3}{1.5k} = 0.87mA$$

$$V_{CE_Q} = V_{CC} - I_C\left(R_C + R_E\right) = 22 - 0.87m\left(10k + 1.5k\right) = 12.034V$$

All other values can be found with the normal equations.

6.2 Comparing Results

These are the results from the normal analysis, the simulation of the normal analysis and the simplification analysis.

	Analysis ($V_{BE} = 0.7$)	Simulation ($V_{BE} = 0.593$)	Simplification
I_B	$6.045\mu A$	$6.541\mu A$	
I_E	$0.852mA$	$0.922mA$	$0.87mA$
I_C	$0.852mA$	$0.916mA$	
V_B	$1.98V$	$1.977V$	$2V$
V_E	$1.28V$	$1.384V$	$1.3V$
V_C	$13.48V$	$12.842V$	
V_{CE}	$12.2V$	$11.458V$	$12.034V$

7 Supply Re-polarization

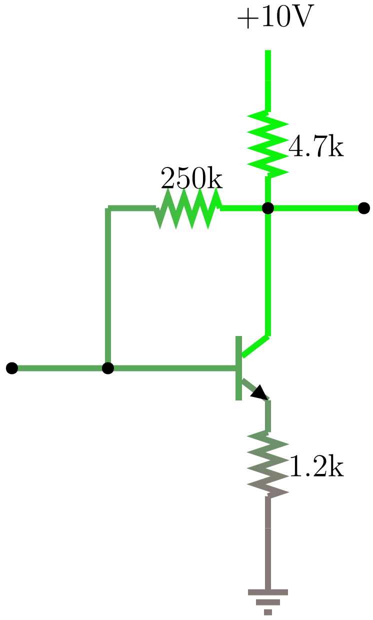

Figure 5: $hFe = 90$

Supply re-polarization ensures the transistor is always on and active, amplifying the signal causes the transistor to conduct even more, increasing I_E and lowering the voltage at the collector.

In essence, it inverts the input signal at the collector, since the voltage at the collector lowers as the voltage at the base increases.

Input Loop

$$V_{CC} - \beta I_B R_C - I_B R_B - V_{BE} - \beta I_B R_E = 0$$

Output Loop

$$I_E R_E + V_{CE} + I'_C R_C - V_{CC} = 0$$

The following equations can be extracted from the loops.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta\left(R_C + R_E\right)}$$

$$V_{CE} = V_{CC} - I_C\left(R_C + R_E\right)$$

7.1 Circuit Analysis

7.1.1 Constants

$$V_{BE} = 0.7V$$
$$V_{CC} = 10V$$
$$\beta = 90$$
$$R_C = 4.7k\Omega$$
$$R_B = 250k\Omega$$
$$R_E = 1.2k\Omega$$

7.1.2 Loops

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta\left(R_C + R_E\right)} = \frac{10 - 0.7}{250k + 90\left(4.7k + 1.2k\right)} = 11.91\mu A$$

$$I_E = \left(\beta + 1\right) I_B = \left(90 + 1\right) \times 11.91\mu = 1.084mA$$

Since $I_E \approx I_C$

$$V_{CE} = V_{CC} - I_C\left(R_C + R_E\right) = 10 - 1.084m\left(4.7k + 1.2k\right) = 3.607V$$

$$V_C = V_{CC} - \left(I_C R_C\right) = 10 - \left(1.084m \times 4.7k\right) = 4.91V$$

$$V_E = V_C - V_{CE} = 4.91 - 3.607 = 1.3V$$

$$V_B = V_E - V_{BE} = 1.3 - 0.7 = 0.6V$$

7.1.3 Simulation

	Analysis ($V_{BE} = 0.7V$)	Simulation ($V_{BE} = 0.597V$)
I_B	$11.91\mu A$	$11.949\mu A$
I_E	$1.084mA$	$1.087mA$
I_C	$1.084mA$	$1.075mA$
V_B	$0.6V$	$1.902V$
V_E	$1.3V$	$1.305V$
V_C	$4.91V$	$4.889V$
V_{CE}	$3.607V$	$3.585V$