

### Lab 8: Common-Emitter Amplifier

**Object:** To explore the design and operation of a single-stage, common-emitter amplifier based upon a 2N2218 bipolar junction transistor.

**Apparatus:** TDS2004B Digital Oscilloscope, HP 260CD Oscillator, Circuit Chassis, 2N2218 Transistor, Various Resistors and Capacitors, and Cables.

**Introduction:** A bipolar junction transistor is an active, solid state device capable of delivering voltage, current, and power gain. To perform as an amplifier, the transistor must be properly biased to place its operation in a region where reasonable linearity and thermal stability are assured. This experiment involves the testing of an amplifier belonging to the common-emitter configuration. This experiment involves transistor biasing, quiescent operating point, small-signal voltage gain, coupling and bypass capacitors, input/output impedances, frequency response, and clipping.

#### Exercises:

1. Wire up the common-emitter amplifier shown in Fig. 1. For the moment leave out the bypass capacitor  $C_E$  and test whether the amplifier works by applying a 10 kHz, 1 V (peak-to-peak) sinusoidal input. Connect the input signal to CH 1 of the oscilloscope and the output signal to CH 2. The circuit's output should be about six times larger than its input. Does this make sense given the circuit component values?

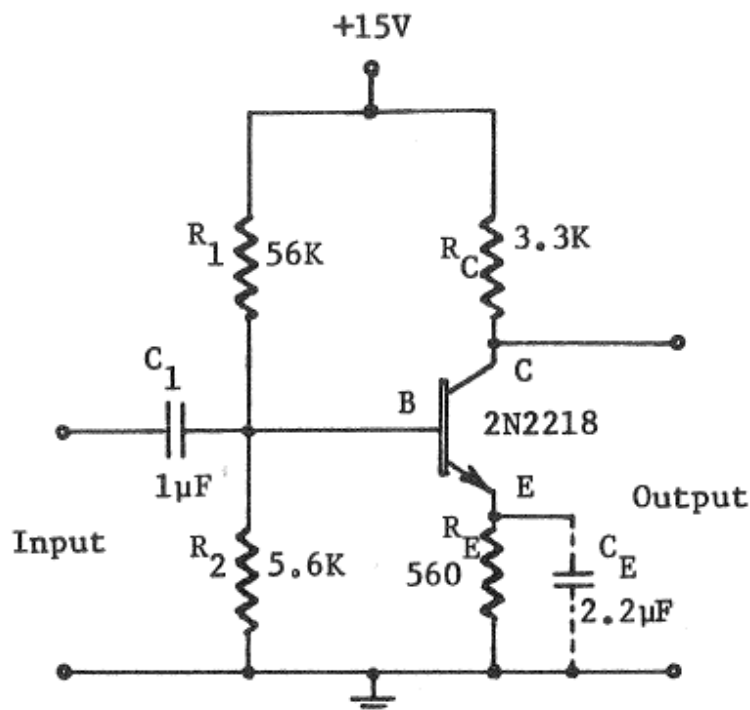


Fig. 1: Common-emitter amplifier circuit.

2. Next use the 10X probe connected to the oscilloscope to experimentally determine the quiescent operating point of your amplifier. Disconnect or turn off the oscillator when you make these measurements. Measure the quiescent collector voltage, emitter voltage, and base voltage. Use the emitter voltage and the emitter resistor value to determine the emitter current (which is approximately equal to the collector current). Sketch the collector circuit load line (graph of collector current vs. collector-to-emitter voltage) and place the measured quiescent operating point on this graph. Is the base voltage consistent with the requirement that the base-to-emitter junction be forward-biased? Is it also consistent with the voltage divider formed by the base biasing network resistors  $R_1$  and  $R_2$ ? These measurements and associated calculations should give you a reasonably complete characterization of the quiescent operating conditions of this amplifier.
3. Next determine the input amplitude  $V_{in}$  at which *saturation* and/or *cutoff* sets in. This is the point beyond which the output signal is not longer proportional to the input. Does *clipping* of the output signal occur symmetrically on the positive-going and negative-going phases of the output? Think about the causes of these effects in terms of the quiescent operating point of the amplifier. Explore the effects of saturation and cutoff by measuring the voltage gain  $A_V = V_{out}/V_{in}$  at a fixed frequency (e.g. 20 kHz) over a range of input amplitudes such as 50 mV to 4 V (peak-to-peak). Plot  $A_V$  versus  $V_{in}$  and identify the input amplitude where saturation and cut-off (separately) set in. For the rest of this experiment, hold the input amplitude below the threshold for saturation and cut-off.
4. Next measure the voltage gain for constant input amplitude but different frequencies. Choose thirty or more frequencies ranging from 20 kHz to 600 kHz. Plot the gain versus frequency (with error bars) and determine the maximum experimental “midband” gain, and compare it to the predicted gain

$$A_V = \frac{-R_C}{(R_E + r_e)} , \quad (1)$$

where  $r_e$  is the Ebers-Moll effective emitter resistance internal to the transistor. The negative sign here implies that the input and output signals are  $180^\circ$  out of phase. Do you confirm?

5. The input coupling capacitor  $C_1$  and the voltage divider formed by  $R_1$  and  $R_2$  (whose parallel resistance is  $R_{eff} = R_1 R_2 / (R_1 + R_2)$ ) constitute a high-pass RC filter with a predicted half-power frequency of  $f_{lo} \cong 1/2\pi R_{eff} C_1$ . Is the action of this filter reflected in your experimental data? More specifically, does the gain take on a value equal to 0.707 times its maximum midband value at this frequency?
6. Note that the gain also rolls off at high frequencies. What effects might be responsible for this high-frequency roll-off? Try to derive an expression for the half-power frequency  $f_{hi}$ .

7. The circuit in Fig. 1 is protected from thermal instability by the inclusion of resistor  $R_E$ . The value of this resistor reflects a common rule-of-thumb that it should be between 10% and 20% of the value of the collector resistor  $R_C$ . The emitter resistor severely limits the amplifier's voltage gain (see Eq. 1 above). One could eliminate this resistor and thereby realize larger gain, but such practice would be unwise because of likely thermal instability. A solution to this dilemma that avoids thermal instability while enhancing the gain for AC signals is to introduce a bypass capacitor  $C_E$ . If chosen appropriately the impedance of the parallel combination of the emitter resistor and bypass capacitor at the frequencies of interest will be much less than the DC resistance. Proceed therefore to insert the bypass capacitor  $C_E = 2.2 \mu\text{F}$  and test its effects on the operation of the amplifier. In anticipation that the gain will be much larger you will need to be careful to keep the input amplitude small (probably less than 20 mV) to avoid the effects of saturation and cut-off explored above. To reduce the input amplitude to this level, load down the HP 200CD oscillator with a  $50 \Omega$  resistance strapped across the maroon terminals. Measure and plot the gain as a function of frequency again. Note the low-frequency half-power frequency is now much larger. Why?
8. Having completed your gain measurements, remove the bypass capacitor and proceed to infer the effective output impedance  $Z_{out}$  of your amplifier at 20 kHz using the  $2.2 \mu\text{F}$  coupling capacitor, the  $10 \text{ k}\Omega$  potentiometer, and a push-button switch as shown in Fig. 2. Attach this subcircuit so that it serves as a real but variable load wired to the output of the amplifier. Apply as usual an input signal and observe the amplified output signal on the scope while alternately depressing and releasing the push-button switch as readjusting the pot until the amplifier's output signal under loaded conditions is exactly half that for the unloaded conditions. Then release the push-button and measure the resistance of your pot with the Fluke DMM. The resulting resistance measurement provides an indirect determination of  $Z_{out}$ . Convince yourself of the correctness of this method by applying Thevenin's theorem to the output loop of the amplifier.

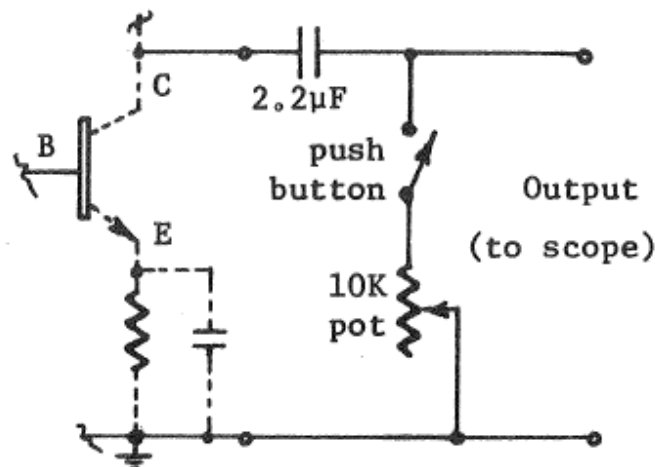


Fig. 2: Circuit for measuring the output impedance.

9. Finally, devise another simple subcircuit that will enable you to measure the amplifier's input impedance  $Z_{in}$ . This time insert the pot in series with the input of the amplifier and observe the amplitude of the input signal both prior to the pot and after the pot (both being measured with respect to ground). Using this approach, infer  $Z_{in}$  by measuring the pot resistance with your Fluke meter; *you circuit should be off and the oscillator disconnected when you make this final measurement.*