Common Emitter Amplifier

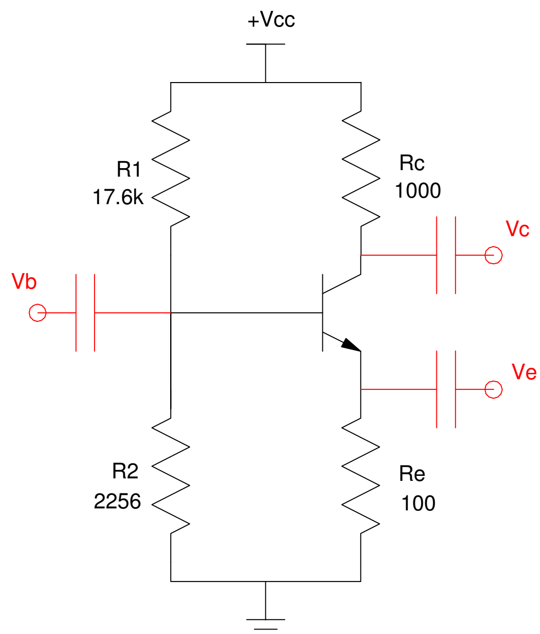
Background:

Assume you have a transistor circuit set up so that the Q point is in the active region. Use this to amplify a small AC signal.

Assume the following circuit for now with the Q-point being

Ic = 6mA

Vc = 6V



To prevent the outside world from messing up the Q-point, add capacitors to the base, emitter, and collector.

For a common-emitter amplifier, connect

- Ve to ground.
- The input to Vb
- The output to Vc.

If you apply an AC signal to Vb, this changes the voltage (and hence current) to the base. This current is amplified by β, which is converted to a voltage and amlified again by Rc. The net is an amplifier.

To analyze this amplifier, ignore the DC terms. The DC analysis set the Q point, and we don't want to mess with that. Besides, the capacitors block DC terms from getting to the amplifier.

Instead, analyze the AC terms. For a resistor, AC and DC look alike. For a diode, however, we need to find the small signal model. We need that AC model for the diode to model the base-to-emitter connection for the transistor.

Recall that for a silicon diode that

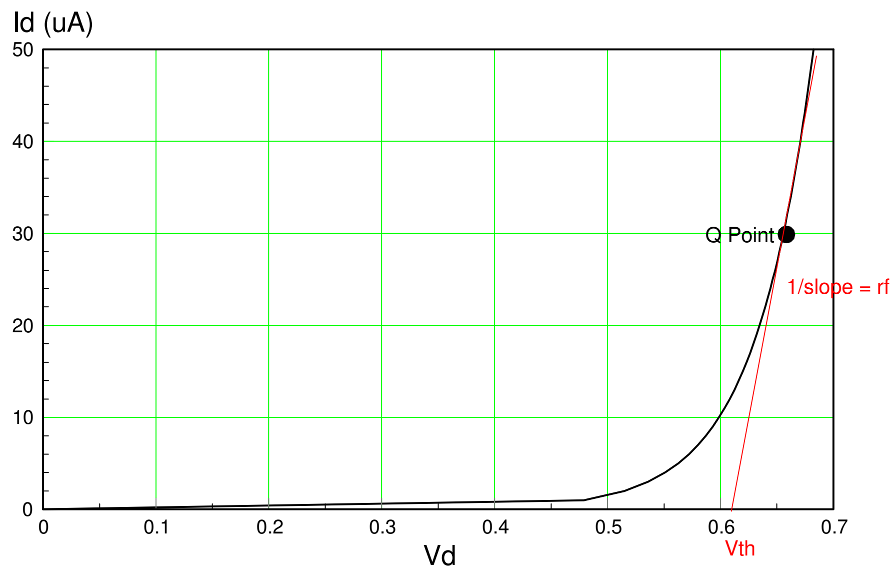
$$V_d = \eta V_T \cdot \ln(I_d/I_o + 1)$$

$$\eta \approx 2$$

$$V_T = 0.026$$

$$I_o \approx 10^{-10} A$$

which gives the following VI characteristic. Drawing the tangent to the VI curve at the Q point gives the small-signal model (a.k.a. the first two terms in the Taylor's series expansion.)



Taking the tangent results in the small-signal model:

$$V_d \approx V_{th} + i_d r_f$$

Taking the derivative:

$$r_f = \frac{dV_d}{dI_d} = \frac{d}{dI_d}\left(\eta V_T \cdot \ln\left(\frac{I_d}{I_o} + 1\right)\right)$$

$$r_f = (\eta V_t)\left(\frac{1}{\frac{I_d}{I_o}+1}\right)\left(\frac{1}{I_o}\right)$$

$$r_f = (\eta V_t)\left(\frac{1}{I_d+I_o}\right)$$

Since $I_o << I_d$ at the Q point,

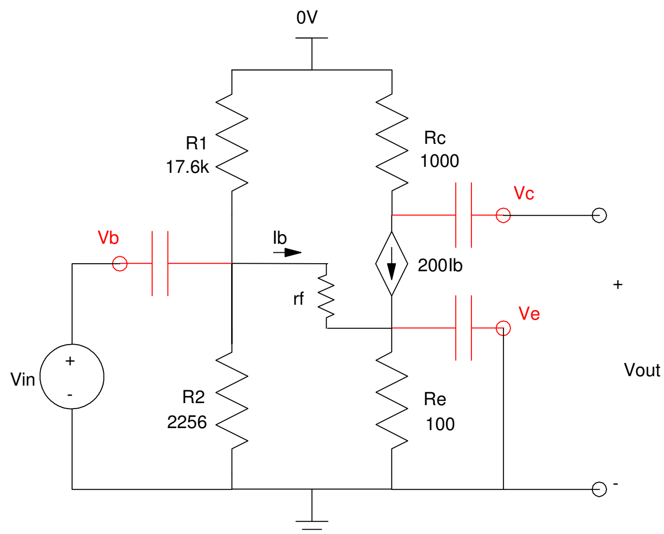
$$r_f \approx \left(\frac{\eta V_T}{I_d}\right)$$

or with the Q point being 30uA (Ib),

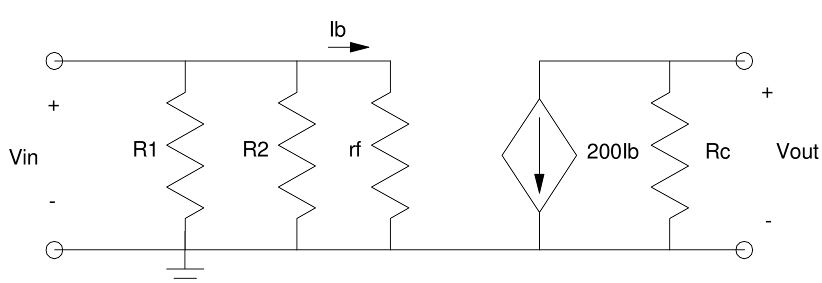
$$r_f = \left(\frac{0.052V}{30\mu A}\right) = 1733\Omega$$

There's also a DC term, but we're ignoring DC terms for AC analysis.

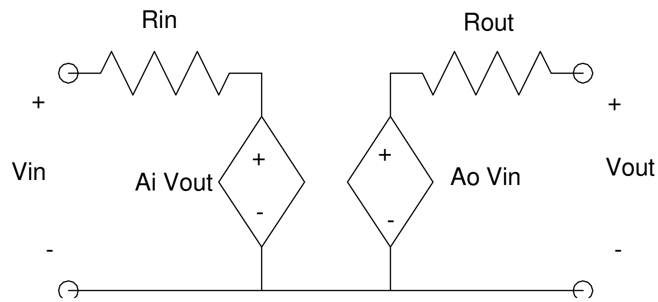
Now, let's look at the small signal model (i.e. the AC model). Note that Vcc = +12V, which has no AC term. Hence, for AC analysis, Vcc = 0V.



Redrawing this results in



To simplify this, use a generic Thevenin equialent for a circuit with an input and output, termed a 2-port model:



To find the two port parameters, come up with a test to find all four paramters for the 2-port model. Do the same test on the CE amplifier circuit.

Rin: For the 2-port model, short Vo so that Vo=0 and $A_i V_{out} = 0$. Measure the resistance at the input. Doing the same for the CE amplifier, this results in

$$R_{in} = R_1 || R_2 || r_f$$

Ai: For the 2-port model, apply 1V to Vout. Measure the resulting voltage at Vin. Doing the same for the CE amplifier results in Vin = 0V, so

$$Ai = 0$$

Rout: For the 2-port model, short Vi so that Vi=0 and $A_o V_{in} = 0$. Measure the resistance at the output. Doing the same for the CE amplifier, this results in

$$R_{out} = R_c$$

Ao: For the 2-port model, apply 1V to Vin. Measure the resulting voltage at Vout. Doing the same for the CE amplifier results in

$$I_b = \frac{1}{r_f}$$

$$I_c = \beta I_b = \frac{\beta}{r_f}$$

$$V_{out} = -R_c I_c = -\frac{\beta R_c}{r_f}$$

so

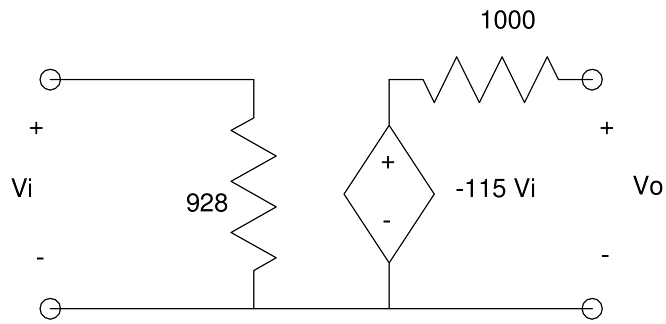
$$A_o = -\frac{\beta R_c}{r_f}$$

The 2-port model for a CE amplifier is then

$$R_{in} = 928\Omega$$

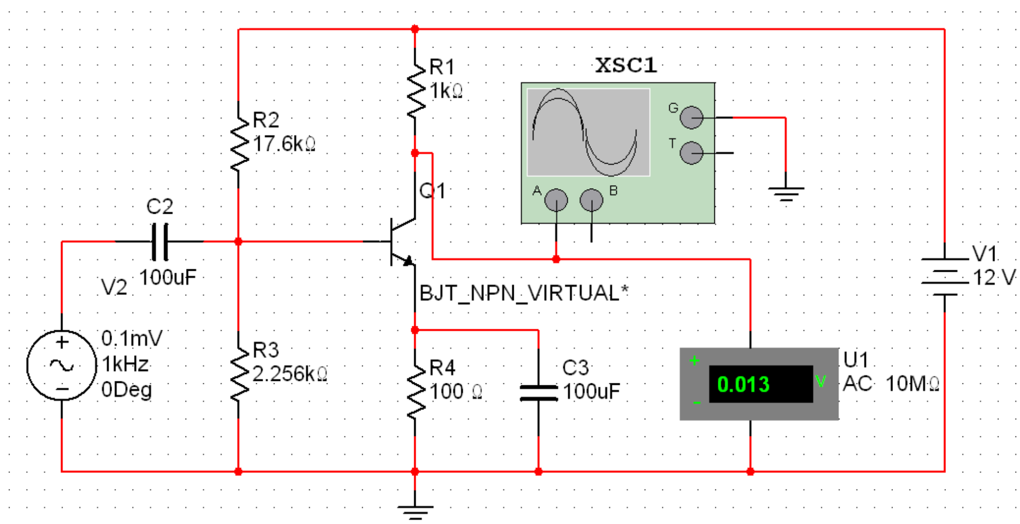
$$R_{out} = 1k\Omega$$

$$A_o = -115$$



Problem: Simulate the response of this circuit to a 0.1mV, 1kHz sine wave input. Assume all capacitors are 100uF.

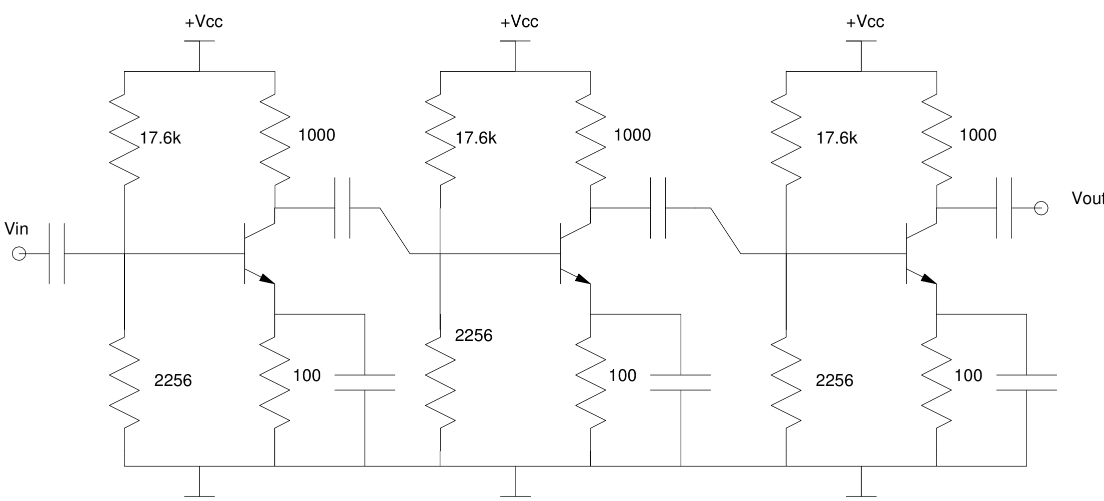
Using MultiSim:



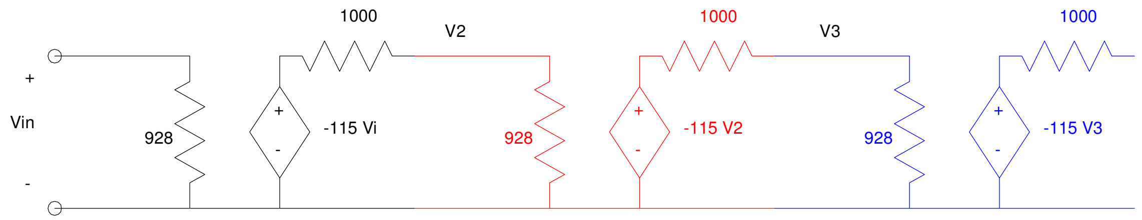
If you use DC coupling on the oscilloscope (left), you see the small AC signal at Vc riding on top of a 6V DC offset. If you switch to AC coupling to remove the DC offset, you can see the AC signal is 13mV rms, resulting in an AC gain of 130. The gain is supposed to be 115, so this is pretty close to our analysis.

DC Coupling showing the DC offset of the Q-point (left) and AC coupling showing the gain (right)

Problem: Find the 2-port model for the following circuit:



Solution: This is the same circuit we've been analyzing, copied three times. The 2-port model will be the same for all three sections since they're identical. Using the 2-port model then,



Now go through the 2-port tests:

Rin: Set Vo = 0V and measure the input resistance. Rin = 928 Ohms.

Ai: Set Vo = 1V and measure the voltage at Vin. Ai = 0

Rout: Set Vin = 0V and measure the resistance across Vo. Vin = 0 sets V2 = 0 sets V3 = 0 sets -115V3 = 0. Rout = 1000 Ohms.

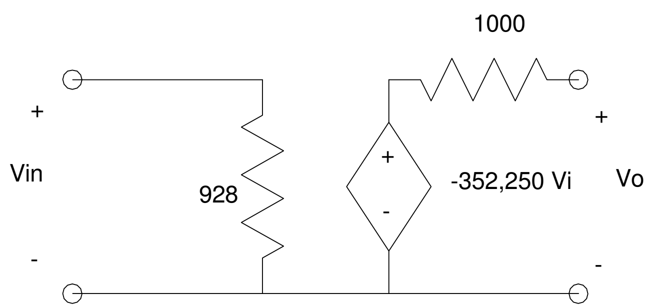
Ao: Apply 1V at Vin and mesure Vout. If Vin = 1V,

$$V_2 = \left(\frac{928}{1000+928}\right)(-115V_i) = -55.35V$$

$$V_3 = \left(\frac{928}{1000+928}\right)(-115V_2) = 3063.9V$$

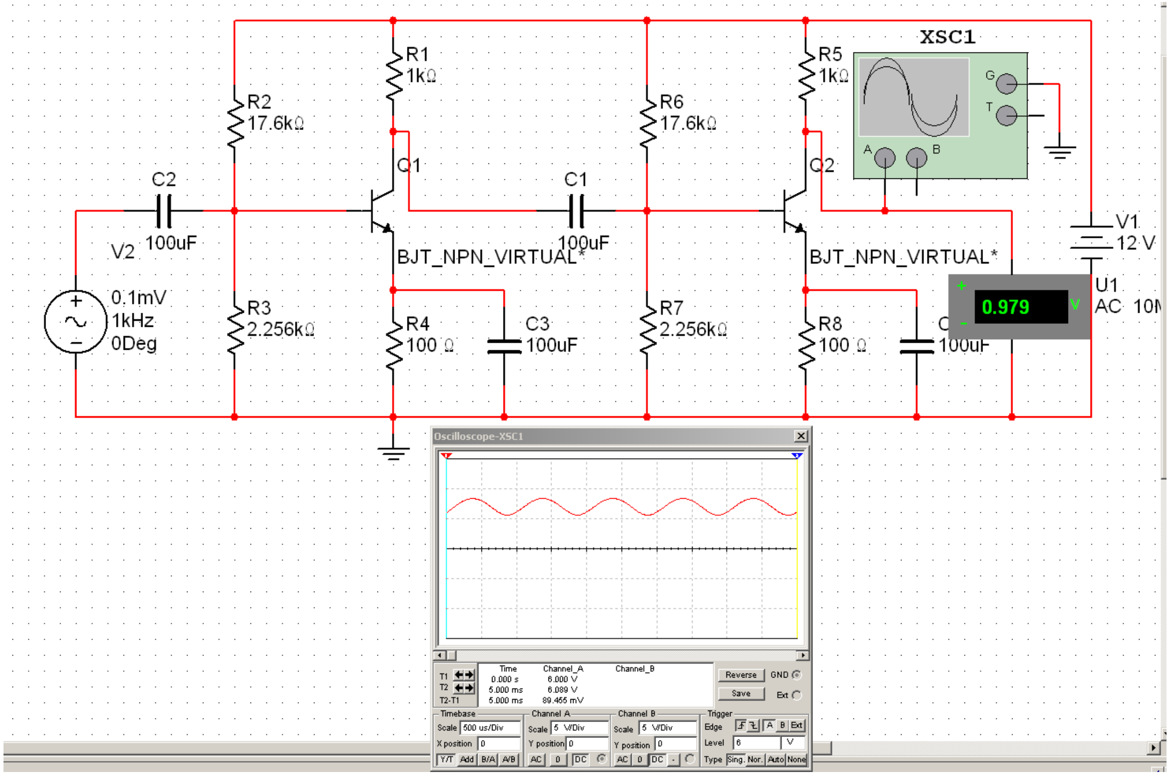
$$V_o = -115V_3 = -352,350$$

So the 2-port model is



CE amplifiers are used to add gain.

In MultiSim, you can see the additional gain from adding stages. Using two stages results in the output still riding on a 6V offset, but now with an amplitude of 0.982V (rms), for a votlage gain of 9,790.


XSC1
G
T
A
B
R1
1kΩ
R2
17.6kΩ
R5
1kΩ
R6
17.6kΩ
Q1
Q2
C2
100uF
C1
100uF
V2
0.1mV
1kHz
0Deg
BJT_NPN_VIRTUAL*
BJT_NPN_VIRTUAL*
V1
12 V
U1
AC
0.979
R3
2.256kΩ
R4
100 Ω
C3
100uF
R7
2.256kΩ
R8
100 Ω
100uF
Oscilloscope-XSC1
Time
Channel_A
Channel_B
T1
T2
T2-T1
Reverse
Save
GND
Ext
Timebase
Channel A
Channel B
Trigger