Experiment #07
Transistors and amplification

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1 Objective

This experiment introduces you to the transistor and building one of the most important circuits of all, the transistor amplifier. An amplifier is a crucial element of your final AM radio circuit, since you need to take very small AC signals, and amplify them to a large enough amplitude to drive a speaker.

2 Learning Goals

After finishing the lab you will:

- know how to build a simple transistor amplifier
- know the limitations of an amplifier, especially the distortion that occurs when voltage limits are exceeded
- measure and understand what linearity means in amplified signals

3 Introduction

The most important semiconductor device, arguably the most important invention of the 20th century, is the transistor. The first successful device was produced by by Bardeen, Shockley, and Brattain at Bell Labs in 1947. Modern versions of the device are at the heart of modern electronics and all its applications e.g. your laptop, cell phone and just about every piece of electronics you own. A single integrated circuit, can contain up to several billion transistors. However, even single transistors are useful in some applications such as high power/voltage switching. In this lab you will characterize and use the properties of a single, bipolar transistor.

4 Bipolar Junction Transistors (BJT)

4.1 Background

There are two distinct kinds a BJT, a npn and a pnp where the n and p refer to the kind of doping in each layer of the semiconductor (see the file Semiconductornotes.pdf on Canvas for more details). The two different BJTs have similar properties and in this lab we will only study the former. The circuit symbol for a npn BJT is shown in Fig. 1. Unlike the other electrical elements we have used so far (other than the variable resistor), the transistor has 3 electrical connection points (or ports) which are labeled as Collector (C), Emitter (E), and Base (B).

If the BJT is setup to act as a current amplifier then $I_C = \beta \times I_B$, where the current gain β depends on the details of the transistor. However, several conditions need to be satisfied:

1. the collector voltage must be *positive* relative to the emitter voltage ($V_C - V_E > 0$)
2. the base-emitter must be forward biased ($V_B - V_E \gtrsim 0.7V$); and
3. base-collector must be reverse-biased ($V_B - V_C \lesssim 0.7V$).

The relation between I_C and I_B holds within some range dependent on the particular model of BJT and enables one to switch /control a large current (I_C) with a smaller one (I_B). It is also possible to set up the transistor as a voltage amplifier (see Fig. 2). The same 3 conditions listed above need to be satisfied, which requires some care.

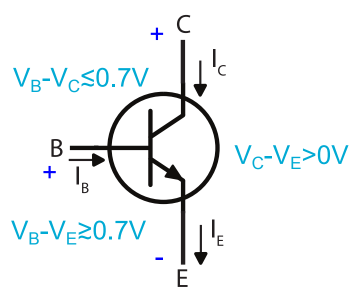

Figure 1: Block diagram of BJT. The BJT has 3 connections: the collector, base and emitter. For current to flow through the NPN junction, specific voltage conditions must be met.

5 Part I: Voltage Amplification using a Transistor

The circuit shown in Fig. 2 functions as a voltage amplifier.

Make sure the power supply to the protoboard is turned off before proceeding since you might damage the transistor if the circuit is not set up properly.

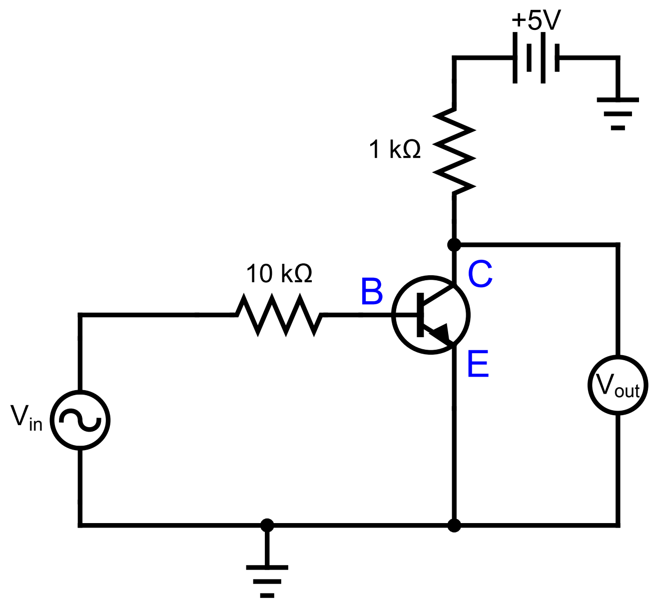

Figure 2: Circuit to amplify voltage with a transistor

- Find a 10 kOhm resistor and a 1 kOhm and record the measurements of their resistances in your notebook. Install the two resistors as shown in Fig. 2.
- When you build your circuit keep all of the wires flat and tidy. The resistors and transistor can be sticking up, but all other wiring should be as two-dimensional as possible. **Your in-class grade will check for tidiness this week.**
- Adjust the function generator to produce a sinusoidal signal with a frequency 100Hz, an amplitude of 0.1V and an offset voltage equal to zero. Then connect the voltage lead to the unattached end of the 10 kOhm resistor; the other end (ground) should go to the emitter end of the transistor. This will be the input voltage signal that will be amplified.
- Make the necessary connections so you can the monitor the input voltage on CH1 and the output voltage from the collector on CH2. Use AC coupling to the scope for CH1 so you can adjust the offset voltage on the function generator without having to readjust the trigger level. Monitor the output voltage signal at the collector on CH2 of the scope. Keep CH2 on DC coupling so you can observe any offset in the output signal.
- Now you can turn on the power to the protoboard. Increase the voltage offset on the function generator from 0 to 1.4 V in small steps of 0.1 V. Report what you observe as the offset voltage changes and save some screenshots (enough to help you describe the behaviour, but you don't need to save them at increments of 0.1 V) of the signals you see to include in your

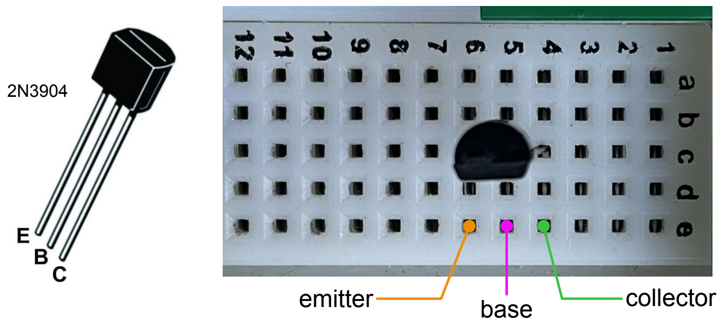

Figure 3: (left) the transistor is a black semi-cylindrical component with three connection pins: the collector, base, and emitter. When installed on the breadboard (right), with the round part facing away from you, the order of the connectors is emitter (column 6), base (middle; column 7), and collector (column 8). You may want to install it on the lower half of the protoboard so it is close to the +5V power line. The specific columns you use to install the transistor are not relevant, but the emitter, base, and collector must be in different columns so that the connection points are not shorted.

notes. In particular make note of the range of offset voltages for which the output signal is an undistorted sine function. Also make note of the amplitude of $V_{out}(t)$ versus $V_{in}(t)$ when there is no distortion.

Checkpoint 1

Have a TA check your circuit and show them the behaviour as you change the voltage offset. Make sure your wiring is tidy and flat!

Obtain an undistorted signal to determine the gain:

- Choose an offset voltage for V_{in} in the middle of the range where you are confident there is *no* distortion in V_{out}. Save the data for both CH1 and CH2.
- Plot both CH1 and CH2 together, and fit a sine wave to each to determine the amplitudes and calculate the gain.

6 Part II: An Improved Amplifier

The circuit shown in Fig. 2 functions as a voltage amplifier provided the input signal has a DC offset which keeps the base emitter forward biased throughout the cycle. However, in real situations the signal you would like to amplify has no such offset in the input signal. As a final step modify the circuit to provide an adjustable offset voltage at the *base* using a variable resistor as shown in Fig 4. The purpose of the capacitor at the input is to block the DC offset voltage from affecting the source.

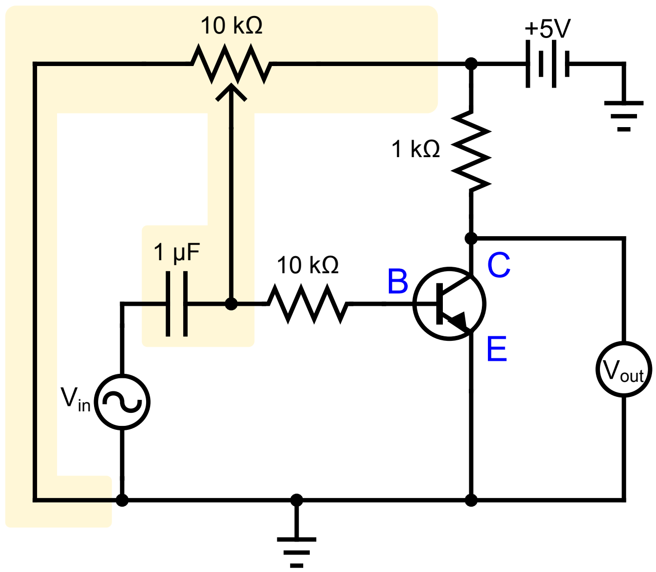

Figure 4: Circuit to amplify voltage with a transistor with an offset on the input. Yellow highlights parts of circuit that differ from the first amplifier design in part I.

- Modify your circuit to apply a variable voltage offset at the base according to the circuit diagram in Fig. 4
- Set the offset on the function generator to zero and instead tune the variable resistor to find the best offset voltage. Make sure you are taking notes throughout this process.

Checkpoint 2

Once you are satisfied with the offset adjustment, have a TA or instructor check the functioning circuit.

- Measure the AC amplitude of the output signal as a function of the AC amplitude of the input voltage signal using the cursors or measure functions similar to Experiment 04. It may be necessary to adjust the offset voltage slightly to avoid distortion.
- For the largest input amplitude used, save the full .csv file so you can perform a sine fit to check for distortion.
- Determine the voltage amplification gain by making a plot of the output voltage amplitude versus the input voltage amplitude; it should be fairly linear, and the gain is simply the slope. Check the limitations on the linear response of the amplifier - what is the range over which the output is proportional to the input? This is the linear range of the amplifier you have built.

Based on the tutorial 6 and the theory for this amplifier discussed in Semiconductornotes.pdf what is β for your transistor?

Before you leave the lab!

Check that you have:

- recorded your name, partner's name, date, and experiment
- have notes on your activities, observations and data throughout
- have diagrams and/or photos of your circuits to include in your notes
- measured your resistor values with the DMM
- saved screenshots of the input/output your first amplifier circuit to help you describe the behaviour
- saved the .csv files of *both* CH1 and CH2 for the undistorted signal in part I
- acquired sufficient output voltage amplitude vs. input voltage amplitude data to fit a line to determine the gain and linearity of the amplifier in part II
- saved at least one set of .csv files to check for signs of distortion at the largest amplitudes

