EE413
Lab 138
Transistors and Amplifiers

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Abstract

This lab is meant to teach and show the practical use of bipolar junction transistor amplifiers. The lab includes constructing and measuring DC circuits, calculating biasing networks, amplification, bandwidth and plotting characteristic curves of circuit parameters.

Contents

1 Ic-Uce-characteristics

1.1 Circuit

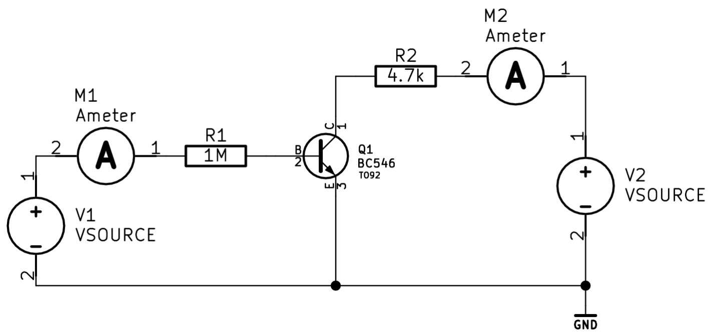

Figure 1: Measurement setup schematic

1.1.1 Fixed collector voltage

With the collector resistor R_2 left out or shorted, an adjustable power supply is connected directly across the collector-emitter junction, fixing the collector voltage. First we get the base currents for known collector currents. Adjusting voltage V_1 translates to varying the base current I_b and in turn the collector current I_c. The transistor used is a BC547C.

1.1.2 Measurements

I_c (mA)	I_b (μA)
0.5	1.14
1.0	2.11
1.8	3.72

Table 1: Measurement of I_b and I_c

The base current is then held at a constant value and the collector-emitter voltage is swept over a range of 0-10V in 1V steps. The results is given in Figure 2.

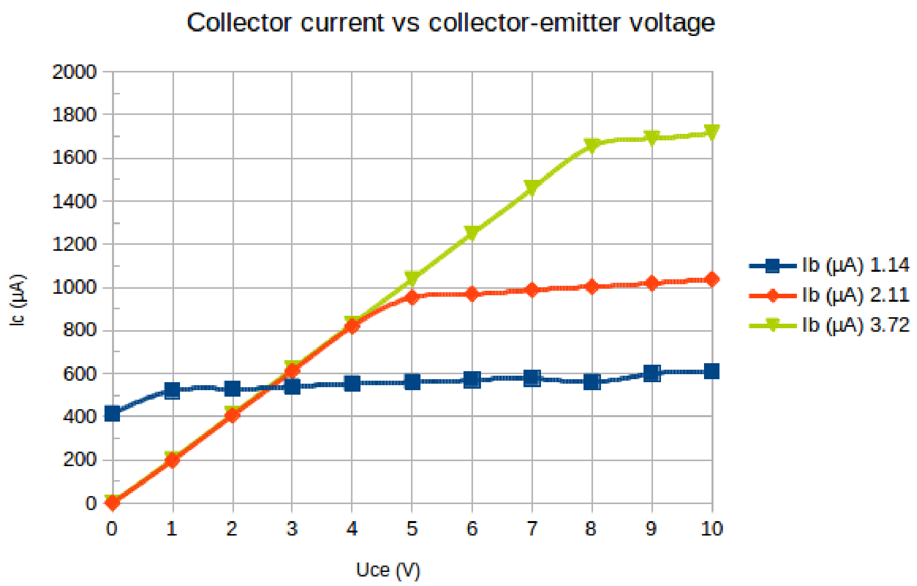

Figure 2: I_c as a function of V_{ce}

1.2 Simulation

Spice circuit simulation with the setup shown in Figure 3 confirms that measurements reflect typical bjt characteristics, shown in Figure 4. The program used is Linear Technology LTspice, with a transistor model based on transistor datasheet values.

2 Quiescent conditions

2.1 Circuit

TODO

2.2 Measurements

TODO

3 Uce/Ib transfer function

Examine the output signal of the first circuit. Determine the linearity of the output, as in the relation of U_{ce} to I_b. Uses the measurement setup and circuit shown in Figure 1. The input voltage source is low enough impedance

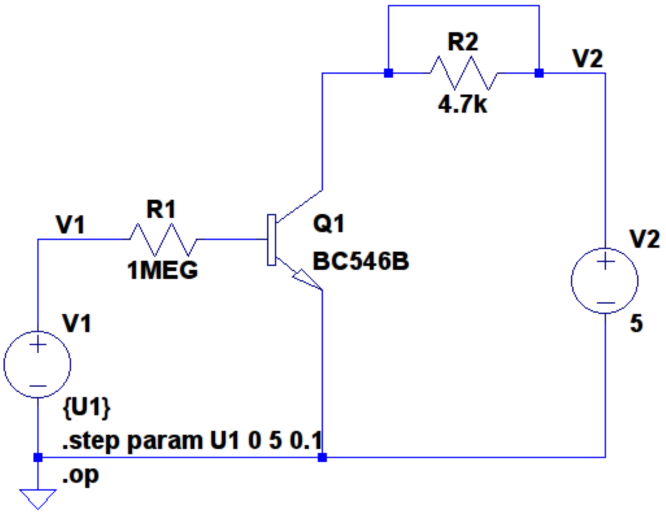

Figure 3: Simulation setup measuring I_c/V_{ce}

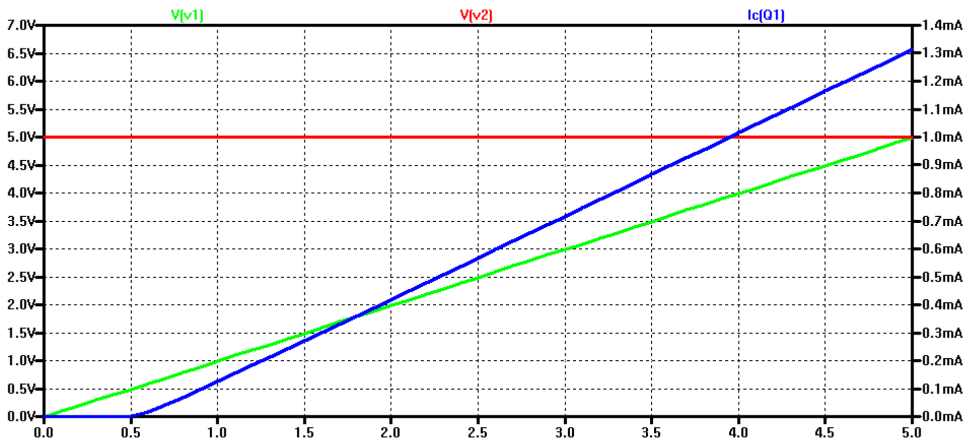

Figure 4: I_c/V_{ce} simulation plot

TODO!

Figure 5:

to be considered constant. The linear region is very small, the transistor is best used as a switch in this configuration.

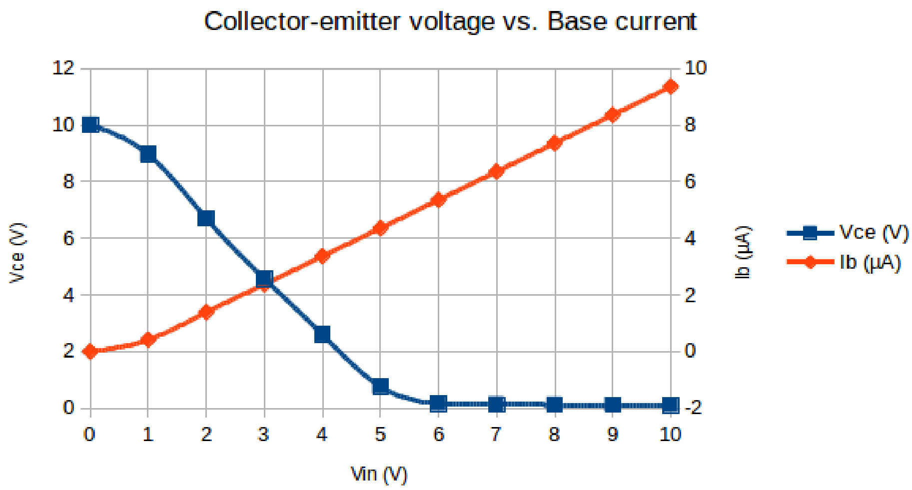

Figure 6: V_{ce} and I_b as a function of input voltage.

4 Ic/Ib characteristics and current amplification

4.1 Measurements

Circuits are simulated in LTspice.

4.2 Comments

Current gain decreases with base current. This is one of many non-ideal characteristics of the transistor. The phenomena is called a “high injection effect”. Source included in references.

5 BJT biasing

Making V_{ce} 10V maximizes the dynamic range of the amplifier, I.E. improves linearity and reduces clipping of higher amplitude signals, by centering the operating "bias" point. The available voltage is split evenly between the three droppers; collector resistor collector-emitter resistance and emitter resistor.

$R_b(\Omega)$	V_e (V)	$R_c(\Omega)$
390k	10.3	1

$R_b(\Omega)$	V_e (V)	$R_c(\Omega)$
470k	9.3	47
560k	8.2	1k
680k	7.7	1k
820k	6.8	1.2k
1M	5.9	3.3k

Table 2: Bias resistor with bias voltages

5.1 Comments

The collector resistor would have to be a short to put Vce at 10V. This method of biasing is thoroughly unpractical.

6 BJT amplifier

6.0.1 Amplification

Coupling	DC	AC
Input voltage (mV_{pp})	100	100
Output voltage (V_{pp})	0.283	9.23
Voltage gain (multiple)	2.83	91.3
Voltage gain (dB)	9.04	39.2
Phase shift (degrees)	180	150

Table 3: Amplifier gain measurements

6.0.2 Frequency response

Frequency response shows no high frequency rolloff in the audible frequency range 20Hz-20kHz. There is however a high frequency limit, set primarily by stray capacitances in breadboards and such.

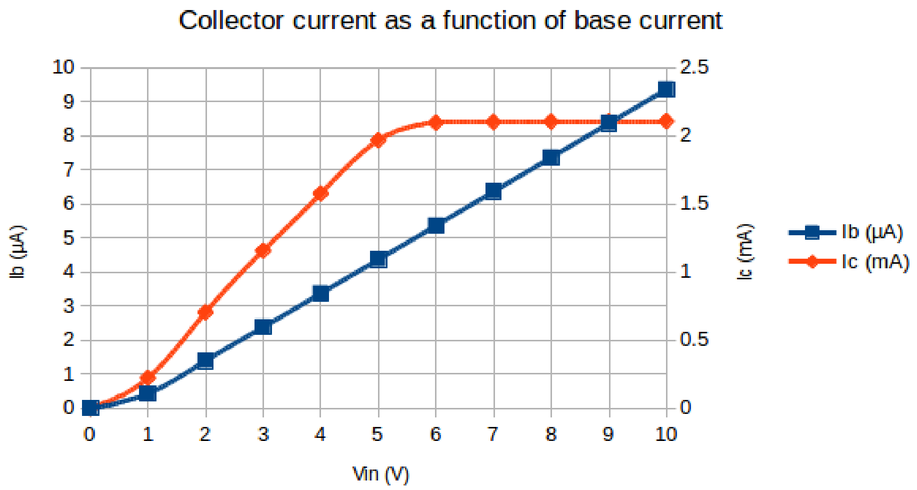

Figure 7: I_c as a function of I_b.

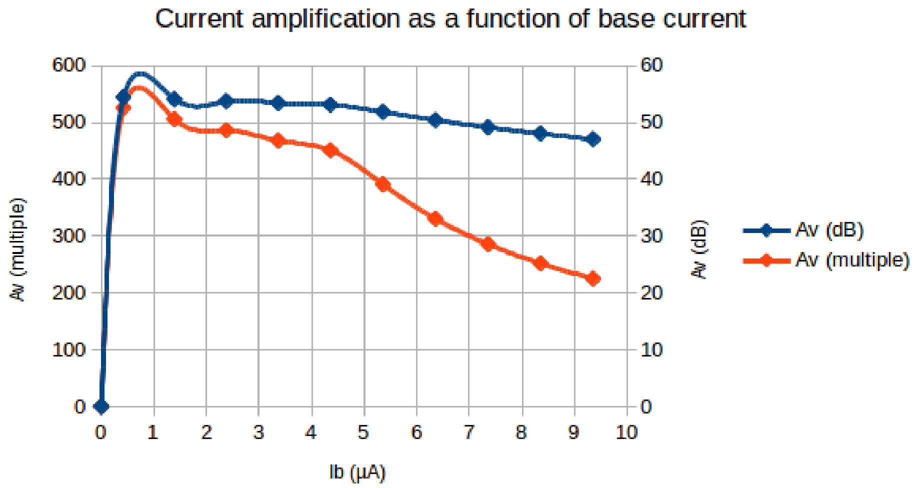

Figure 8: Current gain, β as a function of I_b.

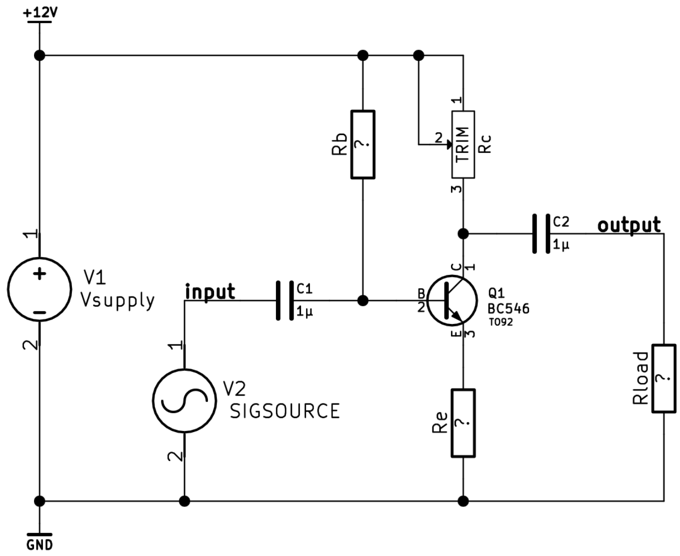

Figure 9: BJT biasing circuit.

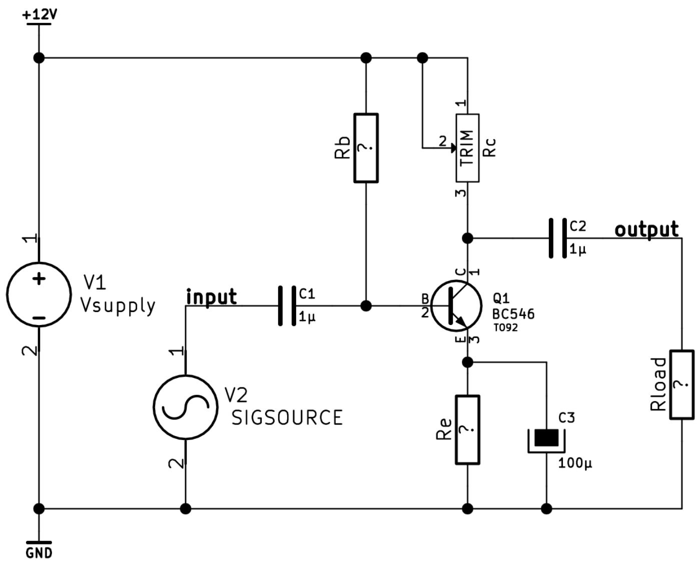

Figure 10: BJT biasing circuit.

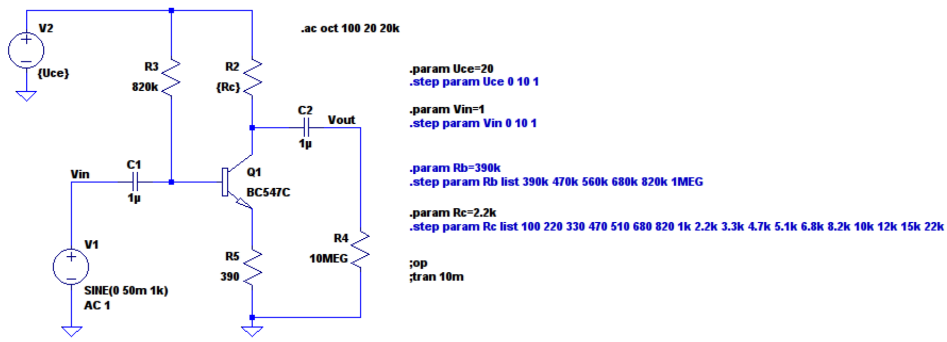

Figure 11: Amplifier frequency response circuit.

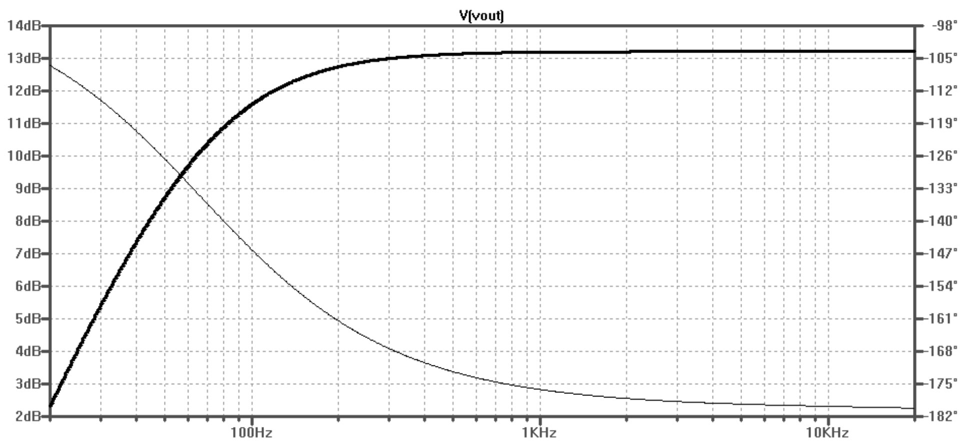

Figure 12: Amplifier frequency response and phase shift.

6.0.3 Improved biasing

The one resistor base bias is in practice not very reliable as it is dependant on transistor beta. A more practical design that scales better for production adds a second resistor, forming a voltage divider that fixes the base at a suitable level. For maximum dynamic range half of Vsupply, plus a diode drop to compensate for the base-emitter voltage.

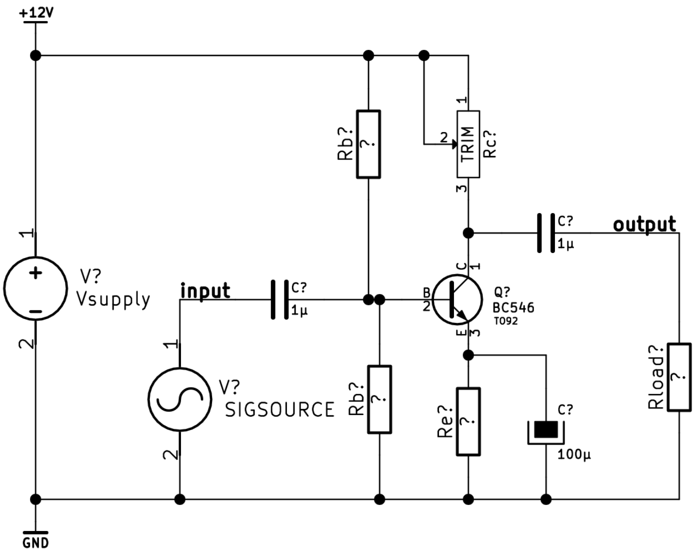

Figure 13: Voltage divider bias.

6.0.4 "Noiseless" biasing

For small signals and high input impedance, the biasing can be improved further in terms of bias voltage "stiffness" and power supply noise rejection. The bias voltage is derived from a separate low impedance voltage divider, heavily filtered and almost a short circuit as far as AC signals are concerned. The bias voltage is tapped with a higher value resistor which effectively sets the input impedance of the stage.

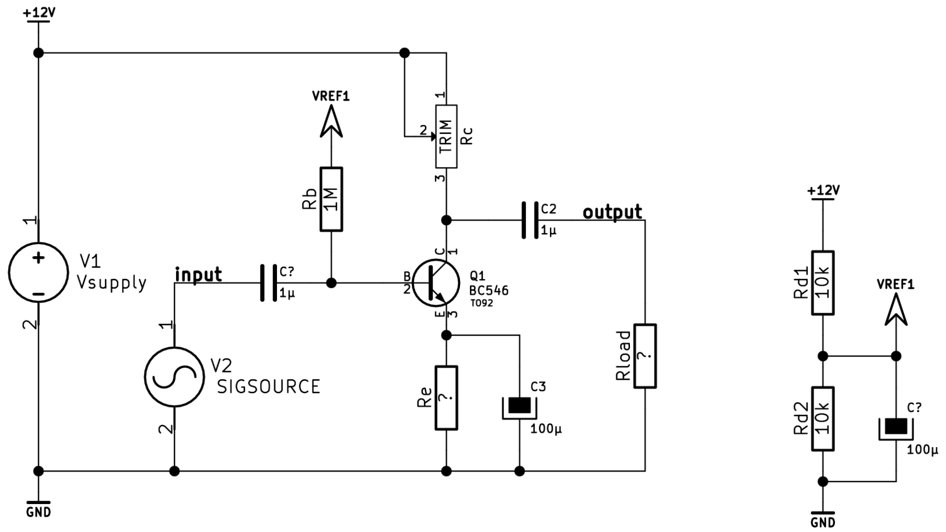

Figure 14: Voltage divider with filtered voltage reference.

7 References

7.1 www

Zeghbroech, B. Van - *High injection effects*, accessed 2014-11-28.
`http://ecee.colorado.edu/~bart/book/book/chapter5/ch5_4.htm`

7.2 Literature

Horowitz P., Hill W. - *The Art of Electronics*, Cambridge University Press 1989.
Horowitz P., Hayes T. - *Student Manual for the Art of Electronics*, Cambridge 1989.

7.3 Sources

Full source, including spice simulation files, CSV data, schematics, etc is available at `https://github.com/jonasjberg/EE413-lab01`