Experiment #1—The Common-Emitter Amplifier

Our first experiment will feature the *common emitter* (CE) *amplifier*. Why the CE amplifier? It is the most common amplifier configuration of all—it is found in analog and digital circuits, from dc through microwaves and it is made of discrete components and fabricated in integrated circuits (ICs). If you understand the CE amplifier, you've made a good start in electronics.

Background

The CE amplifier (Figure 1) is used when modest voltage gain is required along with an input impedance (the impedance seen by the circuit supplying the signal to be amplified) of a few kΩ or more. The output of the CE amplifier is inverted from its input. (We call this 180° of phase shift.) As the input signal swings positive, more current flows into the transistor's base, which also causes more current to flow from the collector to the emitter. This causes more voltage drop across Rc and so the voltage at the collector also drops. The reverse is true when the input signal swings negative.

In order for the circuit to amplify both positive and negative swings of the input signal, its collector current (I_c) must be offset from zero so that it can both increase and decrease. An amplifier that has a continuous output current, even with no input signal, is called a Class A amplifier. The method of controlling this continuous current is called biasing. Resistors in the voltage divider R1 and R2 cause a small amount bias current to flow into the base and thus keep the collector current flowing at all times. The amplifier is then said to be operating in its "active" region. The resulting continuous collector current equals the base bias current multiplied by the transistor's current gain, β. Using Ohm's Law to find the voltages across R_c and R_e, the transistor's collector-to-emitter voltage (V_{ce}) is also determined by the bias current. The combination of continuous I_c and V_{ce} is called the Q-point of the circuit, where Q stands for "quiescent." When an input signal is applied, output voltage and current changes are centered around the Q-point.

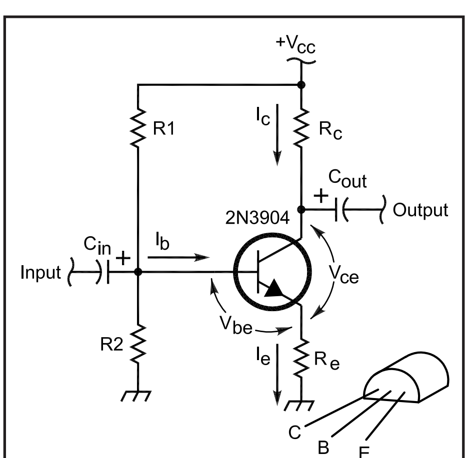

Figure 1—The common-emitter amplifier.

As the collector current changes in response to an input signal, the circuit's output voltage is developed across the collector resistor, R_c. For a given input signal, a larger R_c means a larger output voltage change—a higher voltage gain (A_v). The function of R_e is to set the transistor's Q-point such that the collector voltage can make wide swings without running up to the power supply voltage (V_{cc}) or down to ground. By being in the collector current's path, along with R_c, larger values of R_e work against R_c to reduce voltage gain. In fact, the voltage gain is approximately the ratio of R_c to R_e.

Figure 1 shows capacitors at the input (C_{in}) and output (C_{out}). This is called an "ac coupled" design. The capacitors block the flow of dc current to the load or to the circuit driving the amplifier. These capacitors also cause the gain at very low frequencies to be reduced, as the impedance of a capacitor increases at low frequencies—hence the gain at dc is zero. For this experiment, all capacitors will be 10 µF—a value large enough to act as a short-circuit for most audio signals. If polarized capacitors are used, the positive side should be connected to the circuit.

Terms to Learn

A_v—Voltage gain, the ratio of output to input voltage.

Beta (β)—DC current gain, the ratio of collector current to base current.

Cutoff—Collector current reduced to zero.

I_b, I_c—Base and collector current, respectively.

Q-Point—Quiescent or resting values of collector current (I_{cq}) and voltage (V_{ceq}) with no applied input signal.

V_{ce}, V_{be}—Voltage from collector-to-emitter and base-to-emitter, respectively.

Key Equations

$$I_c \approx I_e,\ I_c = I_b \times \text{Beta } (\beta) \quad [1]$$

$$V_{cc} = (I_c \times R_c) + V_{ce} + (I_e \times R_e) \approx I_e \times (R_c + R_e) + V_{cc} \quad [2]$$

$$A_v \approx R_c / R_e \quad [3]$$

$$V_{R2} = V_{be} + (I_e \times R_e) \quad [4]$$

Designing the Amplifier

1. Choose the circuit's operating requirements:

V_{cc} = 12 V *(our power supply voltage).*

A_v = 5 *(a medium value of gain).*

Q-point of I_{cc} = 4 mA *(a value to keep power dissipation low)* and V_{ceq} = 5 V *(rule of thumb—about one-half of V_{cc}).*

Assume the transistor's β is 150 and base-to-emitter voltage, V_{be} = 0.7 V. *(The actual range of β can be read from the transistor's data sheet and V_{be} is typically 0.7 V for silicon transistors.)*

2. *From equation 2,* $V_{cc} = I_c (R_c + R_e) + V_{ce}$

$(V_{cc} - V_{ce}) / I_c = R_c + R_e$, so $R_c + R_e = (12\text{ V} - 5\text{ V}) / 4\text{ mA} = 1.75\text{ k}\Omega$

3. *From the above,* $R_c = 1750\ \Omega - R_e$ and with $A_v = 5$, $R_c / R_e = 5$ *(equation 3)* so

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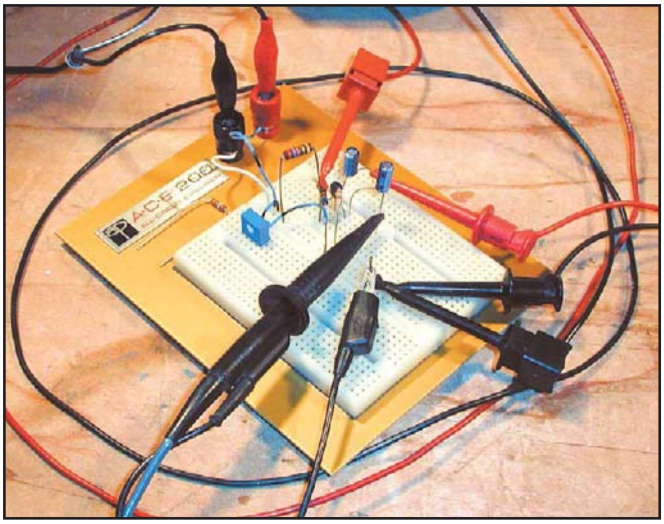

Figure 2—The experimental setup, showing the prototype board and connections to the power supply, oscilloscope and voltmeter. Note that the signal instrument grounds are all connected to a single point—this helps to prevent noise pickup and ground loops.

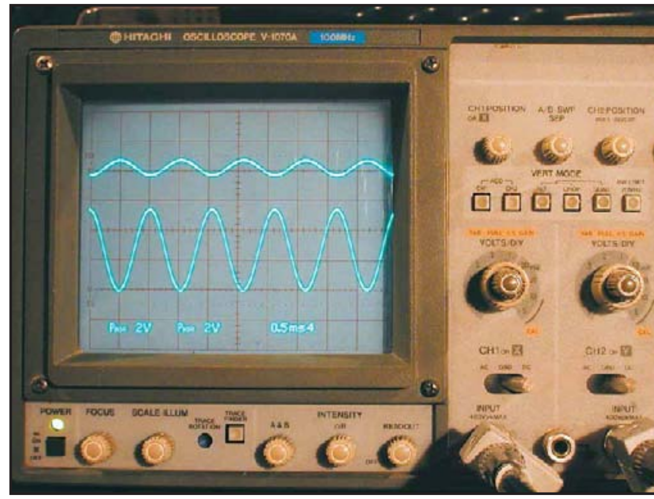

Figure 3—The oscilloscope shows the input (top trace) and output (bottom trace) waveforms. The output is inverted with respect to the input and the voltage gain is approximately 5.

$R_c = 5\ R_e$ and $(1750\ \Omega - R_e) = 5\ R_e$, so $6\ R_e = 1750\ \Omega$ and $R_e = 1750\ \Omega / 6 = 292\ \Omega$ *(use 270 Ω, a standard value).*

4. *From equation 1,* base current, $I_b = I_{cq} / \beta = 4$ mA / 150 = 26.67 µA (27 µA). Set the current through R1 and R2 equal to 10 times I_b or 270 µA. *(This is a rule of thumb simplifying calculations and keeping I_b stable with a "stiff" bias supply.)*

The voltage across R2 = $V_{be} + I_c\ (R_e)$ = 0.7 V + 4 mA (270 Ω) = 1.8 V *($I_c \approx I_e$ and equation 4).*

By Ohm's Law, R2 = 1.8 V / 270 µA = 6.7 kΩ *(use 6.8 kΩ, a standard value).*

The voltage across R1 = V_{cc} – 1.8 V = 10.2 V *(voltage divider)*

By Ohm's Law, R1 = 10.2 V / 270 µA = 37.8 kΩ *(use 39 kΩ, a standard value).*

Testing the Amplifier

1. Connect the power supply only after double-checking all connections, especially the transistor leads.

2. Use a VOM to measure the dc voltage from collector to emitter (it should be about 5 V), from base to emitter (0.6-0.7 V), and from collector and emitter to ground (7 V and 2 V, respectively).

3. Replace R1 with the 100 kΩ potentiometer, set to about 39 kΩ. Confirm that all the dc voltages remain about the same. Connect the VOM between collector and ground and observe what happens as R1 is decreased and increased (raising and lowering base current). Use Ohm's Law to determine what is happening to the collector current as you adjust R1. Reset the pot to 39 kΩ.

4. Set the signal (function) generator to output a 1 kHz sine wave of 200 $mV_{p\text{-}p}$, then connect it to C_{in}. If you are using an oscilloscope, you should see a sine wave at the output of C_{out} with an amplitude of about 1 $V_{p\text{-}p}$ and inverted (180° of phase shift) with respect to the input. (A VOM measuring ac RMS voltage will show values of about 70 mV RMS at the input and 350 mV RMS at the output—a gain of 5.)

5. Adjust R1 in each direction and observe the output signal with the oscilloscope. As you lower the collector current, you will begin to see the output waveform clip on positive peaks as the collector current is cut off. Raising collector current will eventually result in distortion on negative peaks as the transistor enters the saturation region.

6. Return R1 to 39 kΩ and increase the input signal to observe distortion on the output. If you are using a VOM, note that the RMS output increases more slowly as the signal is clipped.

7. Turn down the input signal as far as possible. Connect the third 10 µF capacitor across R_e. (Connect the negative side of a polarized capacitor to ground.) Slowly increase the input signal and observe the new gain of the circuit. By bypassing R_e, the dc operation of the circuit is unaffected, but now the emitter circuit is effectively grounded for ac signals. The gain is now limited only by the internal impedance of the transistor emitter.

8. Now that you have a working circuit—experiment with it!

- Rework the math for a Q-point with 10 times more and 10 times less collector current.
- Raise and lower the input frequency to see where the gain drops to 70% of the peak value. These are the –3 dB frequencies that determine the amplifier's bandwidth. (These frequencies may be out of range, depending on your instruments.)
- Depending on your generator's capabilities, try different waveforms, such as square or triangle waves, at different frequencies. Does the amplifier faithfully reproduce them?
- Substitute other transistors of the same type and of different types to see what happens to the dc and ac performance.

Suggested Reading

"Transistor Amplifier Design—A Practical Approach" in Chapter 8 of *The ARRL Handbook*. For a more complete discussion of the common emitter amplifier, check out Chapter 2 of *The Art of Electronics*.

Shopping List

You'll need the following components:

- 100 kΩ potentiometer.
- ¼ W resistors of the following values: 270 Ω, 1.5 kΩ, 6.8 kΩ, 39 kΩ.
- 3—10 µF capacitors with a voltage rating of 25 V dc or more (electrolytic or tantalum are fine).
- 2N3904 transistor.

Next Month

The common collector amplifier, also known as the emitter follower, will be the subject of next month's experiment. With the exception of a few more resistor values, you'll be able to reuse the components from this month's exercise. See you then!