TRANSISTORS

Instructions: Read Hayes and Horowitz, Class 4, and then do the exercises from Lab 4 listed below. Repeat for Class/Lab 5 and 6. Do NOT write a standard lab report (abstract, introduction, etc.) for the transistor project. Instead, your report will contain 15 very short, independent sections, one for each of the lab exercises. In each section, briefly report and explain your data, address all questions appearing in the lab manual for the given exercise, and demonstrate your understanding of the pertinent concepts.

Lab exercises (see subsequent pages for hints and modifications to Hayes and Horowitz's instructions):

4-1, 4-2, 4-3, 4-4, 4-5, 4-6, 4-7, 4-9, 5-1, 5-2, 5-3, 5-6, 6-1, 6-4
Design task: Water level detector. Design and build a circuit in which a #47 lamp lights up whenever two leads are immersed a few inches from each other in water.

Report Guidelines

- Your **predictions** should be clearly stated, the appropriate equations should be identified, and the numerical values should be provided.
- Important **observations** should selected for graphical display. You are welcome to draw figures by hand. In some sections, figures may be unnecessary, but quantitative and qualitative **results** should always be reported.
- A **comparison** of predictions and observations should be made.

The three items listed above should be included in each of the 15 sections of the electronics lab reports. It is NOT sufficient to state "the circuit worked as expected" without elucidating what was expected, why it was expected, what was measured, and how the measurement compares with expectations.

Modifications. Hints.

4-1. The manual is ambiguous but means that $V_{BE} > V_{BC}$. It suffices to confirm that $V_{BE} > V_{BC}$. The diode test seems trivial, but it is invaluable in two situations: if a transistor circuit isn't working as expected, one of the first debugging suggestions is to perform the diode test on the transistor to make sure it's still functioning properly. Also, the diode test can be used to identify the three pins of an unknown transistor; not all transistors have pins in EBC order.

4-2. The output of an emitter follower should be an exact replica of the input, neglecting DC level. Unfortunately, the circuit shown in Figure L4.2 will severely alter the signal until you change V_{EE} from ground to -15 V. You should explain what happens and why.

4-3. The entire point of an emitter follower is to act as a buffer between two stages of a larger circuit; the emitter follower prevents the subsequent stage from attenuating or distorting the signal fed in from the previous stage. This disaster would occur if Z_{out} of the previous stage were not much smaller than Z_{in} of the subsequent stage; see p. 13 of the Manual for details. The emitter follower effectively multiplies Z_{in} of the subsequent stage (the follower's load) by β, and it divides the previous stage's Z_{out} (in this case the 10k) by β. In other words, Z_{in} of the follower is βZ_{load}, and Z_{out} of the follower is Z_{source}/β, where Z_{source} = 10k in this case. See p. 67 of Horowitz and Hill (the thick text) for a derivation. This is the procedure to measure Z_{out}: Consider the entire circuit to be a Thevenin model with V_{Th} in series with R_{Th} (which we call Z_{out}). Measure the output amplitude when the circuit is unloaded; this gives you V_{Th}, since no current flows through Z_{out} when the circuit is unloaded. Then measure the output amplitude when the circuit is loaded by 1k. The amplitude will be smaller because some of V_{Th} appears across Z_{out} and not across the load (where you want it); Z_{out} and the load form a voltage divider. Using V_{Th} and the loaded output voltage, you can calculate Z_{out}: $V_{Th} = I(Z_{out} + 1k)$ and $V_{loaded} = I(1k)$; eliminate I. To measure Z_{in}, simply measure the amplitude on both sides of the 10k. Consider the 10k to be in series with Z_{in}, with the other end of Z_{in} at ground. If V_{in} is the voltage on the left side of the 10k and V_{in}' is on the right side of the 10k, $V_{in} = I(10k + Z_{in})$ and $V_{in}' = I(Z_{in})$. From the Z_{out} and Z_{in} measured this way, you can calculate two β values that should, in principle, be equal.

4-4. The point of this circuit is to avoid the problem you observed in 4-2, without using a -15 V supply in addition to a +15 V supply. Explain how it works. It may be helpful to refer to Lab 2-8. Don't forget to comment on the clipping you observe.

4-5. **In this and all subsequent sections, use individual resistors instead of a substitution box.** In this circuit, you're simply investigating I_C vs. I_B to determine β yet another way. If β seems to change, that may be a valid observation; β depends on temperature and other parameters, which is why good circuit designers never assume a specific value of β.

4-6. **Instead of a 10k pot, alternately use a 100k and a 1k pot**. Predict the current supplied to the load, assuming the transistor is in the "active regime" ($I_C \approx I_E$). At some point when V_{CE} gets too low, the transistor will transition into saturation, and you will no longer be able to predict I_C. The point of this exercise is to determine the range of load voltages for which the predicted I_C is measured and to explain the point at which I_C begins to plummet.

4-7. Predict and measure the output. In general, you do not want to see clipping unless you're specifically investigating it, so make sure the input amplitude is not too high.

4-9. This is called a transistor switch because the voltage across the lamp is 0 when the transistor is not conducting, and the voltage across the lamp approaches 5 V when the transistor conducts; the transistor switches from one to the other in response to I_B. I don't know what the question below L4.10 is getting at, so you may ignore it (but not the other questions).

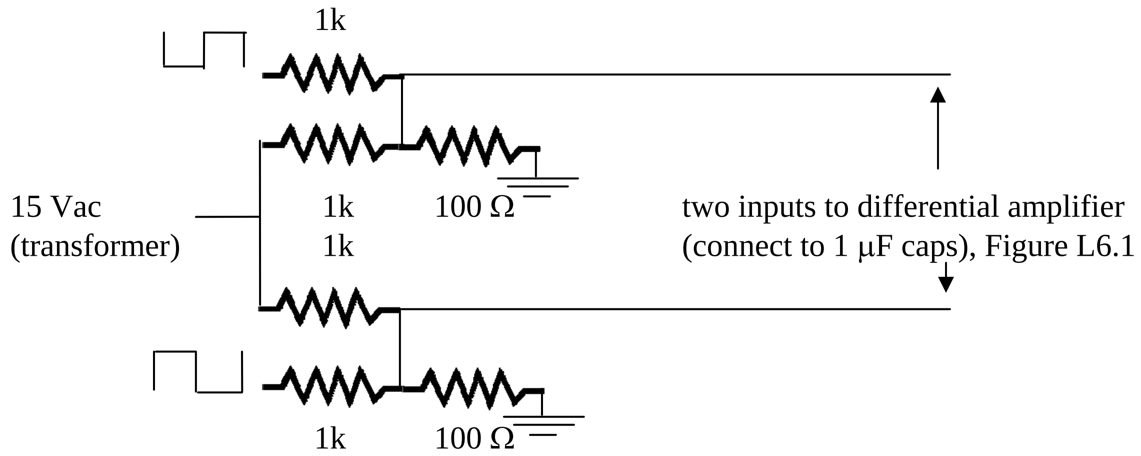
5-1. **Change the 1k to a 10k.** You should understand and briefly explain how we trick the scope, which measures voltage, into displaying a current vs. voltage curve. Make sure you understand what you're measuring. Do you need to invert a channel to see the expected curve? The jargon 100 mV/decade means that I increases by a factor of 10 each time V increases by 100 mV. So 60 mV/decade is a steeper I vs. V curve than 100 mV/decade; the 100 mV/decade curve requires more "run" for a given "rise."

5-2. **Pass the input triangle wave through a divide-by-100 voltage divider: connect the breadboard's triangle wave to a 100k in series with a 1k to ground. Feed the attenuated signal at the top of the 1k into the circuit shown in 5-2.** Predict, measure, and explain the performance of this circuit with and without the 15μF cap. When the cap is in place, the 1k is negligible at signal frequencies. Explain the relative advantages of leaving the cap in place and removing it.

5-3. **Do part A.1 only.** The pnp transistors are the mirror image of the npn transistors you're used to; the polarity of every voltage and current is reversed. Predict I_{out}. Observe the enormous sensitivity of I_{out} to temperature; I_{out} changes dramatically when you touch either transistor. Explain why it changes as it does. Temperature effects are explained on p. 106 of the Manual.

5-6. You should see distortion in the output signal around 0 V. Explain.

6-1. **Our function generators cannot be floated. Ignore "Preliminaries" and "Composite Signal to Differential Amplifier." Instead, construct a composite signal using the circuit shown below.** This circuit is significant because an op amp is basically an enhanced differential amplifier. Observe the startling attenuation of the common 60 Hz "noise" signal and amplification of the 180°-out-of-phase square-wave difference signal. Unlike the low-pass and high-pass filters, this circuit eliminates noise regardless of its frequency.



- Each input into your differential amplifier will be the superposition of a $.1 \times 15$ V $\times 2^{1/2} = 2.1$ V sine wave (a tenth the output of the breadboard transformer) and a 0.1 V square wave (from the breadboard).
- The frequency of the sine wave is 60 Hz; the frequency of the square waves is anything you choose.
- Your differential amplifier will **reduce** the common signal (sine) and **amplify** the difference signal (square waves out of phase).
- To measure common-mode gain: unplug square wave connections.
- To measure differential gain: unplug transformer connection.

6-4. This circuit lets you amplify a current more than a single transistor could. Explain the base and collector voltages that you measure (and clearly specify which transistor you're talking about).

Design task. The current through the water will be very small because its resistance is very high. You need a much higher current through the lamp.