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 **3**
- 1.1 Circuit . . . 3
- 1.2 Fixed collector voltage . . . 3
- 1.3 Measurements . . . 3
- 1.4 Simulation . . . 4

2 Quiescent conditions **4**

3 Uce/Ib transfer function **4**

4 Ic/Ib characteristics and current amplification **7**
- 4.1 Measurements . . . 7
- 4.2 Comments . . . 7

5 BJT biasing **7**
- 5.1 Measurements . . . 7
- 5.2 Comments . . . 8

6 BJT amplifier **8**
- 6.1 Measurements . . . 8
  - 6.1.1 Amplifier gain . . . 8
  - 6.1.2 Frequency response . . . 10
- 6.2 Improved biasing . . . 10
  - 6.2.1 “Noiseless” biasing . . . 11
- 6.3 Comments . . . 12

7 References **13**
- 7.1 www . . . 13
- 7.2 Literature . . . 13
- 7.3 Sources . . . 13

1 Ic-Uce-characteristics

1.1 Circuit

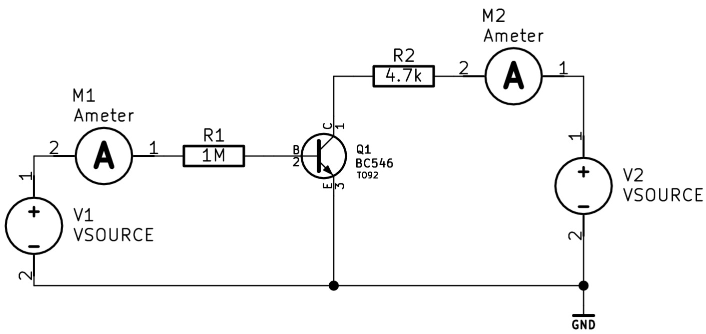

Figure 1: Measurement setup schematic

1.2 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.

1.3 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.

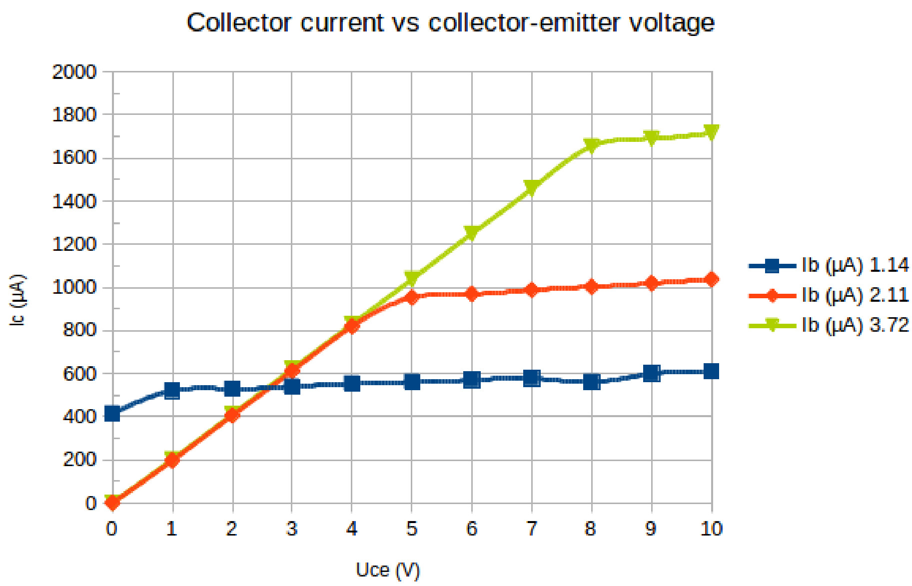

Figure 2: I_c as a function of V_{ce}

1.4 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

The calculated results for the basic circuit is shown in Figure 5.

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

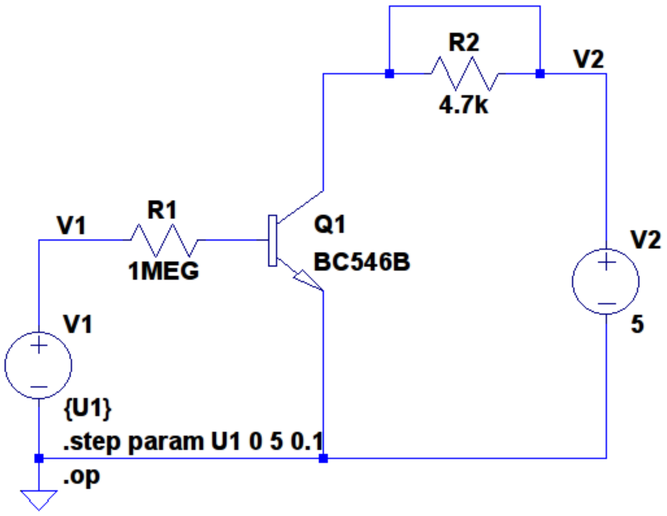

Figure 3: Simulation setup measuring I_c/V_{ce}

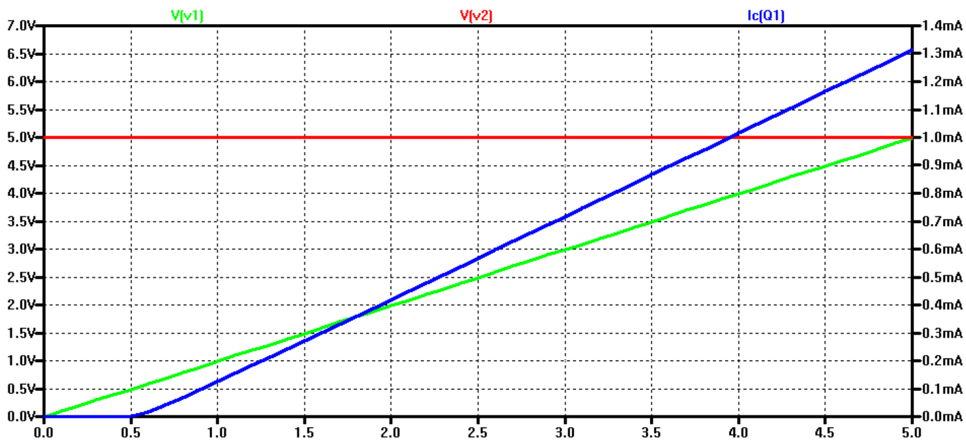

Figure 4: I_c/V_{ce} simulation plot

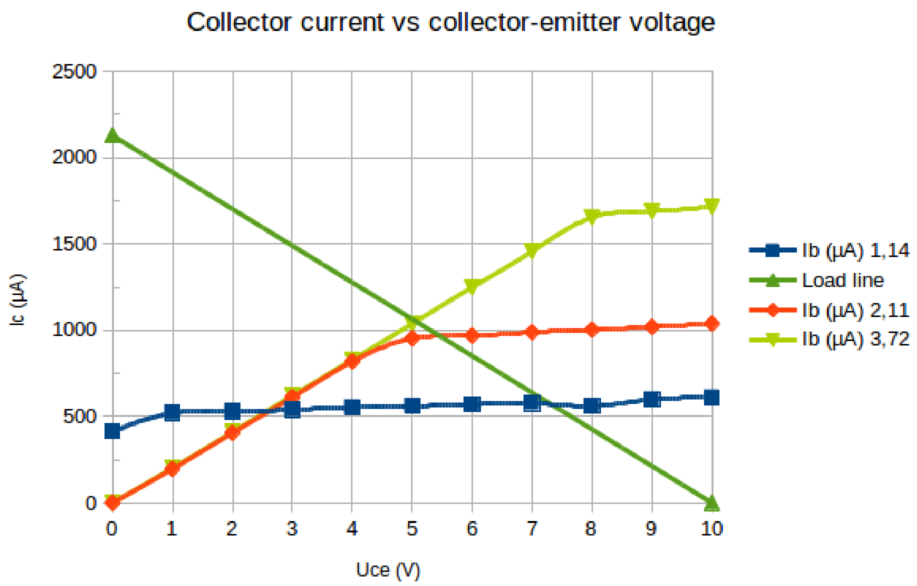

Figure 5: Calculated load line.

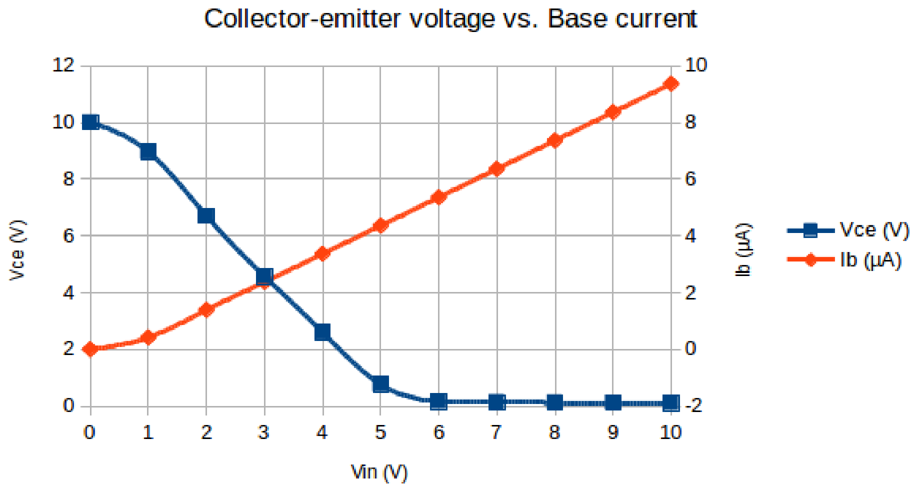

Figure 6: V_{ce} and I_b as a function of input voltage.

4 Ic/Ib characteristics and current amplification

4.1 Measurements

Results for collector current as a function of base current is shown in Figure 7. The current gain, $\beta = \frac{I_c}{I_b}$ is shown in Figure 8 as a function of base current, results in multiples and dBs.

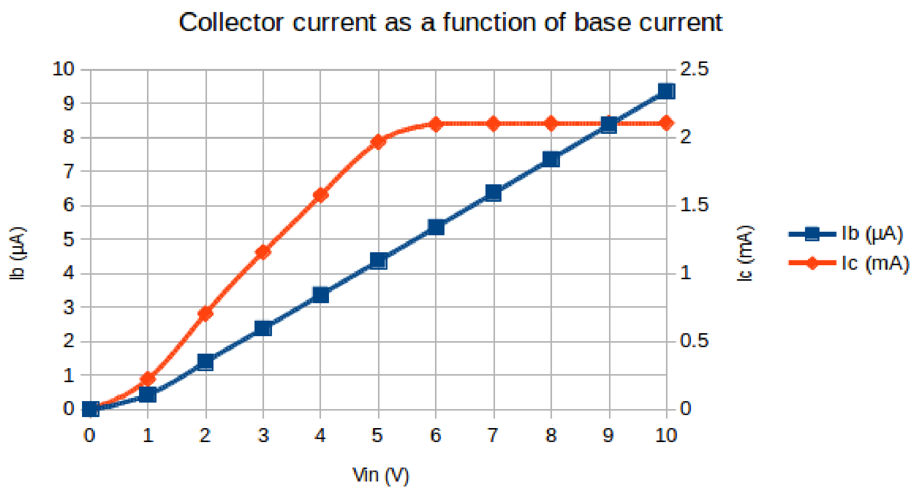

Figure 7: I_c as a function of I_b.

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

5.1 Measurements

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. The circuit used is shown in Figure 9.

$R_b(\Omega)$	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

5.2 Comments

The collector resistor would have to be a short to put Vce at 10V. We come to the conclusion that this method of biasing is thoroughly unpractical.

6 BJT amplifier

6.1 Measurements

An oscilloscope is used for measuring the amplifier gain with a 1kHz 1V peak to peak sine wave. The circuit used is shown in Figure 9, coupling is DC only. For the second measurement, a 100μF capacitor was connected across the emitter resistor, the circuit is shown in Figure 10.

6.1.1 Amplifier gain

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 (°)	180	150

Table 3: Amplifier gain measurements

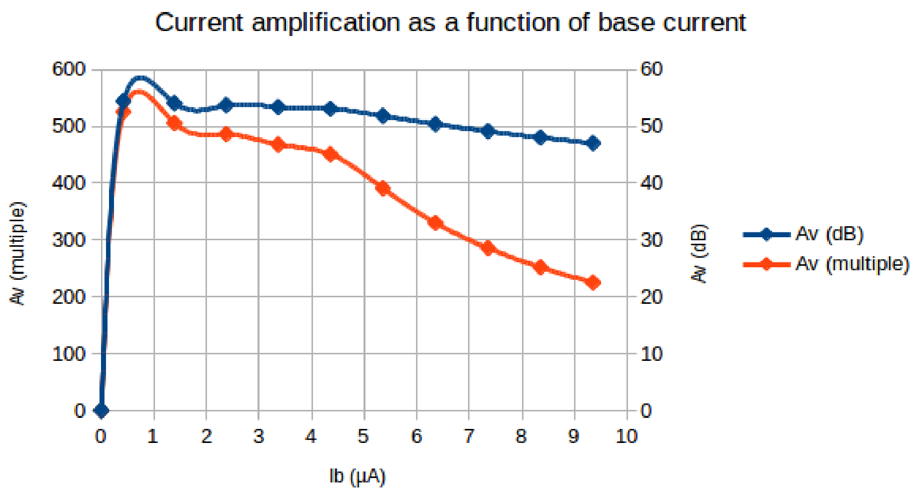

Figure 8: Current gain, β as a function of I_b.

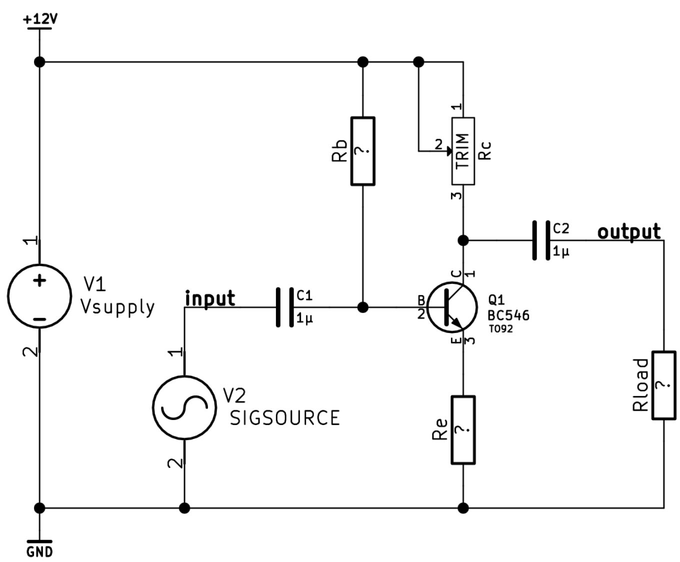

Figure 9: BJT biasing circuit, emitter impedance resistive.

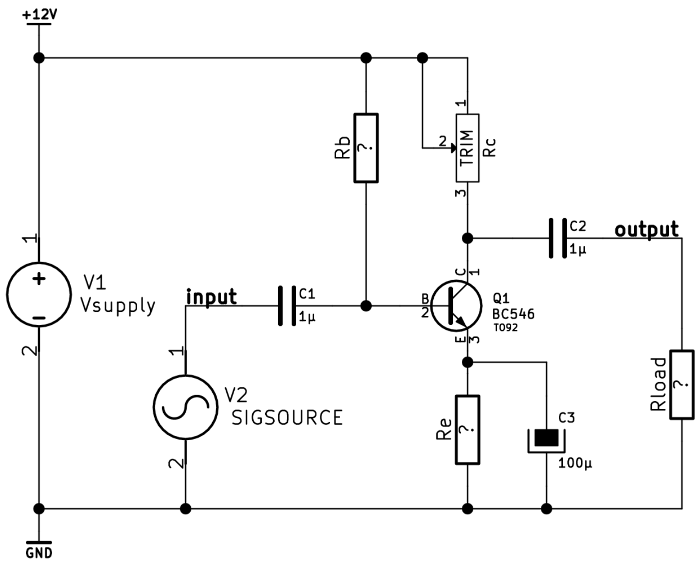

Figure 10: BJT biasing circuit, emitter AC bypassed.

6.1.2 Frequency response

Measurement results for the circuit in Figure 11 are shown in Figure 12. 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.

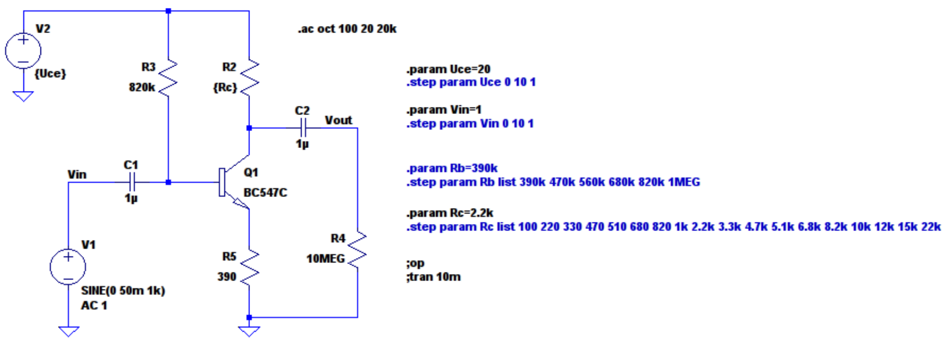

Figure 11: Amplifier frequency response circuit.

6.2 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

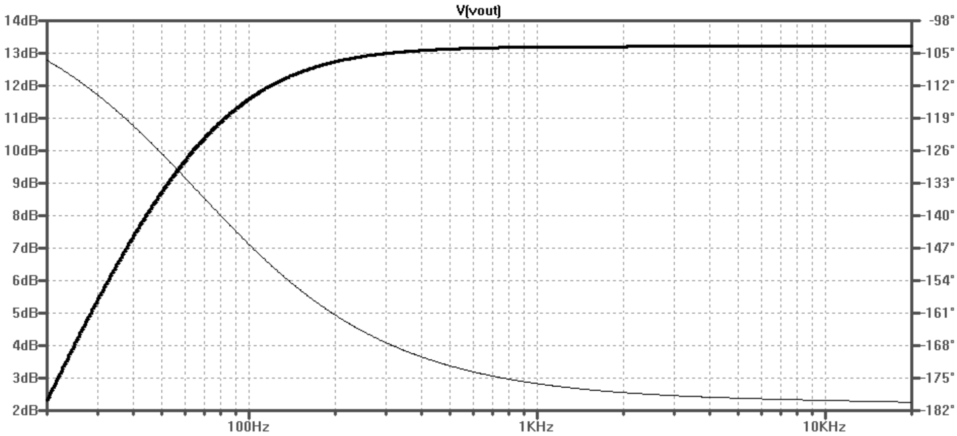

Figure 12: Amplifier frequency response and phase shift.

suitable level. For maximum dynamic range half of Vsupply, plus a diode drop to compensate for the base-emitter voltage.

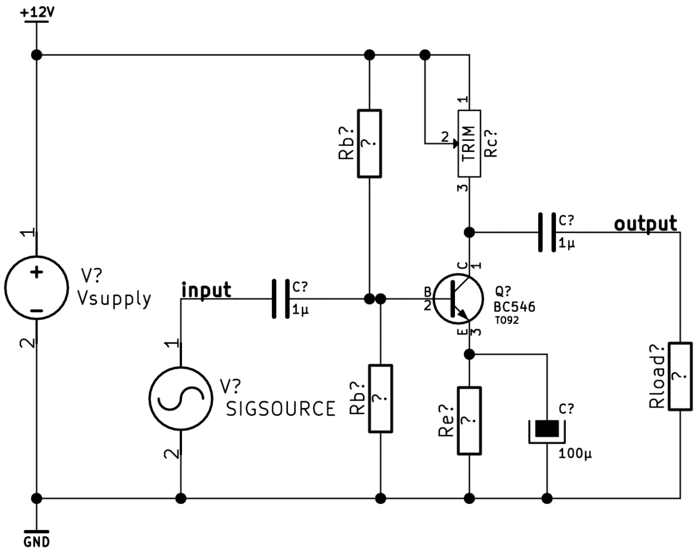

Figure 13: Voltage divider bias.

6.2.1 “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.

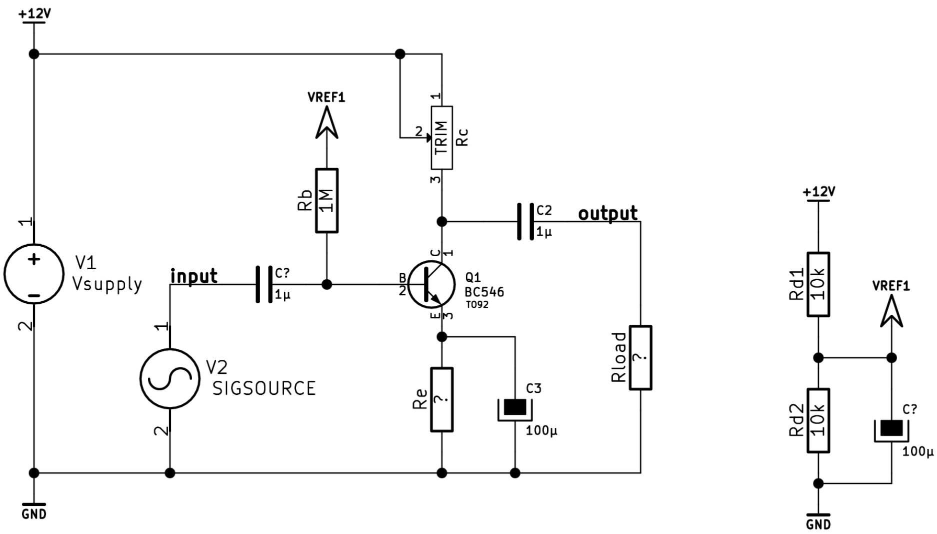

Figure 14: Voltage divider with filtered voltage reference.

6.3 Comments

The AC coupling capacitor forms a high pass filter togeter with the combined parallel resistance of the biasing network and effective input resistance of the transistor base. Values of these components is selected to shave off unwanted frequencies, when dealing with audio often radio frequencies and line voltage hum. Sometimes you can get away with omitting the input coupling capacitor, but only if the input signal rides on top of a DC offset. It is considered best practice to always design circuits for worst case scenarios, I.E. for many scenarios it can be beneficial to decouple and current limit all AC signal inputs and outputs.
The signal phase is shifted 180° when DC coupling the signal, the circuit topology is inverting. When AC coupling, the phase shift changes to 150°, reflecting the high pass filter effect of the input network.

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`