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Title: Hands-On Radio: Experiment #28: The Common Base Amplifier
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Experiment #28: The Common Base Amplifier

Even though it looks "funny," the common base amplifier and the FET common gate amplifier perform some pretty useful tricks. They're more common than you think!

Terms to Learn

- *Indirect Measurement*—calculating the value of a parameter from the measured values of other parameters
- *Isolation*—a lack of effects on one circuit from changes in another circuit
- *Self-biased*—a circuit that operates at a fixed bias point without a separate biasing circuit

Introduction

Common-base (CB) and common-gate (CG) amplifiers are the third form of single-transistor amplifier circuit topology. Their claim to fame is low input impedance, high voltage gain and high output resistance. This makes them a good choice for RF amplifiers. You may have already made use of the vacuum tube version of the CB circuit—a grounded-grid amplifier! As we discuss these amplifiers, I'll make reference to previous experiments that can be downloaded from the Hands-On Radio Web site, **www.arrl.org/tis/info/HTML/Hands-On-Radio/**.

CB and CG Circuits

Figure 1 shows the CB amplifier—the transistor is turned on its side, with the emitter facing the input. How can that possibly amplify anything? Understanding, as it often does, comes from changing one's view of a problem. Figure 1 redraws the odd-looking regular CB circuit in the more familiar common-emitter style. The input is just moved from the base circuit to the emitter circuit.

Remember—the input signal only needs to cause changes in the transistor base-emitter current. Placing the input in the emitter circuit does exactly that, except that a positive change in input amplitude *reduces* base current by lowering V_{BE}, thus raising V_C. As a result, the CB amplifier is *non-inverting* with output and input signals in-phase.

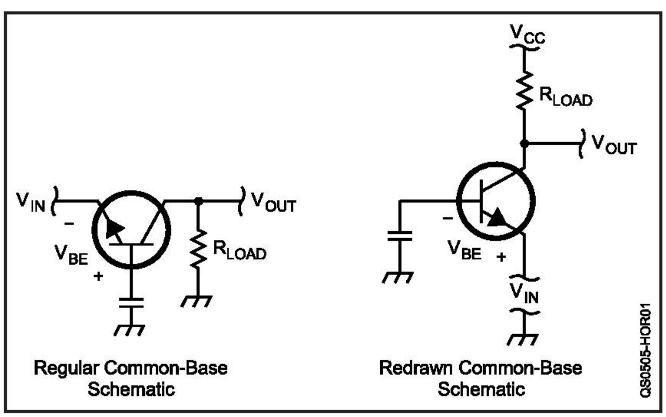

Figure 1—The Common Base amplifier can be redrawn to show its similarity to the better-known Common Emitter amplifier.

Practical circuits for the CB and the JFET CG circuit are shown in Figure 2. Looking at the CB amplifier from a dc point of view (replace the capacitors with open circuits), all of the same resistors are there as in the good old common-emitter amplifier we learned about in Experiment #1. The input capacitors, C_{IN}, allow the dc emitter (or source) current to flow "around" the ac input signal source.

Let's analyze the CB amplifier first. Since the input signal is also the ac emitter current, i_e, the ac collector current must be:

$$i_c = i_e [\beta/(\beta+1)] \text{ so, current gain } A_I = i_c/i_e = [\beta/(b+1)] \quad [1]$$

Current gain is always just below unity, just as voltage gain for the EF amp is just below unity. The neat thing about the CB amplifier is that you can hang just about any load resistance on the output and current gain is unchanged. This configuration has excellent *isolation* between output and input, meaning changes in load don't affect the input impedance—a good thing for RF systems that require stable impedances.

By making the load resistance greater than the input resistance while keeping current constant, you get voltage gain. To calculate the input resistance of the CB amp, we encounter a new transistor parameter, h_{ie}, representing the resistance between the base and emitter. Following reasoning similar to that for the emitter follower (EF) amplifier (see Experiment #2), explaining why current gain multiplied the effect of R_E at the input, we find that input resistance for the CB amp is:

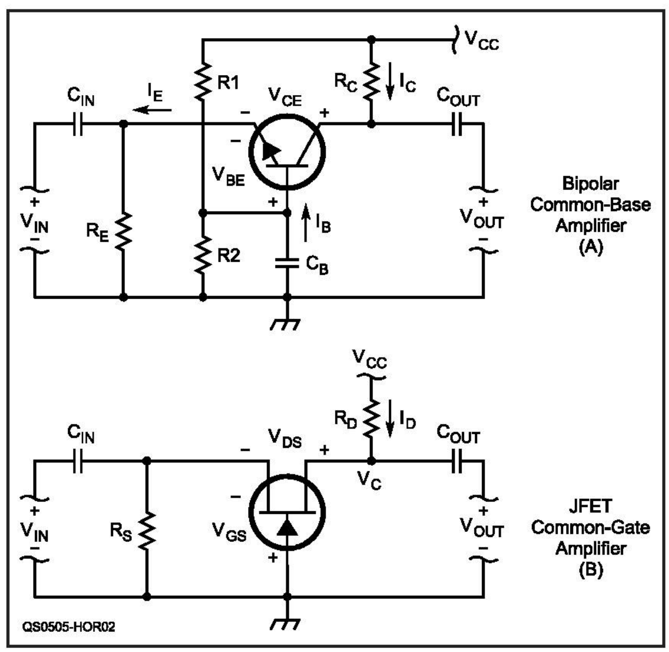

Figure 2—The Common Base and Common Gate amplifiers are great wide-bandwidth amplifiers, with low input impedance and good voltage gain.

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$R_{in} = h_{ie}/(1 + \beta)$ and $v_{in} = R_{in}\, i_e$ [2]

For a 2N3904 transistor, h_{ie} averages about 1 kΩ between 1 and 10 mA of collector current and β is about 150 over the same range. That means the input resistance will be about 6 Ω. A more sophisticated analysis will come up with a somewhat higher figure—around 20 Ω—but the CB input resistance is still quite low and can be controlled by changing the bias current. Transistors used as preamplifiers are designed with h_{ie} to result in a 50 Ω input resistance for reasonable values of collector current.

To figure voltage gain, A_V, start with $v_o = i_c R_L$ and make substitutions from equations 1 and 2. R_L is the parallel combination of R_C and whatever load is attached at V_{OUT}.

$A_V \approx \beta(R_L/h_{ie})$ [3]

It doesn't take a big load resistance to create a substantial voltage gain. Using the 2N3904 again, a 500 Ω load results in A_V = 150 (500/1000) = 75. This is why the CB and CG amplifiers are often used as preamplifiers.

Setting the operating or Q point of the CB amplifier starts with selecting A_V and calculating the required R_L—the parallel combination of R_C and whatever load is connected at V_{OUT}. Determine R_C and proceed to determine R_E, R_1 and R_2, as in the CE amplifier.

In the JFET common-gate amplifier circuit one of the bias resistors is missing. What's up with that? This is called a *source self-biased* circuit. For a depletion-mode JFET, V_{GS} needs to be somewhere between 0 V and V_P, the pinch-off voltage. One way to make V_{GS} negative would be to use a negative supply, but it's easiest to hold V_G at 0 V (by grounding it) and raise V_S instead. With V_G=0:

$V_{GS} = -I_{DS}R_S$ [4]

Since V_{GS} and I_{DS} are predetermined as the selected Q point, you can easily solve for R_S.

The JFET CG performance equations are:

$R_{IN} \approx 1/g_m$, where g_m is the JFET transconductance
$A_V = g_m R_D$

Input and Output Resistance

Much is made of the input and output resistances of the CB/CG amplifier. Can they be measured? Not directly, such as with a VOM, but indirectly, by adding external resistances and observing the effect on the circuit. These methods are illustrated in Figure 3.

Let's start with input resistance. When combined with an external resistor, R_{ADJ}, the amplifier's input resistance, R_{IN}, forms a voltage divider. If I know V_{IN} and V_E, and I can measure R_{ADJ}, I can calculate R_{IN}. Input a known voltage V_{IN} and adjust R_{ADJ} until V_E (measured across R_E) is $^1/_2V_{IN}$. At this point, the resistances in the divider are equal, so $R_{IN} = R_{ADJ}$.

Measuring output resistance is a two-step process. First, disconnect the load resistor, R_L, entirely, and measure the open-circuit voltage, V_{OC}. Then connect a load resistor between one-half and twice the expected value of R_{OUT}. Measure the output voltage, V_L. Once again, you have a voltage divider and, with a little math:

$R_{OUT} = R_L\,(V_{OC} - V_L) / V_L$ [5]

For most transistors in this circuit, R_{OUT} will be approximately the same as R_C. Ready to try it out? Let's go!

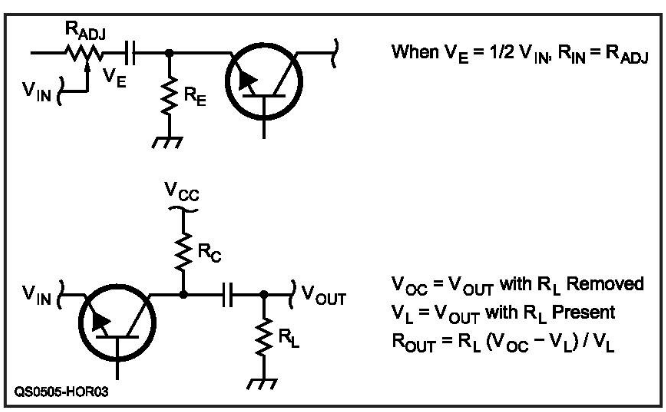

Figure 3—Input and output impedance of amplifier circuits must be measured indirectly.

Building and Testing a CB Amplifier

In this experiment, you'll build a CB amplifier, measure the voltage gain, and then measure the input and output resistance. Start by constructing the amplifier circuit of Figure 2A using resistor values from Experiment #1 (R1 = 39 kΩ, R2 = 6.8 kΩ, R_C = 1.5 kΩ, R_E = 270 Ω), $C_{IN} = C_B = C_{OUT}$ = 10 µF (connect + leads to transistor) and V_{CC} = 12 V. Use equation 3 to calculate the expected value of A_V with R_C as the load. Assume that β=150 and h_{ie} = 1000 Ω. Use equation 2 to calculate the expected value of R_{IN}.

- Confirm that the circuit is operating at its Q point: $V_{CEQ} \approx 5$ V and $I_{CQ} \approx 4$ mA.
- Apply a 10 kHz sine wave to the input at a voltage small enough so that the output is not distorted. (You may have to use a voltmeter to accurately measure the voltage.) Measure the output voltage (which is V_{OC}) and calculate the gain. I obtained a gain of 150. Measured gain will be somewhat lower than the calculations because our equation is somewhat oversimplified. (Voltmeter users—confirm distortionless operation by making sure that changes in the input cause a proportional change in the output.)
- Measure input resistance by placing a 100 Ω potentiometer in series with the input signal and adjusting it until the ac value of $V_E = {}^1/_2\, V_{IN}$. Remove the potentiometer and measure its value—mine was 10.2 Ω.
- Reconnect the input signal directly to C_{IN}. Add a load resistor, R_L = 1 kΩ by connecting it from the OUTPUT side of C_{OUT} to ground, *not* from the collector to ground—that would change the dc biasing. Calculate R_{OUT} by using equation 5. R_{OUT} should be almost the same as R_C—mine was 1.59 kΩ.
- Experiment with different values of load resistance to see what happens to gain.

Shopping List

- 2N3904 transistor
- 270 Ω, 1 kΩ, 1.5 kΩ, 6.8 kΩ, 39 kΩ ¼ W resistors
- 3—10 µF electrolytic capacitors
- 100 Ω potentiometer

Suggested Reading

Common-base amplifiers are not often covered in detail, since they are not common. Chapter 6 of TAB Books' *Guide to Understanding Electricity and Electronics*, 2nd edition, has broad coverage of all three types of amplifier circuits. A simple UHF preamplifier project using a JFET is available at **www.dxzone.com/cgi-bin/dir/jump2.cgi?ID=9258**.

Next Month

Who is this Kirchhoff guy and what are his laws that electrical engineers keep referring to? Tune in next month and learn about two fundamentals of all circuit analysis and design—Kirchhoff's Voltage and Current Laws.