EE351 Laboratory Exercise 2
Transistor Biasing

Sept. 14, 2008

The purpose of this laboratory exercise is to illustrate the concepts of bias in a transistor amplifier stage. Much of the lab involves the student making various adjustments and observing what happens rather than using mathematics. The mathematics of bias that we will go over in depth in class will make more sense if you have already had experience that you can relate to. The concepts of bias are simple but difficult to explain. It is much easier to illustrate.

1.0 Common-emitter Amplifier

1.1 Build the circuit in Figure 1. Note that the voltage divider from the signal generator is used to millivolt input signals to the transistor – this is discussed further in step 1.3. R_B is used to convert the 0-6 Volt (V_{BB}) power supply into a current source for biasing the transistor. R_C is the collector load resistor. The 0-20 Volt power supply is V_{CC}.

1.2 Oscilloscope set up

1.21 Set channel 1 of the oscilloscope to DC coupled, 0.1 Volts per division, and the ground reference should be the center of the screen.

1.22 Set channel 2 of the oscilloscope to DC coupled, 2 Volts per division, and set the ground reference to the bottom graticule on the screen.

1.23 Set the horizontal time base to 200 microseconds per division and the trigger source to be channel 1.

1.24 Initially, the scope should be set to view both channels. ***At various steps during the lab it may be convenient to turn off the display of channel 1 as it may get in the way of your observations.***

1.3 Signal generator set up. Connect channel 1 of the scope to Vin (see the schematic) and adjust the signal generator for a sine wave output of 1000 Hz, 0.5 Volts peak-peak. Make sure the DC offset on the signal generator is turned off. It is not necessary to be exactly on 1000 Hz – anything within reason will do. If everything is going well you should see about five complete cycles on the screen. Note that the actual input signal to the transistor is 0.5/101 or 0.00495 Vpp. We need a small signal at the base and use a voltage divider to achieve it. It is easy to set the signal generator for 0.5 Vpp but difficult or impossible to set it to 0.005 Vpp. Note that you will measure the output of the signal generator and compute the output of the voltage divider in the following steps.

1.4 Power supply setup. Set V_{BB} to 0 Volts and V_{CC} to 15 Volts.

EE351 Laboratory Exercise 2
Transistor Biasing

1.5 Connect channel 2 of the scope to V_C. You should see a flat line at 15 Volts DC. Right now the transistor is biased to cut-off (no collector current). Slowly start increasing V_{BB} (this applies bias to the transistor) and observe the effects on V_C. The first effect you should see are negative half-wave like peaks on V_C.

1.6 As V_{BB} is increased more you should see a sine wave at V_C. As V_{BB} is increased even further you should observe that the DC value of the sine wave (i.e. V_C) becomes lower and the amplitude of the sine wave should increase (the gain of the transistor increases as the emitter bias current is increased). Measure the peak-peak amplitude of the sine wave when it first becomes unclipped and then measure again as V_{BB} is increased to the point where you can observe that the output sine wave is distorted – you will observe that the downward swing is greater than the upward swing from the zero reference point – that is a consequence of the exponential transfer function – your signal is becoming too large to treat the operating point as linear.

1.7 As you further increase V_{BB} the negative peaks of the V_C sine wave should begin to clip near zero Volts. The sine wave has a high degree of non-symmetry prior to this point because of the exponential transfer function.

1.8 Keep increasing V_{BB} until it is as high as it will go and also observe that the V_C sine wave become more and more clipped until the signal is gone completely. The transistor is now biased in to voltage saturation (V_{CE} is approximately zero all the time) and the transistor is no longer working as an amplifier.

1.9 From the preceding it is obvious that there is an optimum point between the two extremes to bias the transistor. Find this optimum point experimentally by adjusting both V_{BB} and the amplitude of the signal generator for the largest possible undistorted sine wave at V_C. You are tweaking two things searching for an optimum. For this experiment the sine wave is considered to be distorted if you can visibly see a difference between the upper half-wave and the lower half-wave – generally one peak will look noticeably wider or higher than the other. This point is well below the clipping level. This level of distortion is a bit subjective and not everyone will agree on the level. Where there is disagreement in the level, use the value where half of the lab group thinks the signal is distorted and the other half does not. Once you find this point, record the following: Vinac, V_{BB}, $V_B$dc, $V_C$dc, and $V_C$ac. The AC signals should be measured in peak-peak. Use a DC voltmeter to measure the DC signals. As a hint, the output of the signal generator should be in the general range of 3 Volts peak-peak – use this value only as a reality check of your experiment. Another hint is that the DC collector voltage should be fairly low but not too low.

1.10 Observe that the sine wave at VC is inverted from Vin. Try to understand why.

1.11 Connect channel 2 of the scope to V_B. Change the settings to 0.1 Volts per division. Make sure that the ground reference is still the lowest graticule on the screen. You should see a DC level of about 0.6 Volts with a small AC signal (about 30 mVpp) superimposed. The amplitude of the AC level is Vin/101. Observe that the sine wave at V_B is in phase with Vin. Restore channel 2 of the scope to the original settings and reconnect to V_C.

1.12 Calculate the base current and collector current of the transistor and then calculate the beta. Hint: measure the DC voltage drops across R_B and R_C.

1.13 Calculate the magnitude of the gain of the transistor stage by dividing the magnitude of the $V_C$ac voltage by the $V_B$ac voltage (Vin / 101).

1.14 Compute the dynamic AC resistance, re = $0.026/I_E$, of the transistor from the bias conditions and calculate the theoretical AC gain = (B/(B+1)) * (R_C/re). Compare this value with the actual. They should be similar within roughly 20 percent.

1.15 Without changing anything else from step 1.8 connect the load circuit shown in Figure 1 and note that the amplitude of the AC signal has dropped – the DC level of V_C should not change. Measure the AC amplitude of the signal at V_C.

1.16 Using voltage divider algebra, compute the output resistance of the transistor amplifier. The result should be close to 4700 Ohms – the resistance of R_C.

1.17 Observe the signal directly across the load resistor and observe that there is no DC level. You will have to adjust the ground reference of channel 2 to the middle of the screen to see this.

1.18 With the load connected repeat step 1.9 and experimentally determine the optimum bias point that provides the maximum possible undistorted AC signal. Record the conditions as before. In class we will cover the algebra that predicts the optimum bias point based on the load.

2.0 Temperature Stability

2.1 Build the circuit in Figure 2. The voltage divider on the V_{BB} power supply provides the fine adjustment needed.

2.2 Adjust V_{BB} until V_C is 8.0 Volts. You will probably notice that there is drift in this adjustment. The drift is due to small temperature changes in the transistor as you make the adjustment. Wait 10 seconds or more until the reading stabilizes and then readjust. Repeat as necessary until V_C stabilizes to within +-0.2 Volts of 8.0 Volts. Record the final value of V_C.

2.3 Hold the transistor case between your thumb and index finder being careful not to touch the wires – that would upset the measurement. You should notice that V_C drops noticeably over the course of about one minute as you heat the transistor. Measure the new value of V_C. This is an example of temperature drift that good design can greatly reduce.

2.4 Use your data from the previous steps to compute the change in collector current.

3.0 Common Collector Amplifier

3.1 Build the circuit in Figure 3. Set the initial conditions to: V_{BB} = 0, V_{CC} = 6, Vin = 1 Volt peak-peak sine wave at 1000 Hz. Connect the oscilloscope as follows: Channel 1 to Vin and set to DC couple, 1 Volt per division, and zero reference to middle of screen; Channel 2 to V_E and set to DC couple, 1 Volt per division, and zero reference to lowest graticule on screen. The horizontal time base should be set to 200 microseconds per division and trigger from channel 1.

3.2 Observe the V_E signal on channel 2 of the scope. You should see a mostly flat line at 0 Volts with possible small rises on the positive peaks of the input. The transistor is presently biased into cutoff.

3.3 Slowly increase V_{BB} until an undistorted sine wave is at V_E. You will first see positive peaks of the sine wave and then the complete sine wave will be present. The amplitude of this sine wave should be almost the same as Vin. Note that the output waveform is in-phase with the input. Try to understand why.

3.4 Keep increasing V_{BB} and note that the amplitude of the sine wave at V_E remains constant and that the DC voltage at V_E rises. At some point the positive peaks of the sine will begin to clip. The bias level is now too high.

3.5 As before, adjust V_{BB} and the signal generator amplitude for the maximum possible undistorted sine wave at V_E. This is the optimum bias point that we will compute in class. Record the values of V_{BB}, Vin, $V_E$dc, and $V_E$ac.

3.6 Now connect the load circuit shown on Figure 3.

3.7 Note that the signal voltage at V_E is clipped (if not then it should be – you either have the wrong load resistor or your $V_E$ac value in step 3.5 is too small). Adjust V_{BB} and the amplitude of the signal generator for the maximum possible undistorted sine wave at V_E (this will be less than in step 3.5). Record the values of V_{BB}, Vin, $V_E$dc, and $V_E$ac. Later in class we will use these values to confirm the algebra that will predict how to bias the transistor for optimum linear operation.

3.8 Using the data in 3.7, calculate the voltage gain of the circuit. This should be less than 1.0.

3.9 Without changing any else, disconnect the load. Measure the output signal voltage which should be higher in amplitude than in step 3.7. Using voltage divider algebra, compute the output resistance of the transistor amplifier. It should be a fairly low value.

EE351 Laboratory Exercise 2
Transistor Biasing