ECE 327: *Electronic Devices and Circuits Laboratory I*

Procedure Notes for Lab 1 (Bipolar (Junction) Transistor Lab)

Abstract

The laboratory procedure is broadly outlined in the lab *book*. You are expected to gather all data and answer all questions required by that text. Here, some additional details are presented that should help you build and troubleshoot your circuits. Another supplementary handout will give schematics and explanatory information about the circuits.

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1 Common-Emitter Amplifier ("Level-Shifter Amplifier")

Building and testing of this circuit will take the majority of this laboratory's time. Do not be discouraged if things move slowly through this circuit. The remaining four parts of the lab move quickly. If you have trouble, consult the troubleshooting section below on page 2.

- Input: 0.5 V amplitude (1 V_{pp}) and 0 offset
  - On older generators, press AMPL −20 dB button to get Amplitude knob to reach 0.5 V
  - Use 1 kHz frequency during testing
- Output: 6 V_{pp} and 5 V offset (i.e., circuit **gain** of 6 with 5 V **offset shift**)
- Pick $R_C \ll 300\,\text{k}\Omega$ so that the scope and probe do not load the high-impedance output. Otherwise, your output may look severely attenuated (especially at 15 kHz due to *capacitive* loading).
- Pick R_1 and R_2 **as large as possible** while maintaining $R_1 \| R_2 \ll \beta R_E$ with $\beta \approx 100$
- Plot collector waveforms with `2 V/div` and others with `1 V/div`. **Align grounds** on a **low** grid line.
- For 100 **Hz**, 1 **kHz**, and 15 **kHz** inputs,
  - Use `Quick Meas` to show input `Peak-to-Peak`, output `Peak-to-Peak`, and output `Average`
  - **Save input and collector (i.e., output) together on same screen**. Find gain and offset.
- For 1 **kHz** input, **save input and EMITTER together on same screen**.
- For 1 **kHz** input, determine the effect of input offset on the output (i.e., collector)
  - Add small (e.g., 1 V) offset to input (and observe what happens as offset is *moving*)
  - **Save input and COLLECTOR (i.e., output) together on same screen**.
  - Don't forget to *turn off* offset before continuing!
- Verify: gain decreases as frequency decreases (may need *very* low frequency and wide scope time scale).

Troubleshooting the Common-Emitter Amplifier

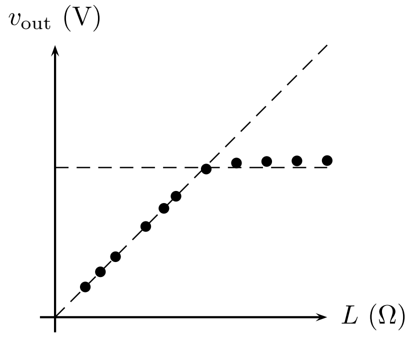
1. Probe the input: Is the amplitude less than it should be?
   - Probe input when it is **disconnected from circuit**. Does it return to its expected value?
   - The oscilloscope has a $50\,\Omega$ output impedance so that it can be used in RF applications with no reflection. In most of our circuits, the function generator sees a high impedance load, and so the voltage divider between the output impedance and our circuits has near unity gain.
   - If the parallel combination $R_1 \| R_2$ of your biasing resistors is very low, the voltage divider at the output of the function generator has a sub-unity gain.
   - Options (from most desirable to least):
     - Pick a larger $R_1 \| R_2$ combination, but make sure that $R_1 \| R_2 \ll \beta R_E$ (where $\beta \approx 100$).
     - Use the *bootstrapped* configuration (see supplementary handout).
     - Increase your function generator's amplitude to compensate.
2. Probe both ends of the input capacitor: Are the signals identical (aside from a DC offset)?
   - At signal frequencies, they should be identical (except for a DC offset)
   - If they are not, choose a larger input capacitor.
   - Avoid using electrolytic capacitors. Find ceramic $1\,\mu$F capacitors (code: `105` because $1\,\mu\text{F} = 1\,000\,000\,\text{pF}$) and combine a few of them (e.g., 3 or 4) in parallel.
   - Increasing $R_1 \| R_2$ combination will also improve bandwidth.
3. Probe the base of the transistor. Under scope's `Quick Meas`, use the `Average` measurement (or use your digital multimeter (DMM) to measure the DC signal at the base) to find the DC component.
   - The value should be $(12\,\text{V}) \times R_2/(R_1 + R_2)$
     - If it is far too high, your collector (i.e., output) and emitter waveforms will be identical. Additionally, changing R_C and R_E will have no impact on gain; it will only change offset.
     - If it is moderately high, your collector (i.e., output) waveform will be asymmetrical, where one portion matches the emitter and the other does not
     - If it is slightly high, your **output offset** will be too low
     - If it is too low, your collector waveform will look clipped
   - Try replacing the R_1–R_2 divider with a single potentiometer
     - Potentiometer: $10\,\text{k}\Omega$ (code: `103`) or $20\,\text{k}\Omega$ (code: `203`)
     - Attach one outer leg to 12 V and the other outer leg to 0 V
     - Attach middle leg to base of transistor
     - Turn screw until base average is desired value (output offset will also shift as you turn screw)
4. Make sure your R_C/R_E ratio matches the desired gain (i.e., $R_C/R_E \approx 6$)
   - If too high, the collector (i.e., output) waveform may look asymmetrical and strange
   - If too low, the collector (i.e., output) waveform will have a small magnitude and high DC offset
   - Adjust by placing large resistors (e.g., $500\,\text{k}\Omega$) in *parallel* with either R_C or R_E. For example, putting $500\,\text{k}\Omega$ in parallel with R_C will slightly decrease the R_C/R_E gain.
5. Make sure your R_C is not too large (e.g., keep $R_C \ll 300\,\text{k}\Omega$)
   - If it is, your output may look attenuated, and it will be **severely attenuated** at 15 kHz.
   - The **output impedance** of your amplifier is equal to R_C (i.e., any change in current output Δ_i will result in a change in voltage output of $\Delta_i R_C$)
   - So the Thévenin equivalent output resistance is R_C, and a load with capacitance C will form a *low-pass filter* with *time constant* $R_C C$. If R_C is very large, then that time constant will also be very large even with a small C. That large time constant will give the low-pass filter a very low *corner frequency* (note that the oscilloscope has significant capacitance).

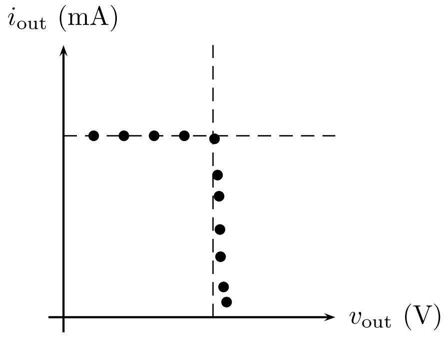
2 *pnp* Current Source (“Common-Base” (Power) Amplifier)

- Choose one of the two current sources or the current mirror
- Vary loads from 200 Ω to ∼8 kΩ
  - Take enough (11?) data points to find nominal current and compliance limit
    - ⋆ **You may use the resistance boxes from the cabinet or shelves**
    - Choose 4 resistances between 200 Ω and 1.2 kΩ
    - Choose 4 resistances between 1.2 kΩ and 2.5 kΩ
    - Choose 3 kΩ, 5 kΩ, and 8 kΩ resistances
  - Measure voltage *across load*
    - **Use the *digital multimeter (DMM)***
    - **Do NOT use the oscilloscope!**
    - **Turn off power between each load** (to let the transistor(s) cool)
  - **Save voltage for each load** (i.e., record a table of voltage-load pairs)
  - **Make sure** that output current is 5 mA
    - DO NOT attempt to measure current directly!
    - Divide measured voltage by load resistance
    - For example, verify that
      - a 1 kΩ load has ∼5 V across it
      - a 500 Ω load has ∼2.5 V across it
- Determine nominal current
  - Flat part of voltage-versus-current curve
  - Slope of linear portion of resistance-versus-voltage curve
- Determine compliance (i.e., output voltage range where device acts like a constant current source)
  - Highest voltage on flat part of voltage-versus-current curve
  - Highest voltage of linear region of resistance-versus-voltage curve

Example Data Plots

Make sure to show each data point **as a solid dot** (i.e., do not show me only the interpolation).





3 Followers

The following three circuits are strongly related. Each iteration adds complexity (and power dissipation) to the previous circuit in order to reduce distortion and make the output a "higher fidelity" copy of the input.

- There are **no calculations** necessary to build these circuits. All component values are *given.*
- **INPUT** is sinusoid with 5 V amplitude (i.e., $10\,\mathrm{V_{pp}}$ with 0 V offset) at 1 kHz
- You *need* to use **three** supply channels: +6 V, 0 V, and −6 V
  - Scope probes should be referenced to 0 V "**ground**" and not −6 V negative power rail
  - Load is tied to ground (i.e., 0 V)
- **Your plots should** have:
  - both input and output on the **same screen**
  - identical `2 V/div` channel scales
  - channel references (i.e., "grounds") aligned on **middle grid line** (i.e., the hashed horizontal line)
- *Can* use `Averaging` feature under `Acquire` button to clean up scope display. Use low `#` of samples.

Emitter Follower ("Common-Collector" (Power) Amplifier)

- As given in lab book, emitter resistor value $R_E = 1\,\mathrm{k\Omega}$.
- **Save input and output for no-load (i.e., $\infty\,\Omega$, an OPEN circuit) case**
  - Output will look like shifted version of input
- **Save input and output for loaded (i.e., $1\,\mathrm{k\Omega}$) case**
  - Output will look like shifted version of input that is clipped at −3 V

Simple Push–Pull Amplifier

- Notice similarity to emitter-follower
  1. Emitter resistor is replaced by *pnp* transistor
  2. Transistor bases are shorted together
- **Use $1\,\mathrm{k\Omega}$ load**
- Output should look similar to input, but will have *crossover distortion* for small values of the input
- **Save input and output as before**

Biased Push–Pull Amplifier

- Notice similarity to simple push–pull amplifier
  1. Bases are connected through two general purpose diodes
  2. Input connects at junction between two diodes
  3. Diodes are biased into operation by resistors
- **Use $1\,\mathrm{k\Omega}$ load**
- Output should be nearly identical to input but will mismatch more as input moves away from 0 V
- **Save input and output as before**
- Determine price of improvement (i.e., other than extra components, what is the tradeoff?)