Fundamentals of Electronics
Week 9

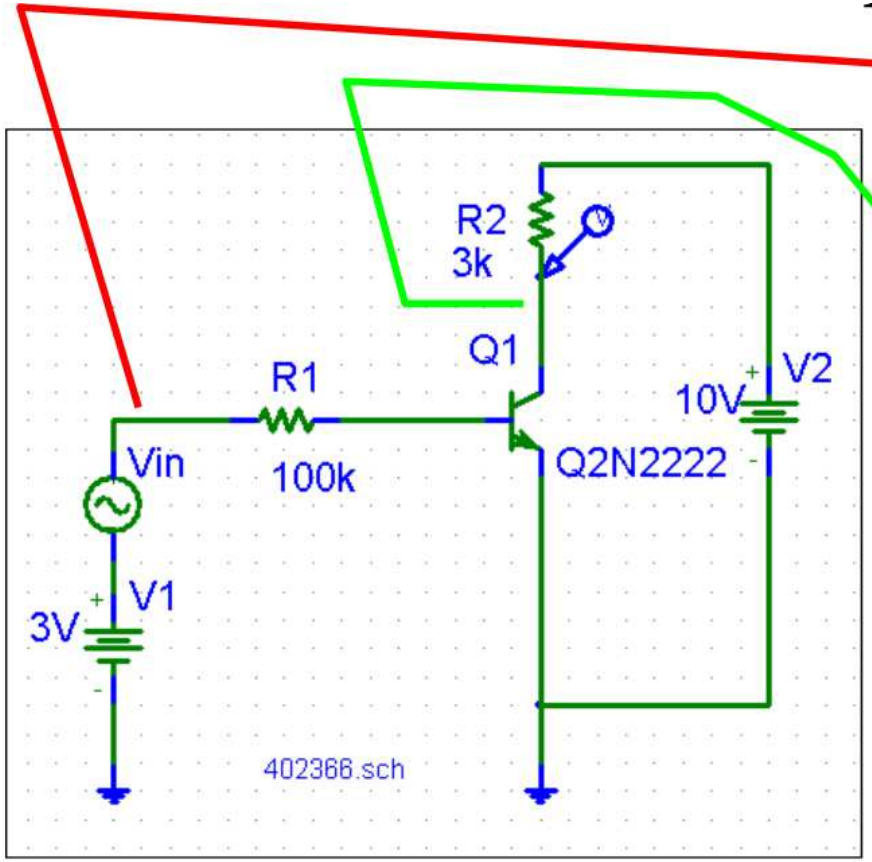
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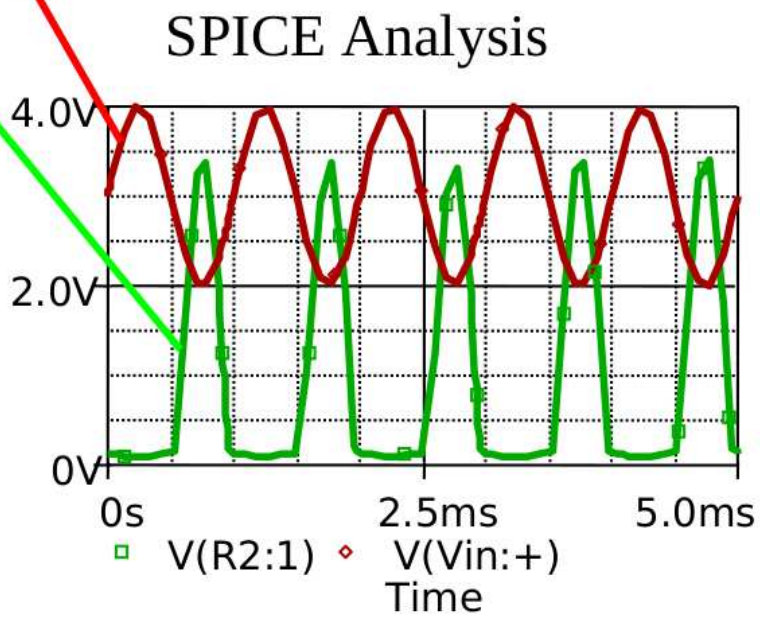
Oct 2024

Agenda

- Some Small-Signal-Model Examples
- The Early Voltage in the AC Model
- Transistor Amplifier
  - Graphical Solution
  - Computational Solution
- Amplifier Design Issues
- Biasing Arrangements
- Four Amplifier Circuits

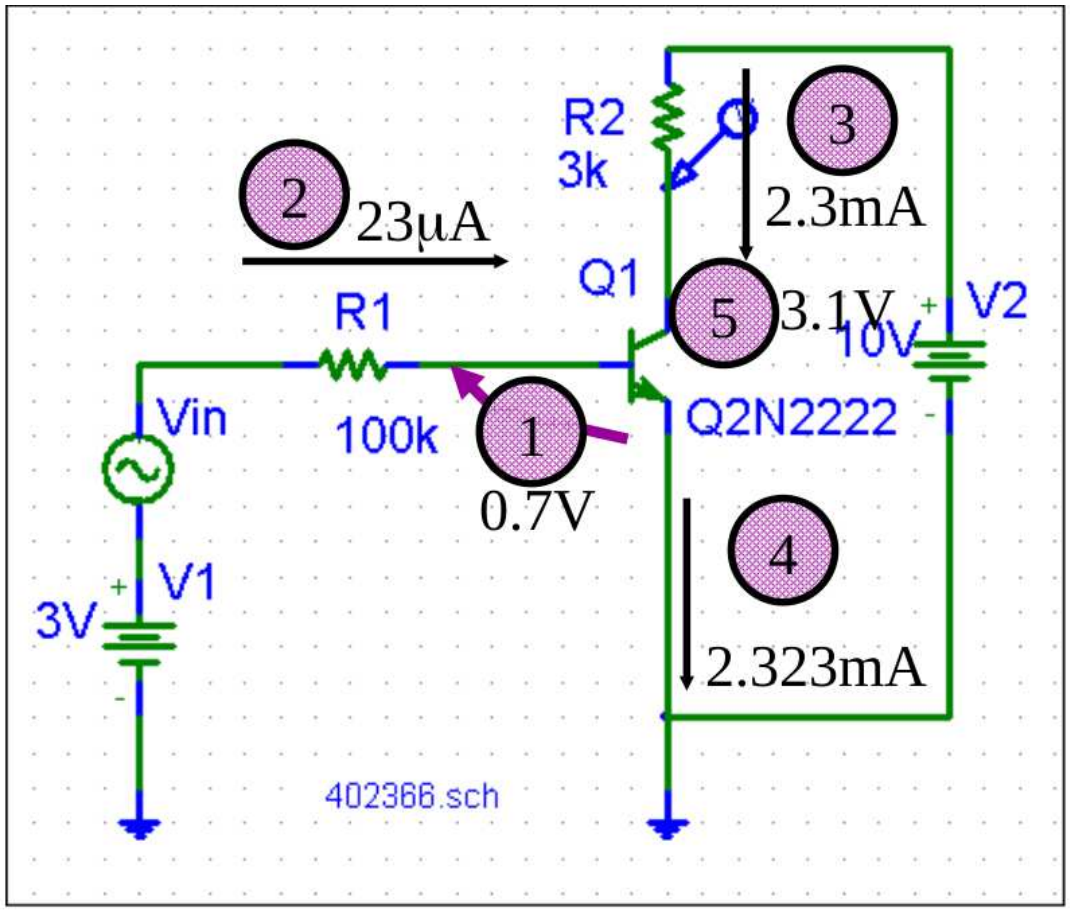
An Example: 4.9





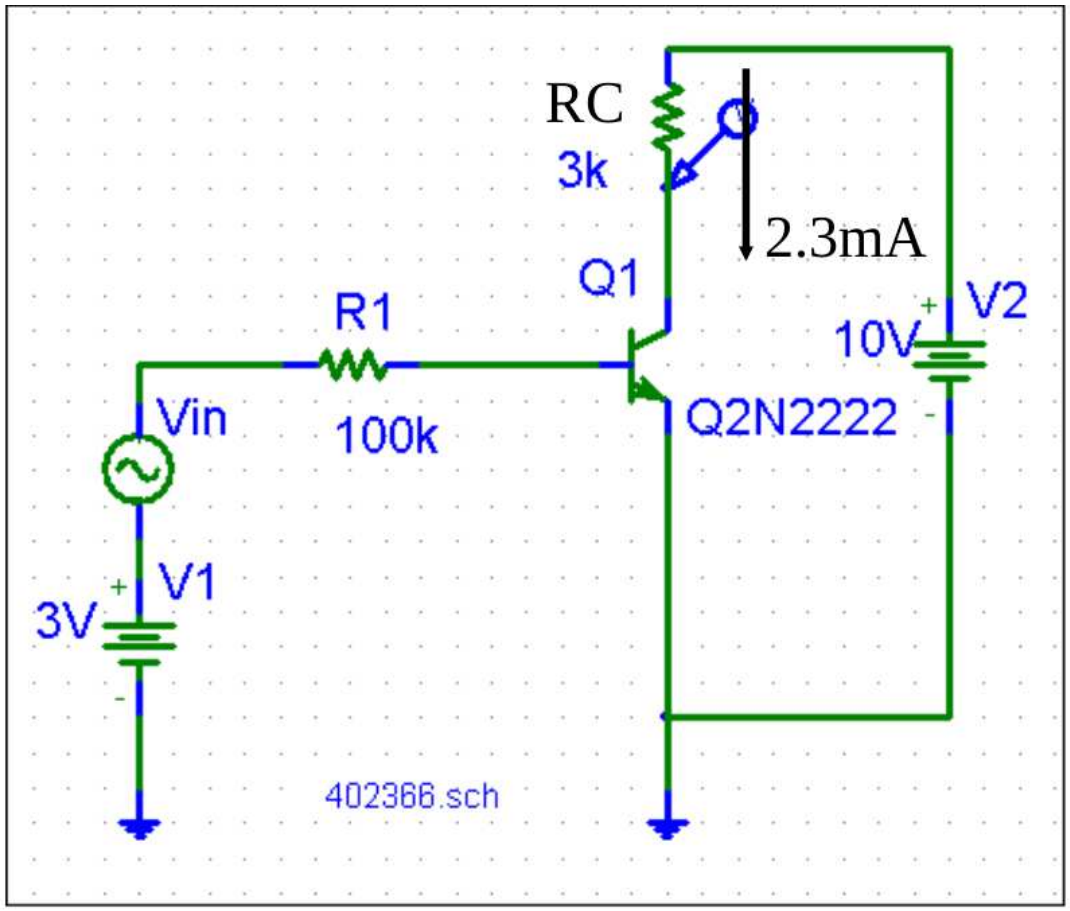
β=100

Example 4.9: DC Analysis



1. Guess
2. V/R
3. βi_b
4. $i_c + i_b$
5. $V_c = V_2 - i_c R_c$ $= 3.1\text{V}$
6. Active Mode OK

Example 4.9: AC Parameters



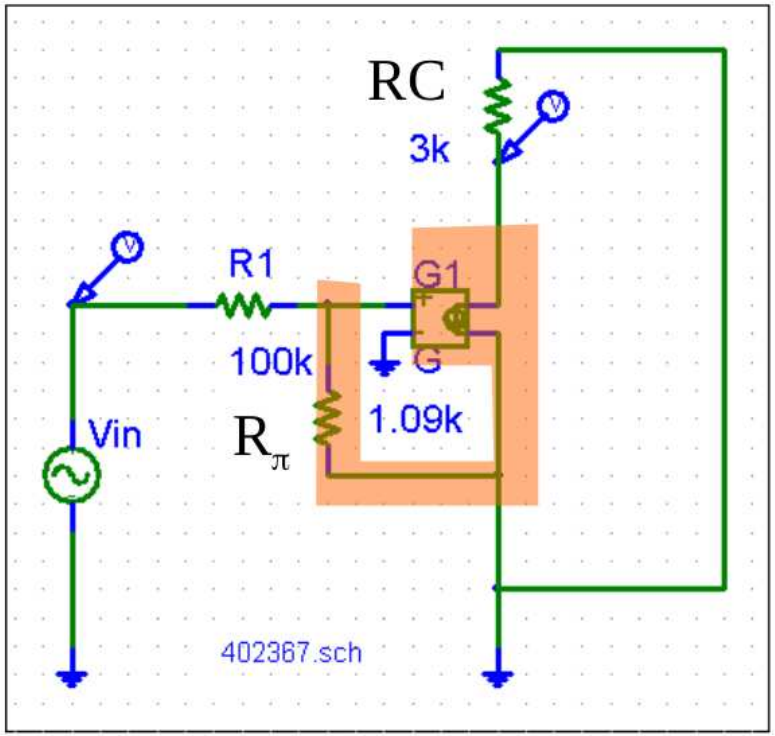
$$g_m = \frac{I_C}{V_T} = 92\text{mA/V}$$

$$r_\pi = \frac{\beta}{g_m} = 1.09\text{k}\Omega$$

Base Current Depends Mostly on V1 and R1, so Collector Current is a Strong Function of β.

Thus, so is g_m, and r_π.

Example 4.9: AC Pi Model

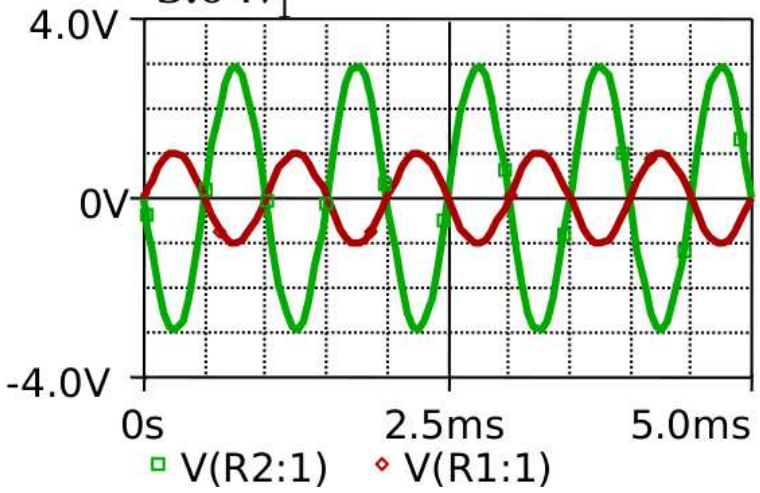


$$v_{be}^{(AC)} = v_{in}^{(AC)} \frac{r_\pi}{R_1 + r_\pi} = 0.011 v_1^{(AC)}$$

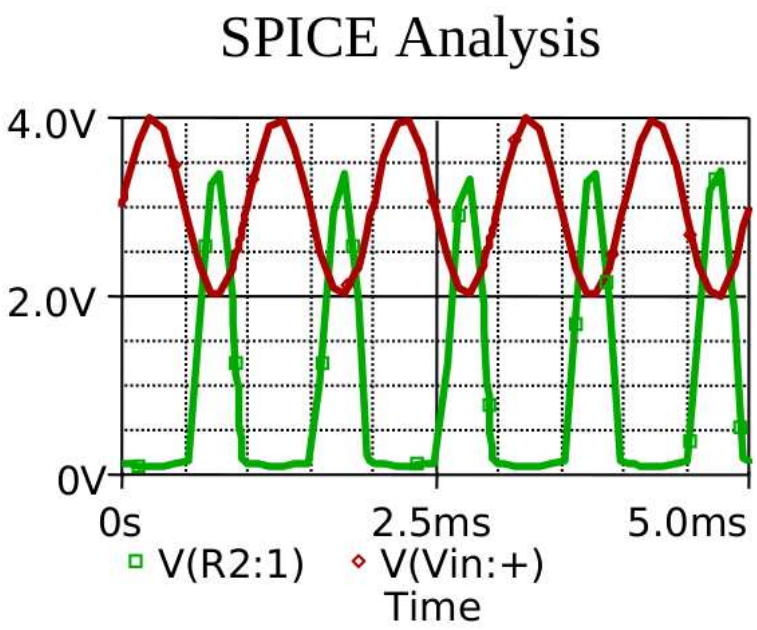
$$v_{out}^{(AC)} = - g_m v_{be}^{(AC)} R_C =$$

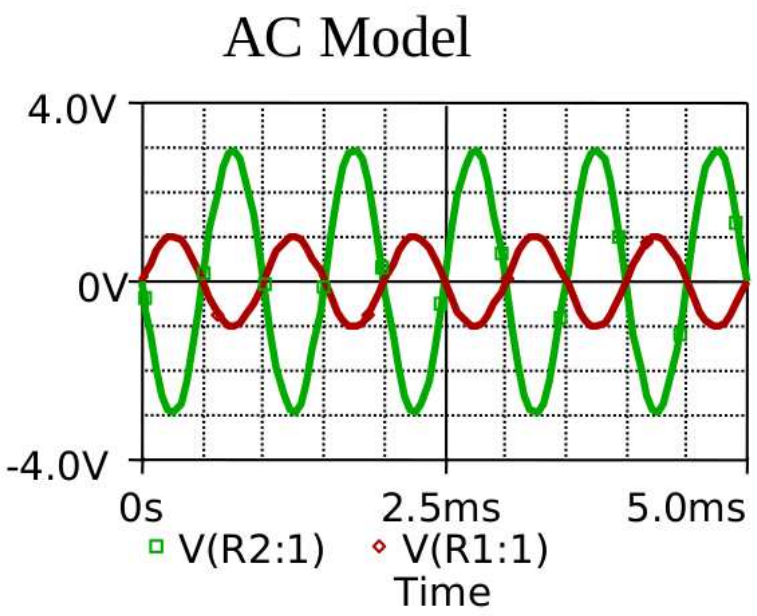
$$- 92\text{mA/V} \times 0.011 v_1^{(AC)} \times 3\text{k}\Omega$$

$$= - 3.04 v_1^{(AC)}$$



Example 4.9: AC Signal Model





Example 4.9: Conclusion

- Amplifier Voltage Gain
  - g_v=-3.04
- Power Gain

$$dBm = 10\log\left[\frac{\left(v^{(RMS)}\right)^2}{50\Omega \times 0.001\text{W}}\right] = 20\log\left[\frac{\left|v^{(RMS)}\right|}{50\Omega \times 0.001\text{W}}\right]$$

  - *10 log(3.04²)=9.7* dB
- Example
  - Input = 7 mV RMS = 10 mV Peak = -30 dBm
  - Output = -30 dBm + 9.7 dB = -20.3 dBm

An Example: 4.10

- The AC Base Voltage Should Not Exceed About 10 mV

$$i_C = I_C^{(DC)} e^{v_{be}^{(AC)}/V_T}$$

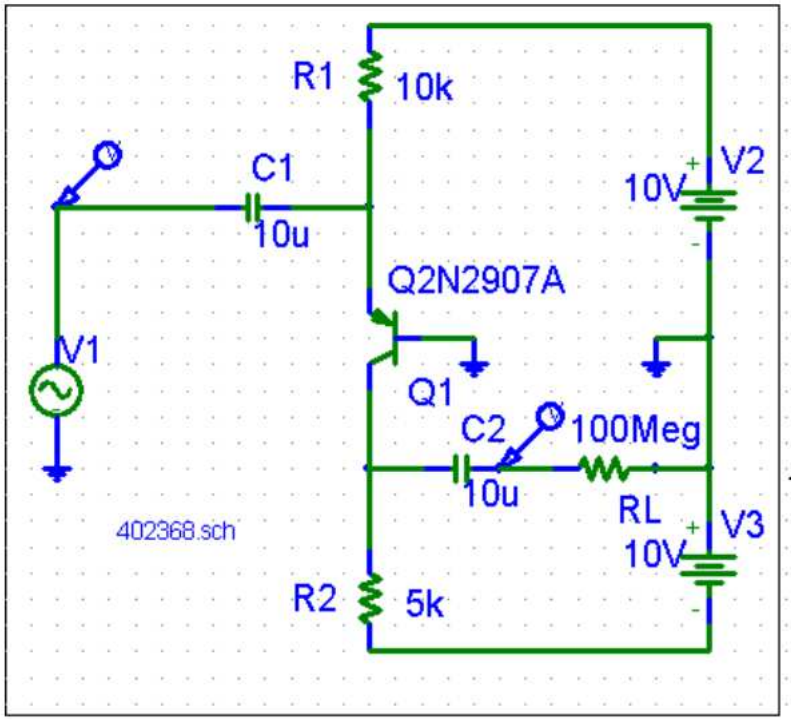
$$i_C \approx I_C^{(DC)} \left[1 + \frac{v_{be}^{(AC)}}{V_T} + \frac{1}{2!}\left(\frac{v_{be}^{(AC)}}{V_T} \right)^2 + \cdots \right]$$

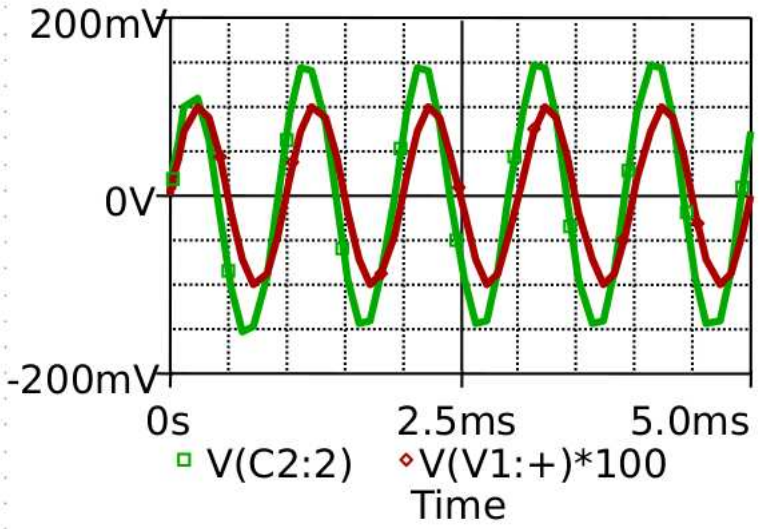
$$i_C \approx I_C^{(DC)} \left[1 + \frac{10\text{mV}}{25\text{mV}} + \frac{1}{2!}\left(\frac{10\text{mV}}{25\text{mV}} \right)^2 + \cdots \right]$$

$$i_C \approx I_C^{(DC)} \left[1 + 0.4 + 0.08 + \cdots \right]$$

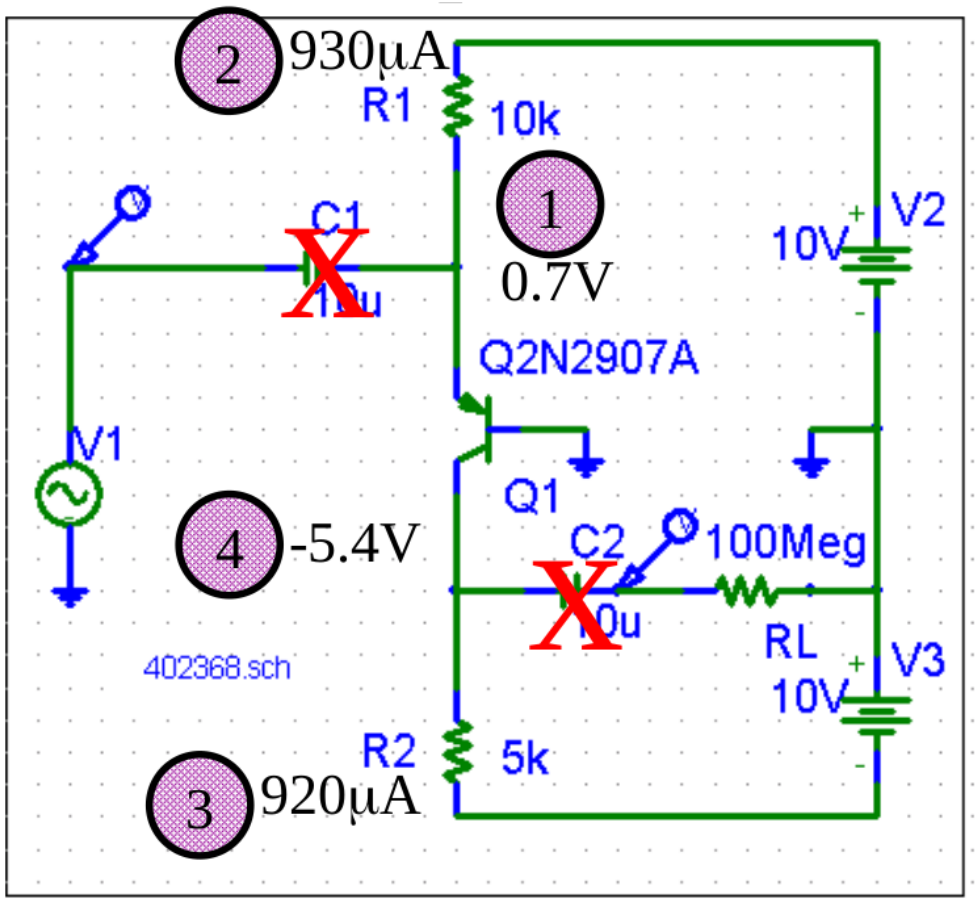
$$\text{distortion} = 0.08/0.4 = 20\%$$

An Example: 4.11



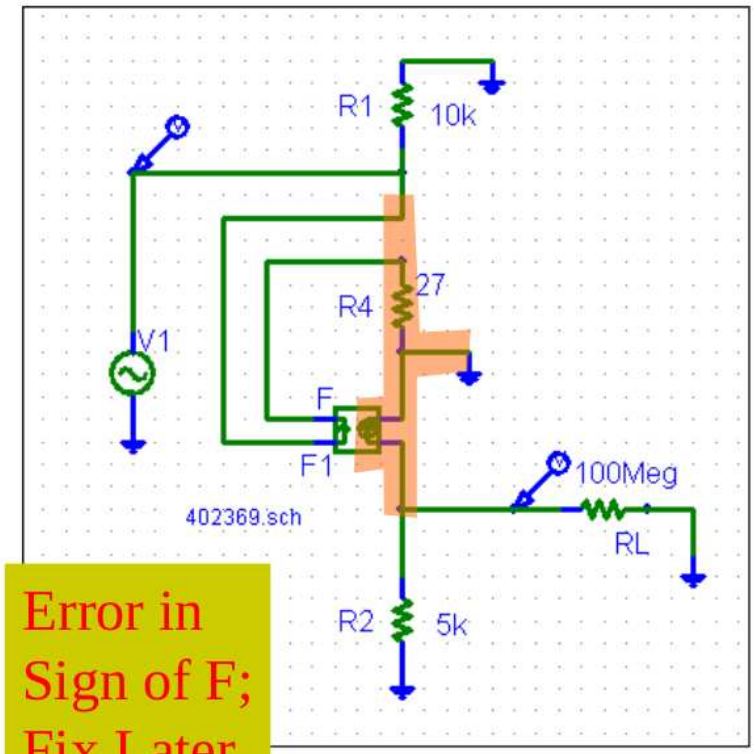


Example: 4.11: DC Analysis



1. Guess
2. $(10-0.7)/R_1$
3. $I_E\alpha$
4. I_CR_2
5. Active Mode OK

Example: 4.11: AC Tee Model



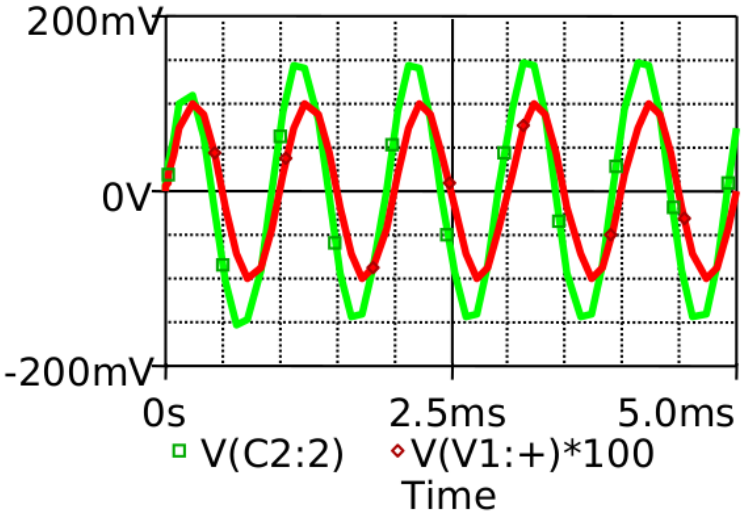
Error in Sign of F; Fix Later

$$r_e = \frac{V_T}{I_E^{(DC)}} = 27\Omega$$

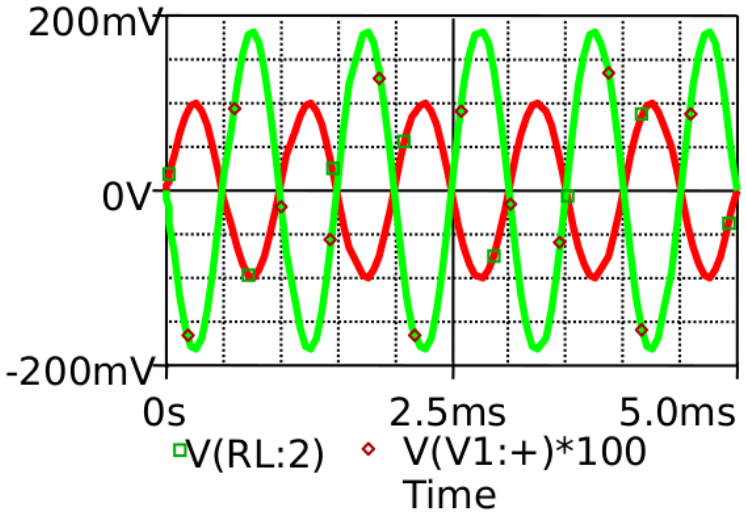
$$i_c^{(AC)} = \alpha i_e^{(AC)}$$
$$= 0.99 v_{in}^{(AC)} / 27\Omega$$

$$v_{out}^{(AC)} = i_c^{(AC)} R_C = R_C \alpha i_e^{(AC)}$$
$$= 5000 \times 0.99 v_{in}^{(AC)} / 27\Omega$$

Example: 4.11: SPICE Comparison



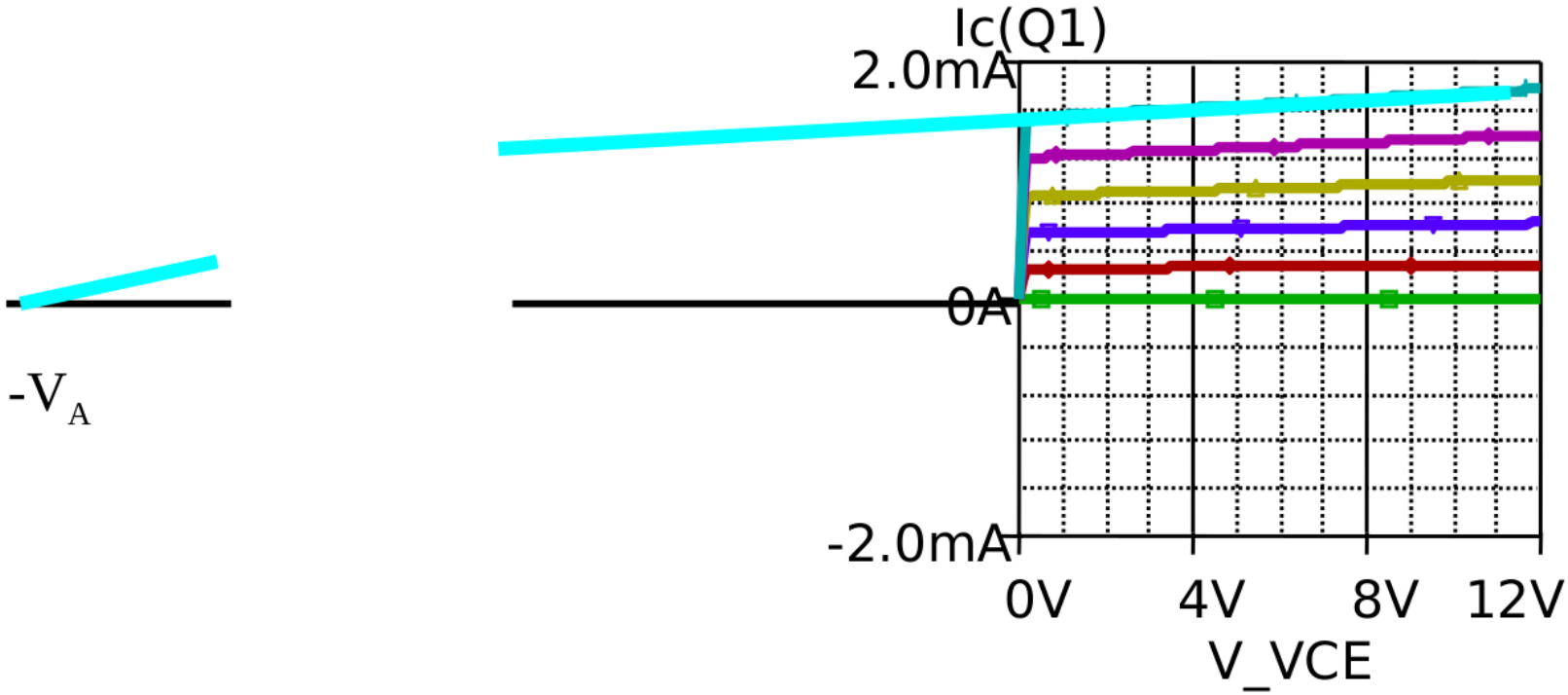
Spice



AC Model

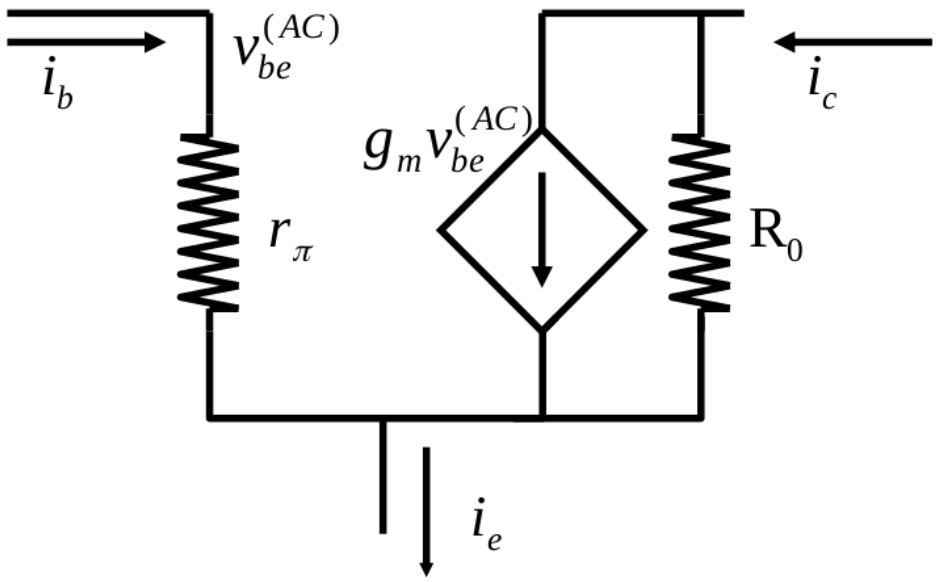
Error in sign: Fix Later

Early Voltage Again

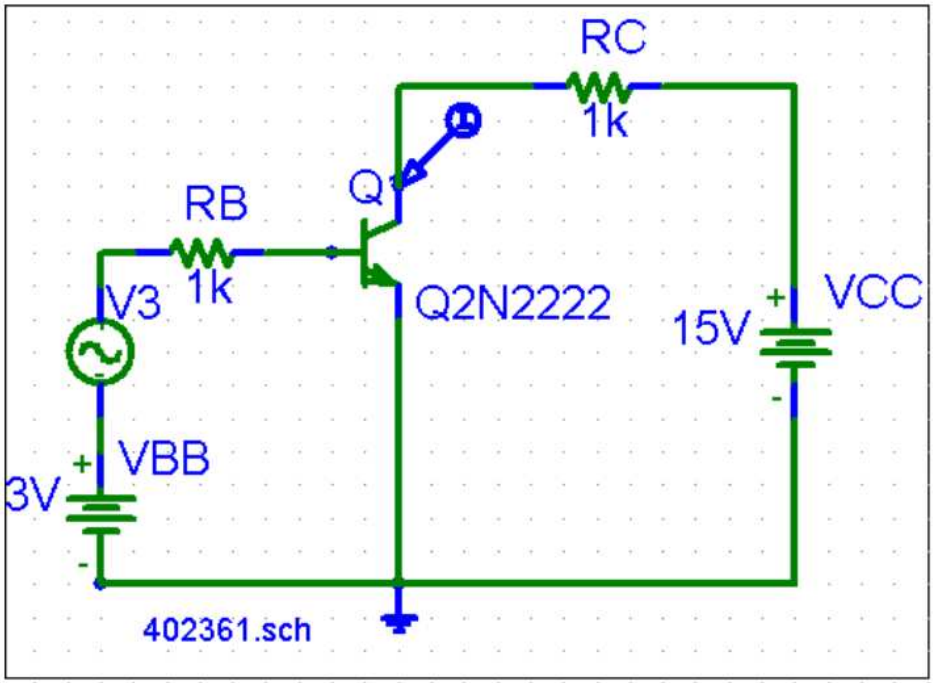


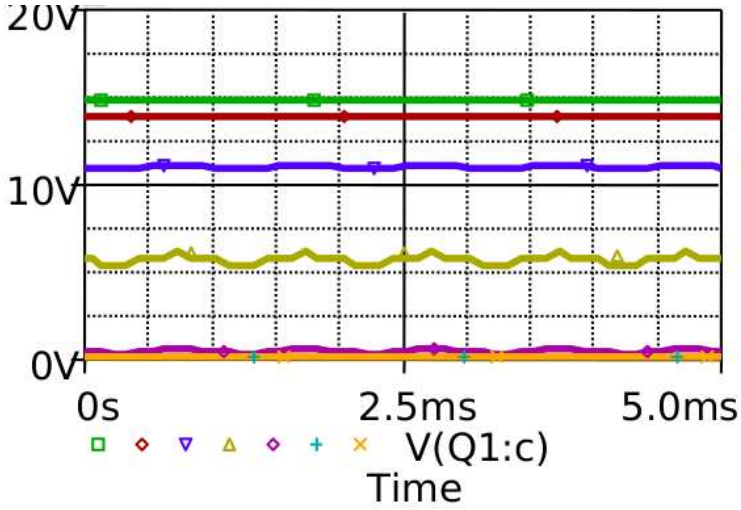
AC Model for Early Voltage

Additional Current Beyond That in Simple Model is Proportional to Voltage, and thus Can Be Modeled with a Resistor



Transistor Amplifier: Common Emitter

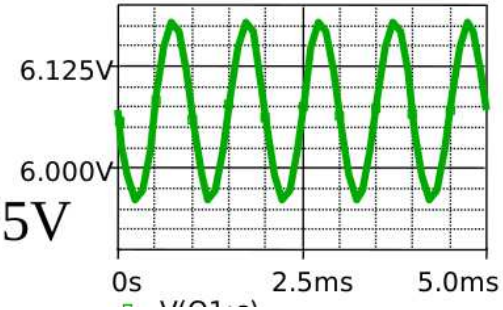




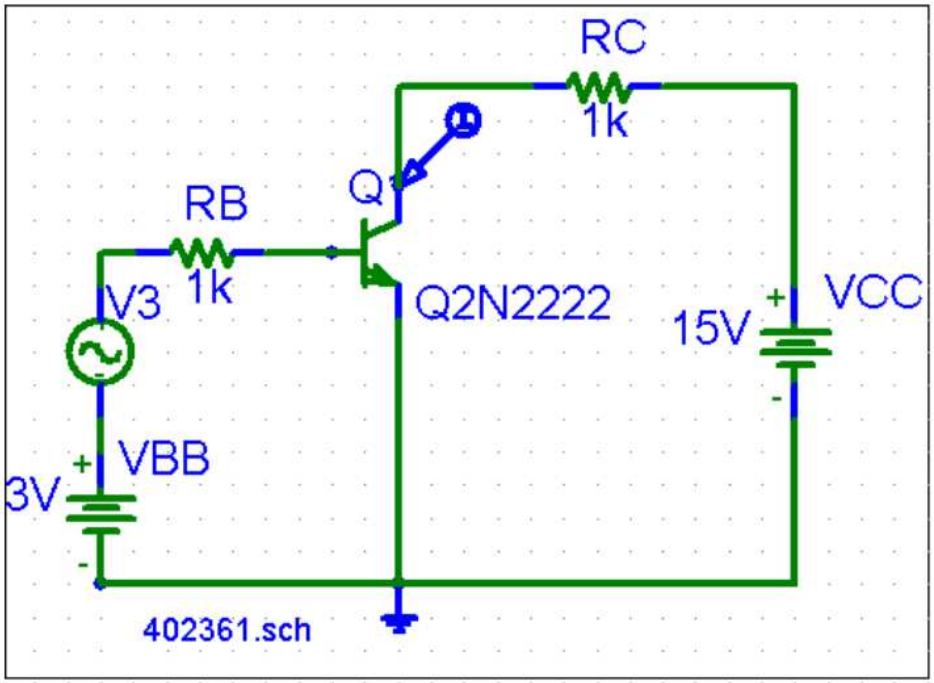
V_{BB}=[0.6:0.05:0.9]Volts

Bias Choice is Critical

V_{BB}=0.75V



Transistor Amplifier



$$V_{BE}^{(DC)} = 0.7\text{V}$$

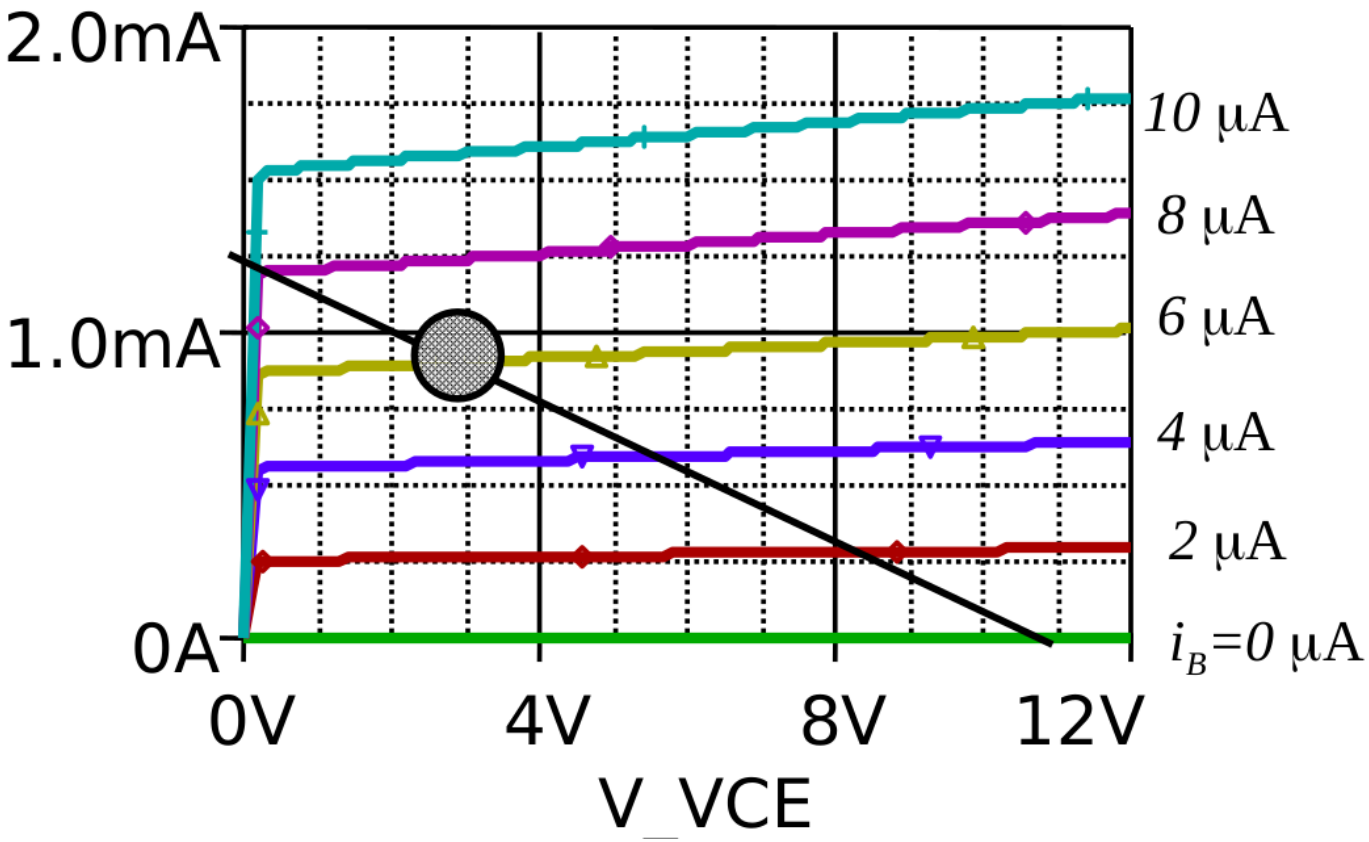
$$I_B^{(DC)} = (V_{BB} - 0.7\text{V}) / R_B$$

$$I_C^{(DC)} = \beta I_B^{(DC)} \left(1 + \frac{V_C^{(DC)}}{V_A} \right)$$

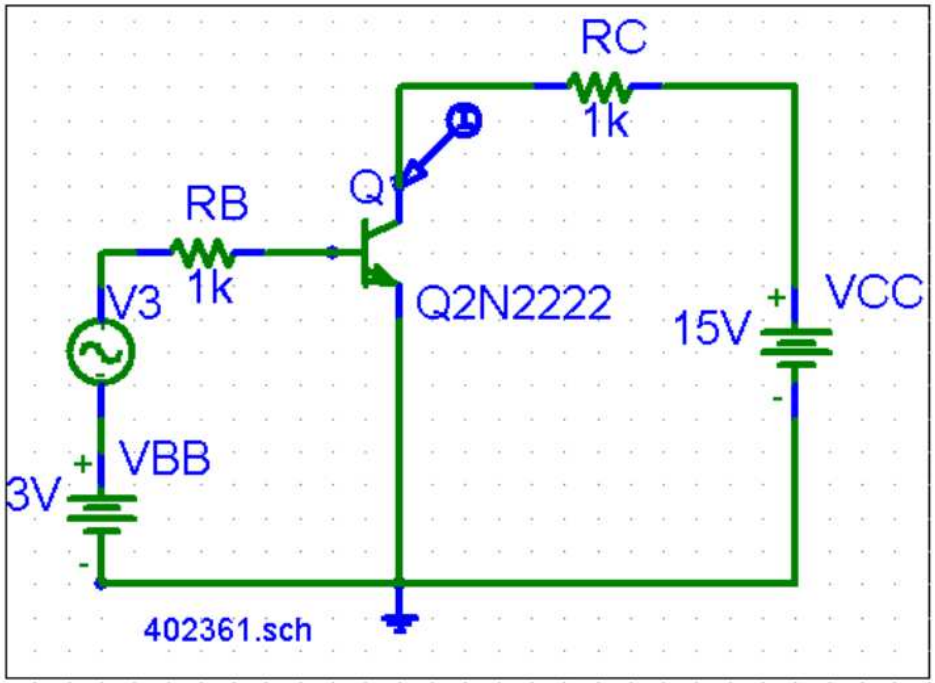
Load Line

$$I_C^{(DC)} R_C = V_{CC} - V_{CE}$$

Operating Point



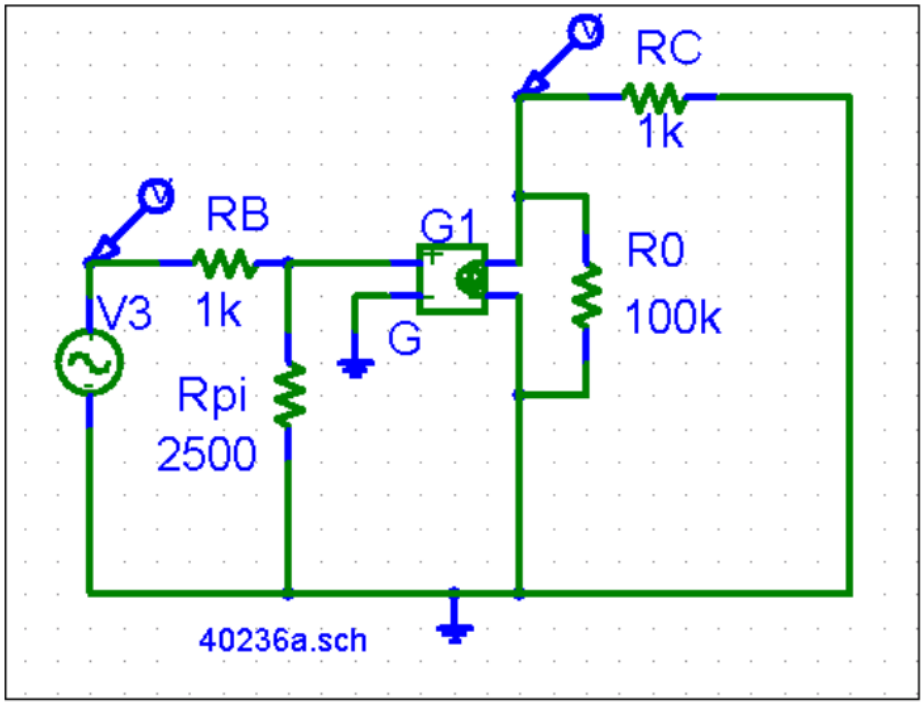
AC Analysis

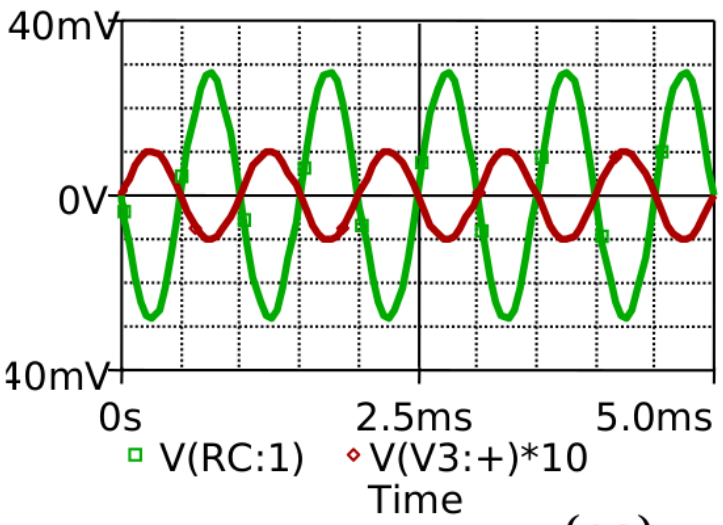


$$g_m = \frac{I_C^{(DC)}}{V_T}$$

$$r_\pi = \frac{\beta}{g_m}$$

Transistor Amplifier: AC Model

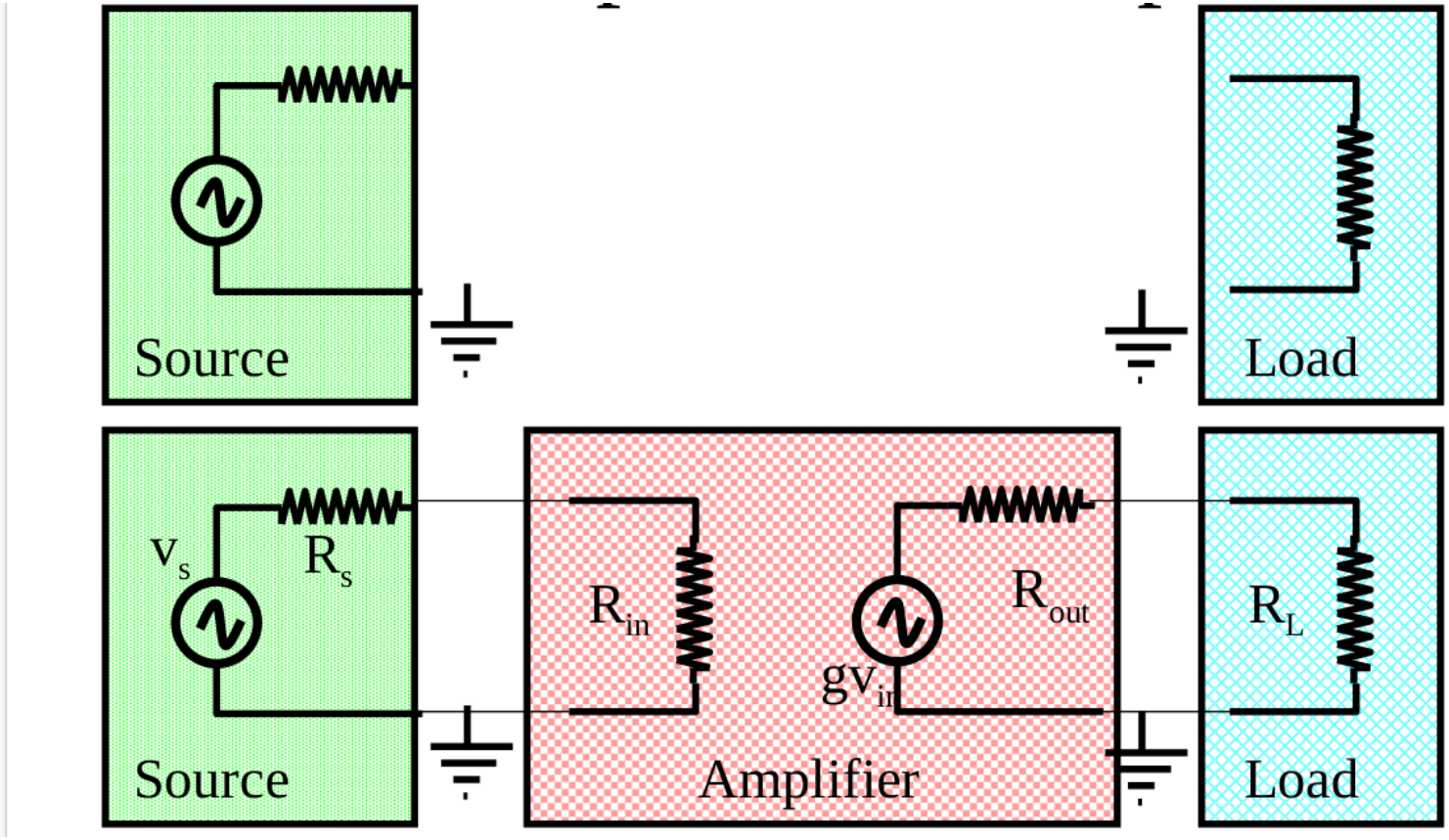




$$v_{out}^{(AC)} = (R_C \parallel R_o)\beta \frac{v_{in}^{(AC)}}{R_B + r_\pi}$$

$$g_v = - \frac{R_C \parallel R_o}{R_B + r_\pi} \beta$$

Amplifier Concepts

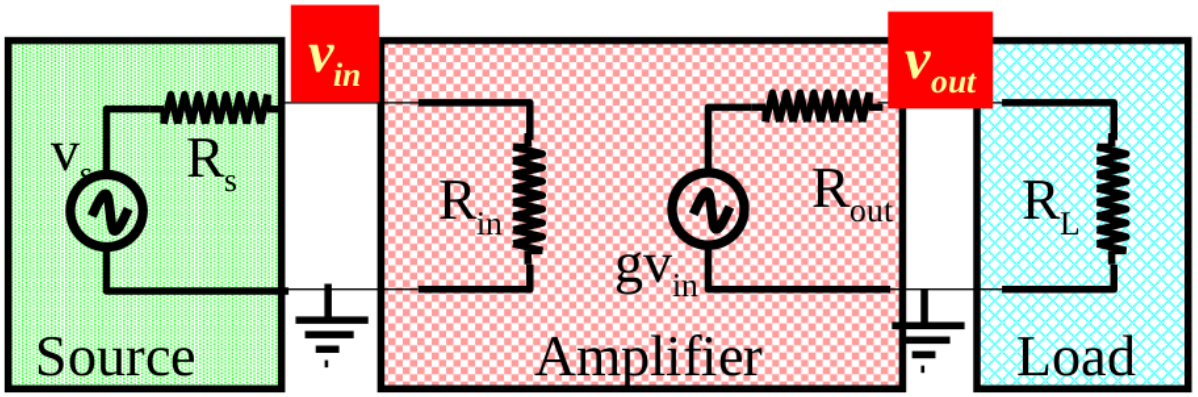


Amplifier Goals

- Gain (or Transconductance, Transresistance)
  - Specified Value, Usually Large
  - Well Known
  - Stable against Supply/Temperature Changes
  - Stable Against Component Variations
- Input Impedance
  - High for Voltage Source, Low for Current
  - Matched?
- Output Impedance
  - Low for Voltage Output, High for Current
  - Matched?
- Dynamic Range
- Others

A Note About Gain

- Gain is usually quoted with the “appropriate” load attached.
- The gain in this circuit must be larger.
- The ratio is a factor of two for a matched load.
- You won’t measure the “right” gain unless you have the right load.



Common Amplifier Circuits

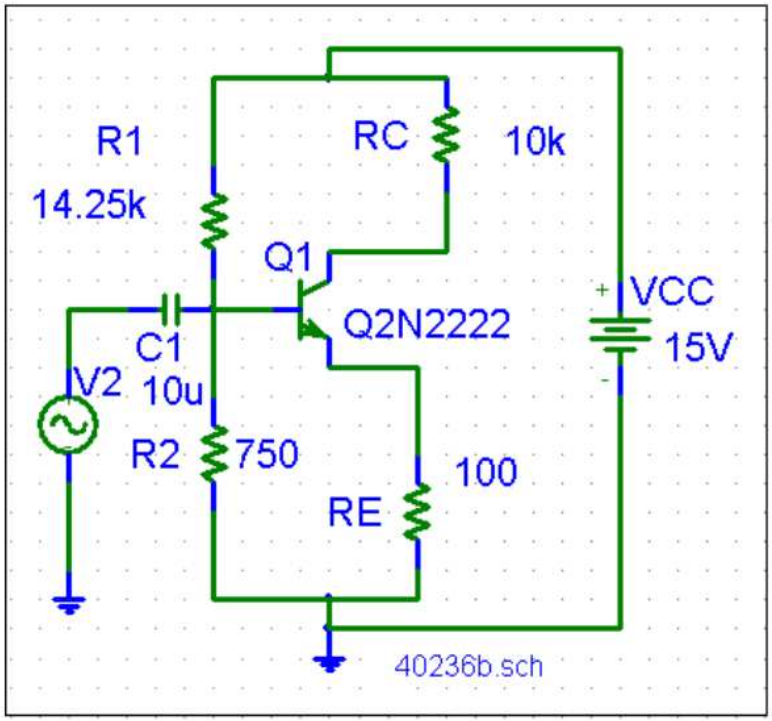
- Common Emitter
  - Voltage Amplifier
- Common Emitter with Emitter Resistor
  - Lower Gain, Higher Input Levels
- Common Base
  - Current Buffer: Low input impedance
- Common Collector
  - Voltage Buffer: High input impedance

Amplifier Design Approach

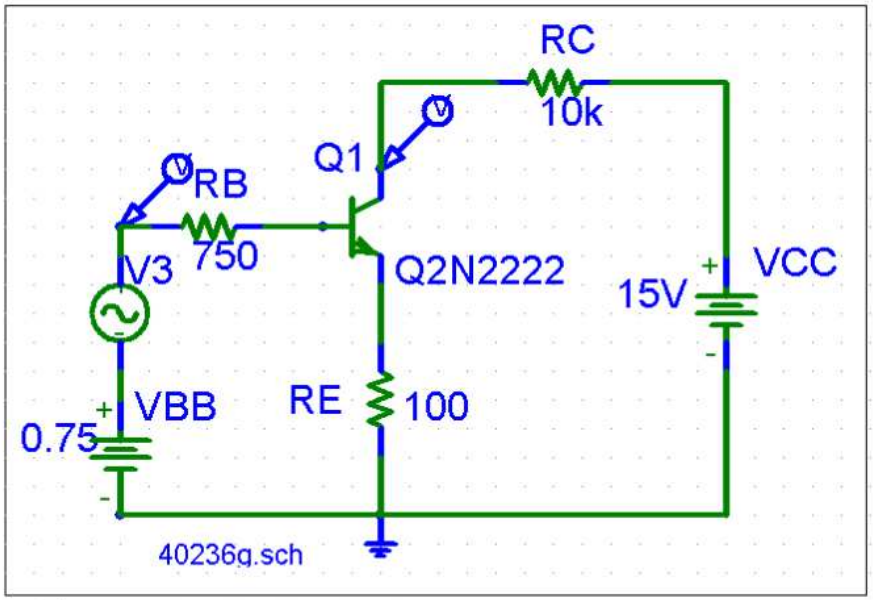
- Basic Configuration
- Biasing (DC Model)
  - One or Two Supplies
  - Component Values
- AC Parameters of the Transistor
- Small-Signal Circuit Model
- Amplifier Parameters
  - Gain (Voltage and Current)
  - Impedance (Input and Output)
  - Dynamic Range

Bias with One Power Supply

Actual Circuit



Equivalent Circuit



$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}^{(DC)}$$

$$R_B = R_1 \parallel R_2$$

Calculating the Current

Base Loop

$$V_{BB} - I_B^{(DC)} R_B - V_{BE}^{(DC)} - I_E^{(DC)} R_E = 0$$

But...

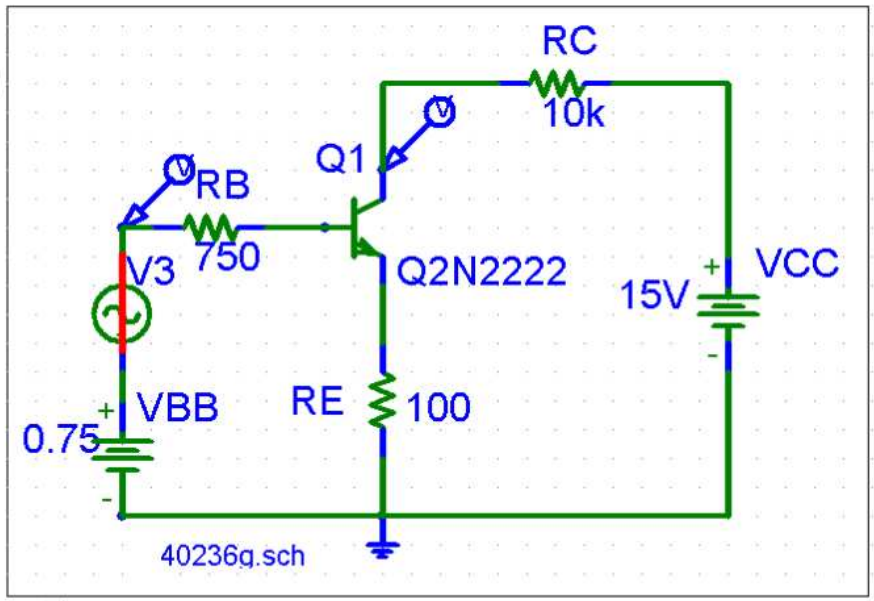
$$I_B^{(DC)} = \frac{I_E^{(DC)}}{\beta + 1}$$

So...

$$V_{BB} - \frac{I_E^{(DC)}}{\beta + 1} R_B - V_{BE}^{(DC)} - I_E^{(DC)} R_E = 0$$

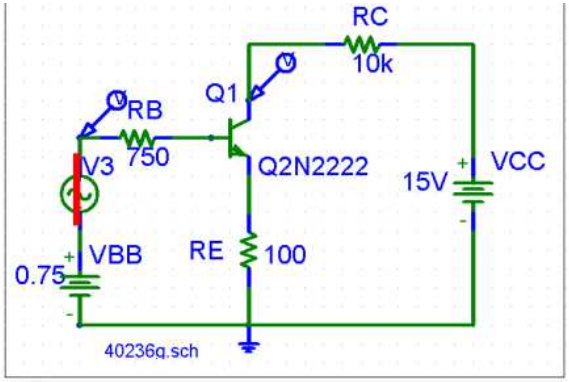
Solve for Emitter Current

$$I_E^{(DC)} = \frac{V_{BB} - V_{BE}^{(DC)}}{R_E + \frac{R_B}{\beta + 1}}$$



Choosing Components

$$I_E^{(DC)} = \frac{V_{BB} - V_{BE}^{(DC)}}{R_E + \frac{R_B}{\beta + 1}}$$

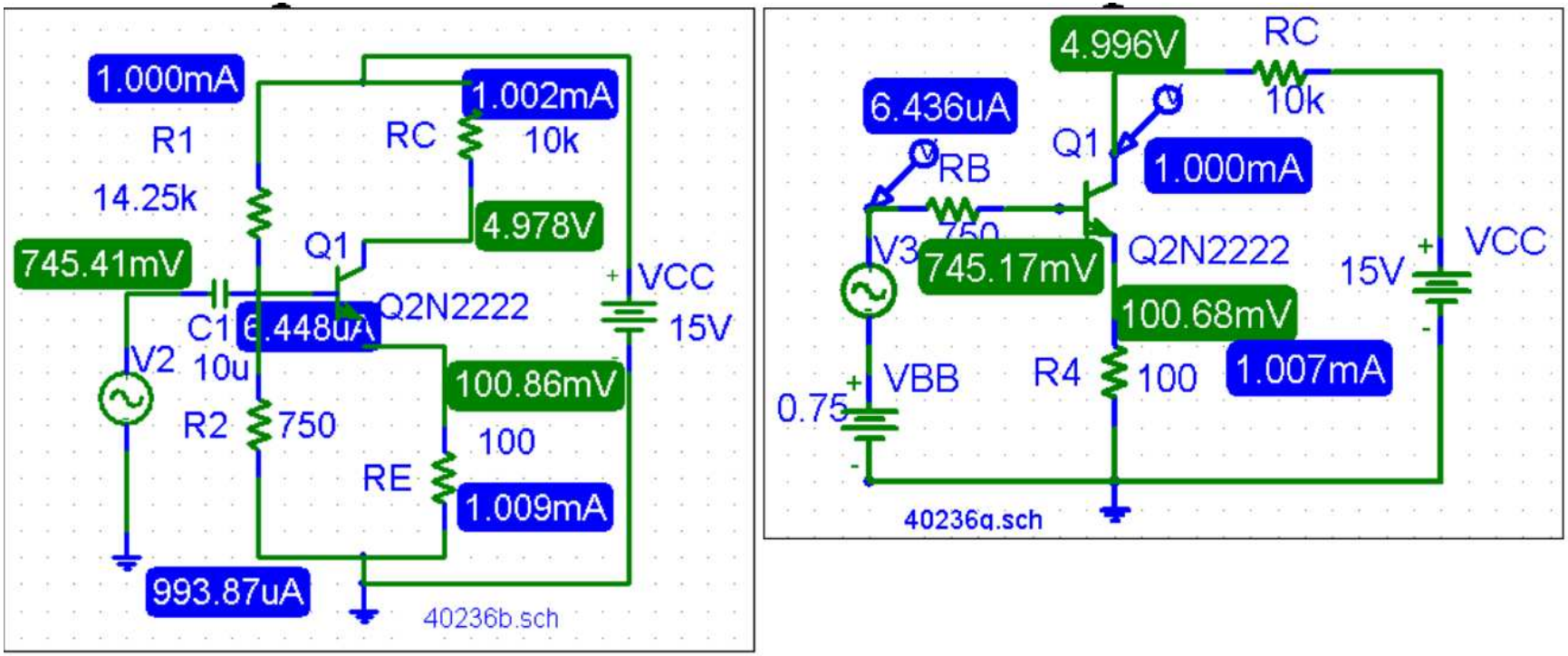


Pick Base Bias Resistors for...

$$V_{BB} >> V_{BE}^{(DC)} \quad \text{And} \quad R_E >> \frac{R_B}{\beta + 1}$$

Note: Because $R_B = R_1 \parallel R_2$ This means choose R_1 and R_2 Small enough so there is more current in them than in the emitter resistor

Equivalent Circuit Comparison

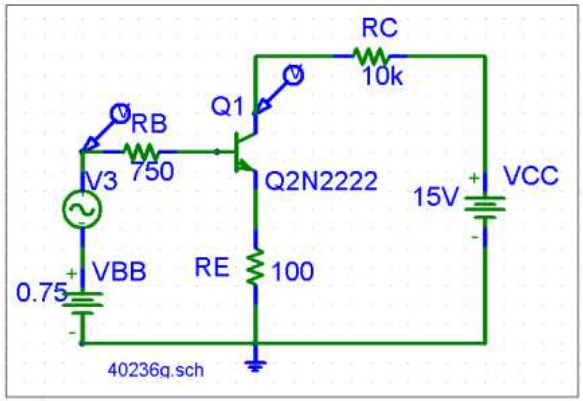


Norton Equivalent on BE Circuit

AC Parmeters

$$V_{BB} >> V_{BE}^{(DC)} \qquad R_E >> \frac{R_B}{\beta + 1}$$

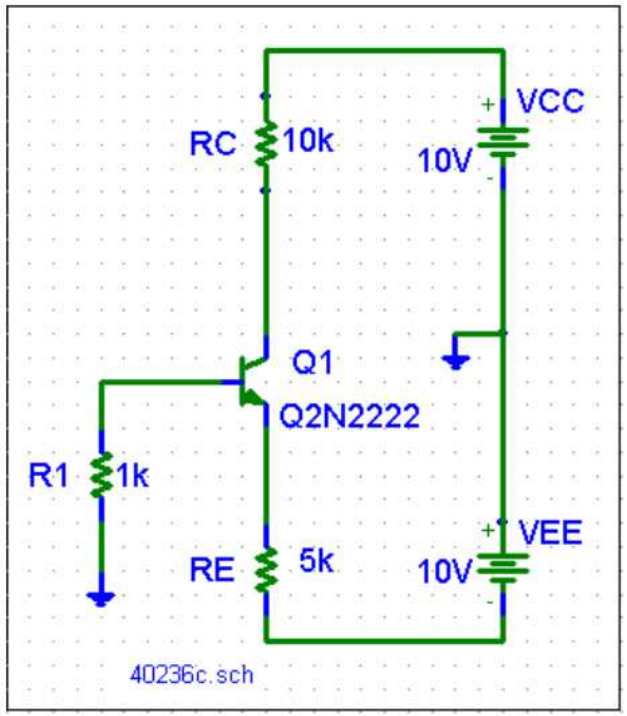
$$I_E^{(DC)} = \frac{V_{BB} - V_{BE}^{(DC)}}{R_E + \frac{R_B}{\beta + 1}}$$



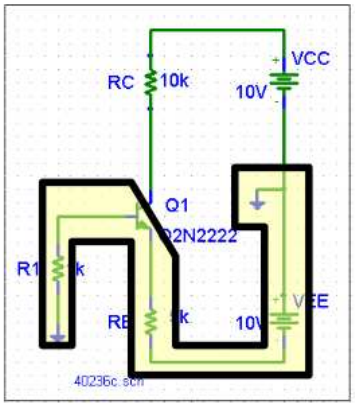
$$g_m = \frac{I_C}{V_T} = \frac{\alpha I_E}{V_T} \approx \frac{I_E}{V_T} = \frac{V_{BB}}{V_T R_E}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{\beta R_E V_T}{V_{BB}}$$

Bias with Two Power Supplies



Signal Input on Emitter or Base

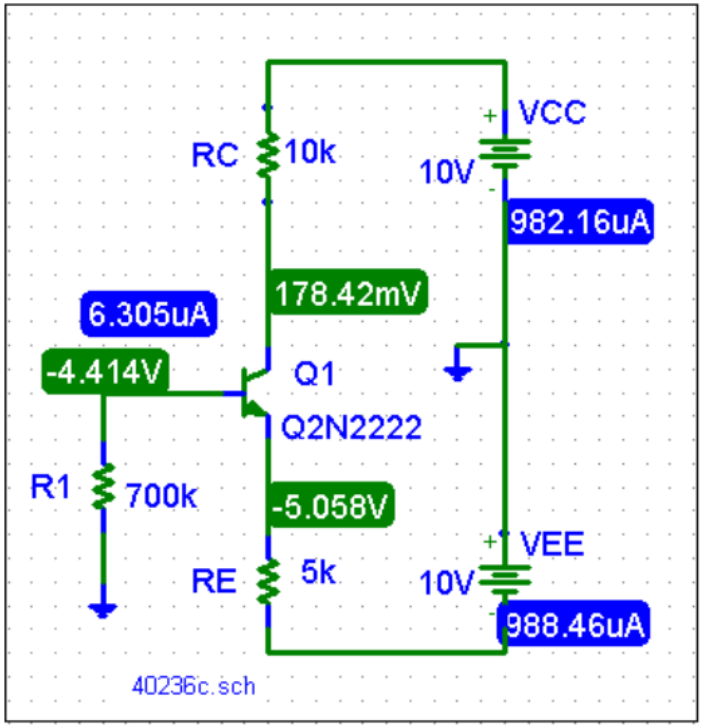


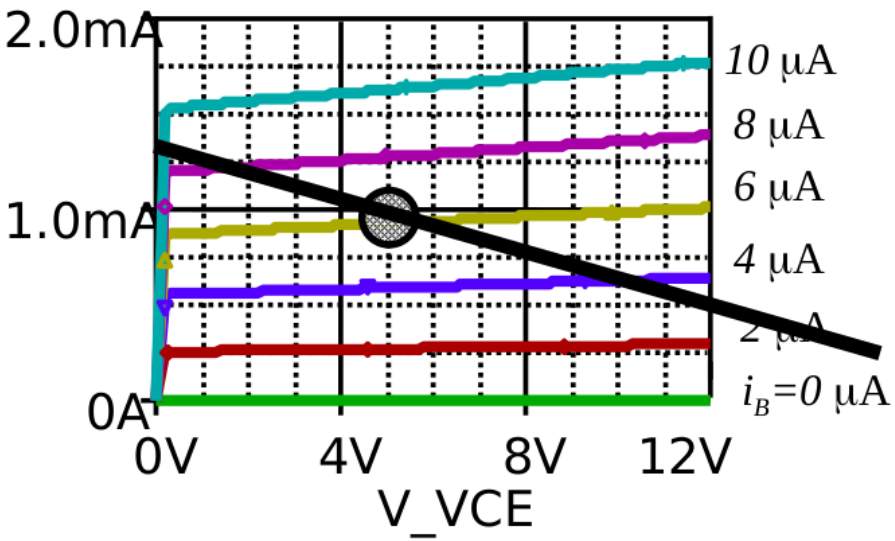
$$I_E^{(DC)} = \frac{V_{EE} - V_{BE}^{(DC)}}{R_E + \frac{R_B}{\beta + 1}}$$

$$g_m = \frac{I_C}{V_T} = \frac{\alpha I_E}{V_T} \approx \frac{I_E}{V_T} \approx \frac{V_{EE}}{V_T R_E}$$

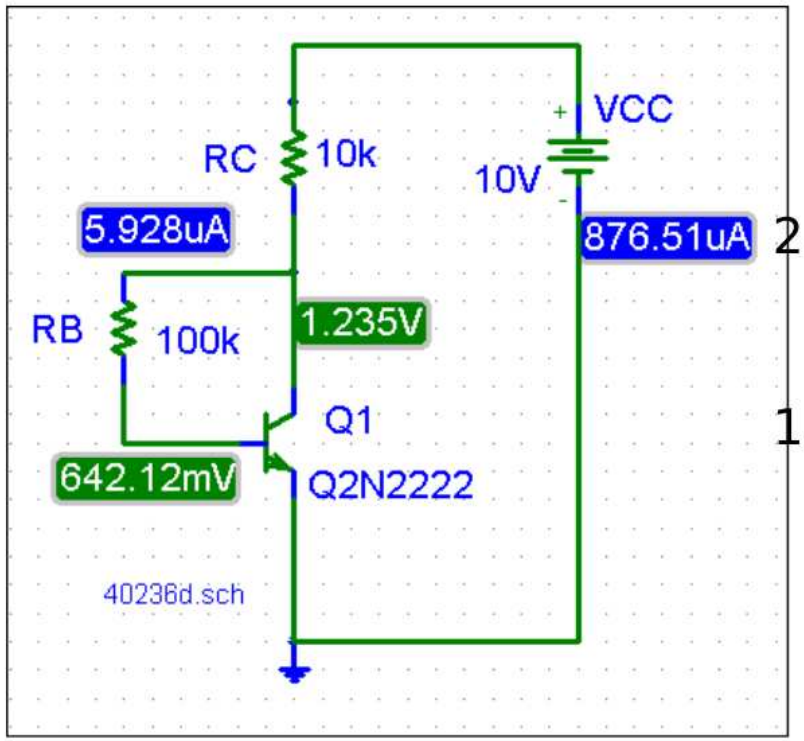
$$r_\pi = \frac{\beta}{g_m} = \frac{\beta R_E V_T}{V_{EE}}$$

Bias Point with 2 Supplies

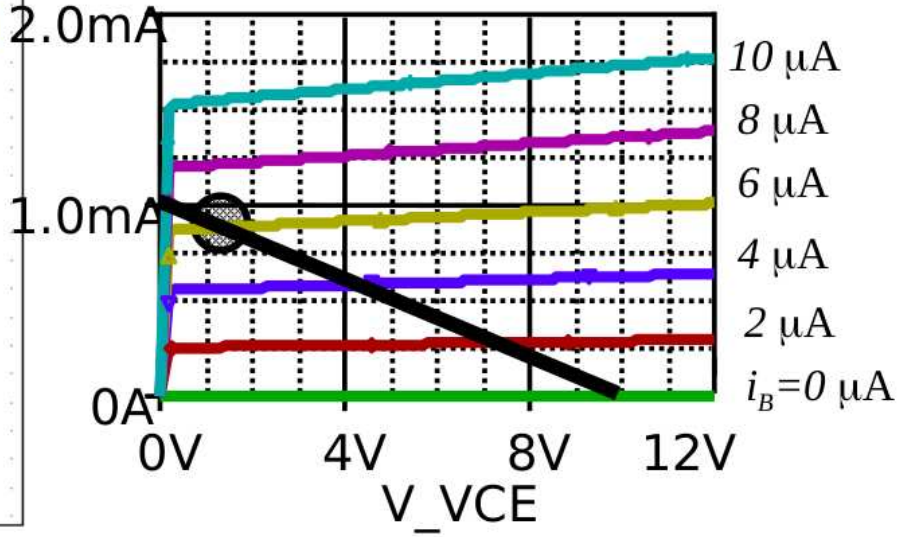




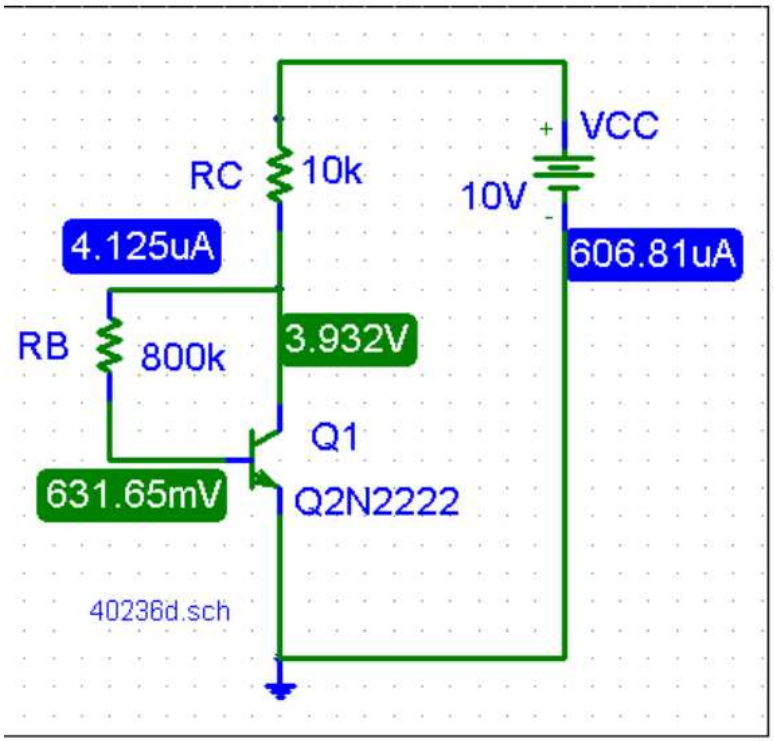
Another Common Bias Circuit



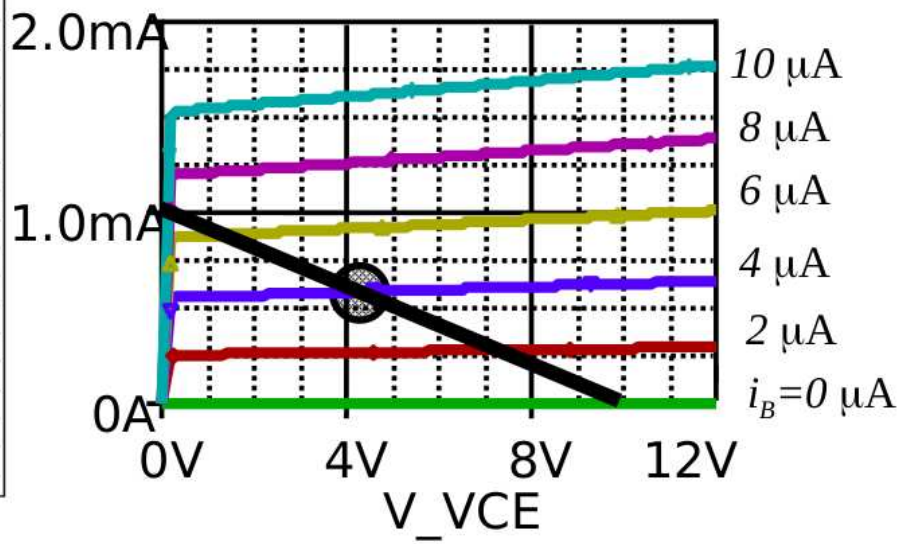
Bad Component Choices



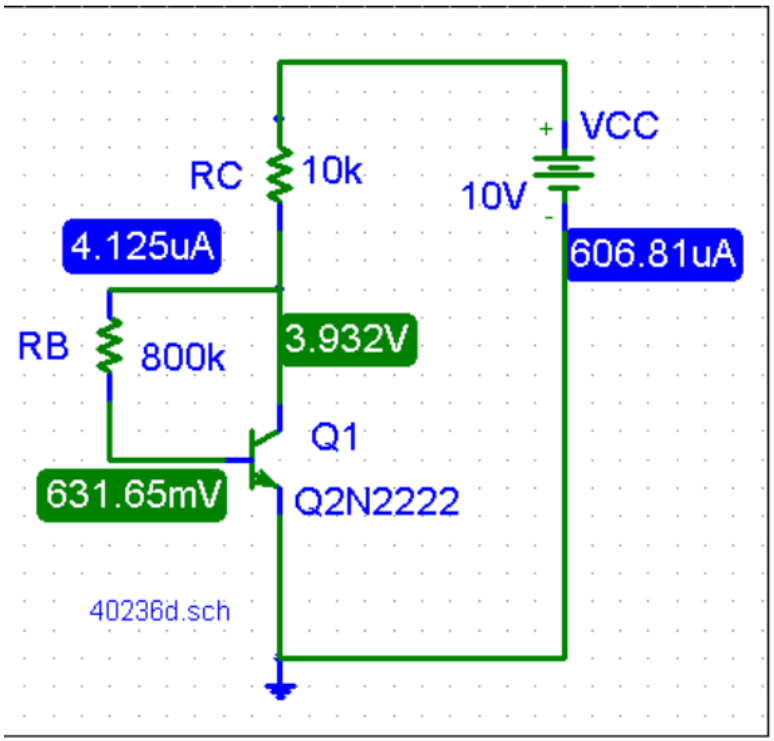
Same Circuit, Better Choices



Better Component Choices



Bias Analysis

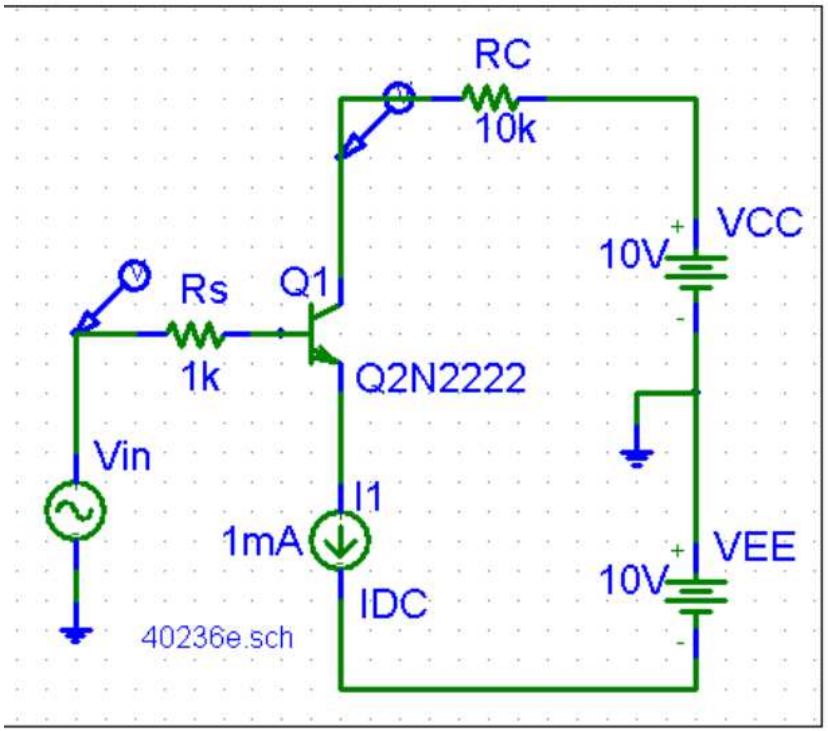


$$I_E^{(DC)} = \frac{V_{CC} - V_{BE}^{(DC)}}{R_C + \frac{R_B}{\beta + 1}}$$

$$g_m = \frac{I_C}{V_T} = \frac{\alpha I_E}{V_T} \approx \frac{I_E}{V_T} = \frac{V_{CC}}{V_T R_C}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{\beta R_C V_T}{V_{CC}}$$

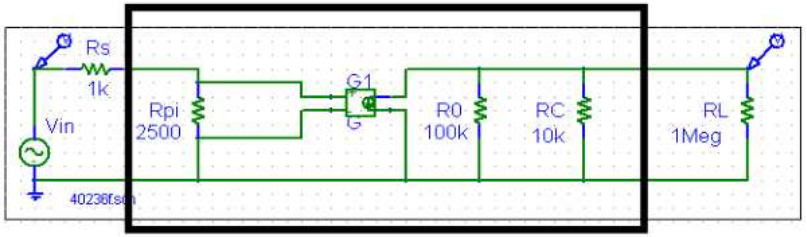
Common Emitter Amplifier



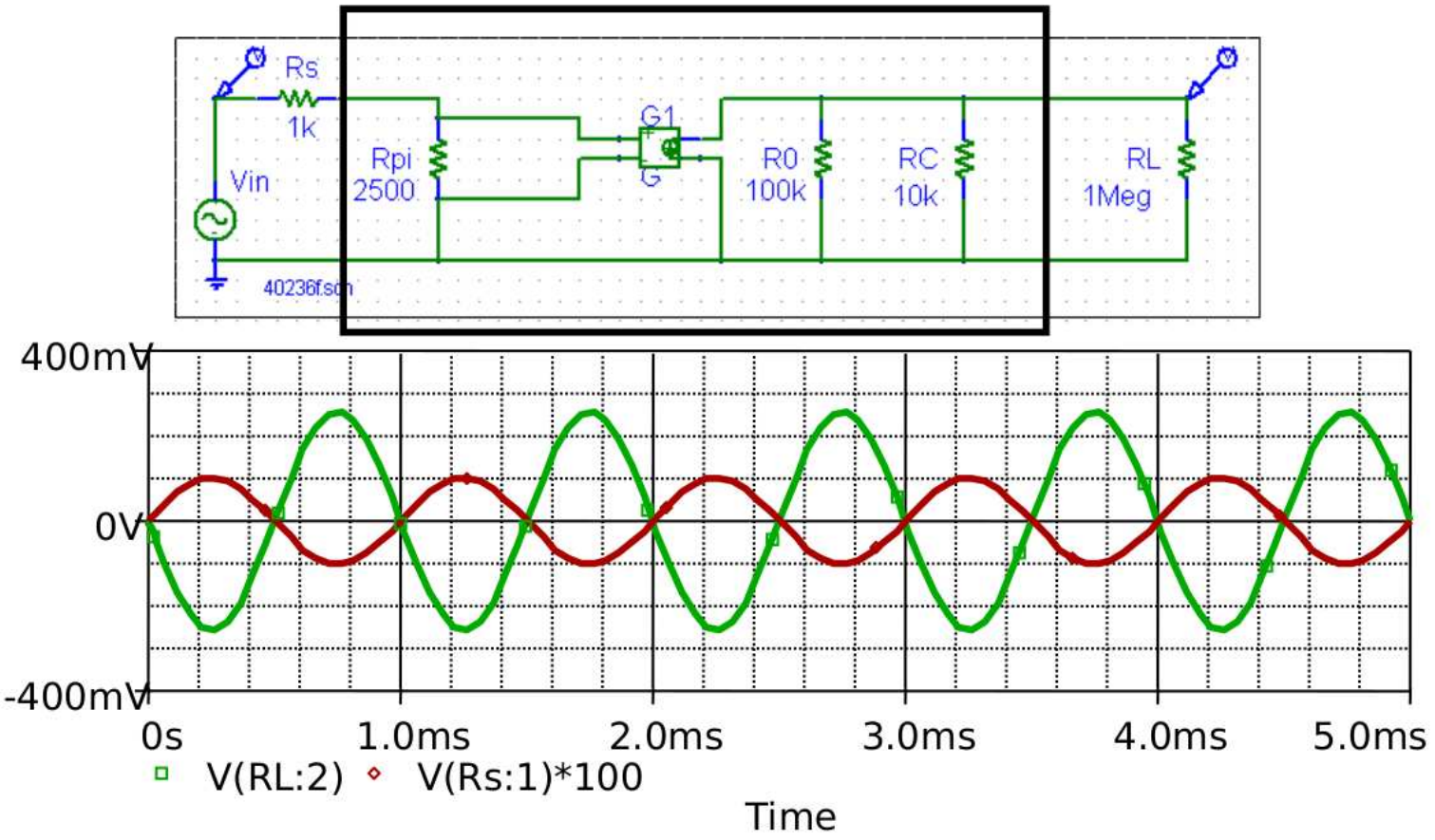
Voltage Amplifier

R_s is part of source?
R_L is the Load (not shown in original circuit).

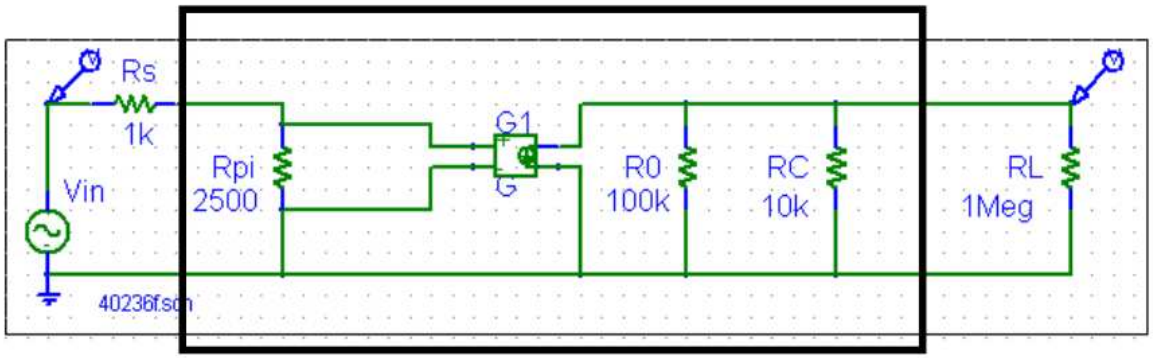
Pi Model Below



CE Amp: AC Model



CA Amp: AC Characteristics



Input Resistance $$r_{in} = r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_E^{(DC)}\alpha} = (\beta + 1)\frac{V_T}{I_E^{(DC)}}$$

Output Resistance $$r_{out} = R_C \parallel R_0$$

Voltage Gain $$A_v = \frac{v_{out}^{(AC)}}{v_{in}^{(AC)}} = - g_m \frac{r_\pi}{R_s + r_\pi}(R_C \parallel R_0 \parallel R_L)$$

CE Amp: Voltage Gain

$$A_v = \frac{v_{out}^{(AC)}}{v_{in}^{(AC)}} = - g_m \frac{r_\pi}{R_s + r_\pi} (R_C \parallel R_0 \parallel R_L)$$

$$A_v = - \frac{r_\pi g_m (R_C \parallel R_0 \parallel R_L)}{R_s + r_\pi} = - \frac{\beta (R_C \parallel R_0 \parallel R_L)}{R_s + r_\pi}$$

But; $r_\pi = \beta / g_m = \frac{(\beta + 1) V_T}{I_E^{(DC)}}$

$$A_v = - \frac{\beta (R_C \parallel R_0 \parallel R_L)}{R_s + \frac{(\beta + 1) V_T}{I_E^{(DC)}}} = - \frac{(R_C \parallel R_0 \parallel R_L)}{\frac{R_s}{\beta + 1} + \frac{V_T}{I_E^{(DC)}}}$$

CE Amp: Gain Approximations

Low Source Impedance: High Load Impedance

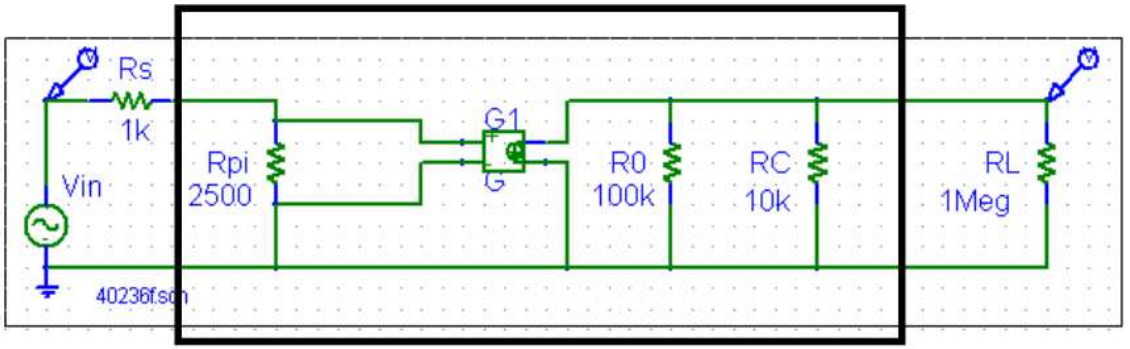
$$A_v = -\frac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + (\beta+1)\frac{V_T}{I_E^{(DC)}}} = -\frac{(R_C \parallel R_0 \parallel R_L)}{\frac{R_s}{\beta+1} + \frac{V_T}{I_E^{(DC)}}} \approx -\frac{(R_C \parallel R_0) I_E^{(DC)}}{V_T}$$

Matched Impedances

$$A_v = -\frac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + (\beta+1)\frac{V_T}{I_E^{(DC)}}} = -\frac{\beta(R_C \parallel R_0)/2}{2(\beta+1)\frac{V_T}{I_E^{(DC)}}} = -\frac{\beta}{(\beta+1)}\frac{(R_C \parallel R_0) I_E^{(DC)}}{4V_T}$$

?

CE Amp: Current Gain



Current Gain

$$A_i = \frac{i_{out}^{(AC)}}{i_{in}^{(AC)}} = -\beta \frac{R_C \parallel R_0}{(R_C \parallel R_0) + R_L}$$

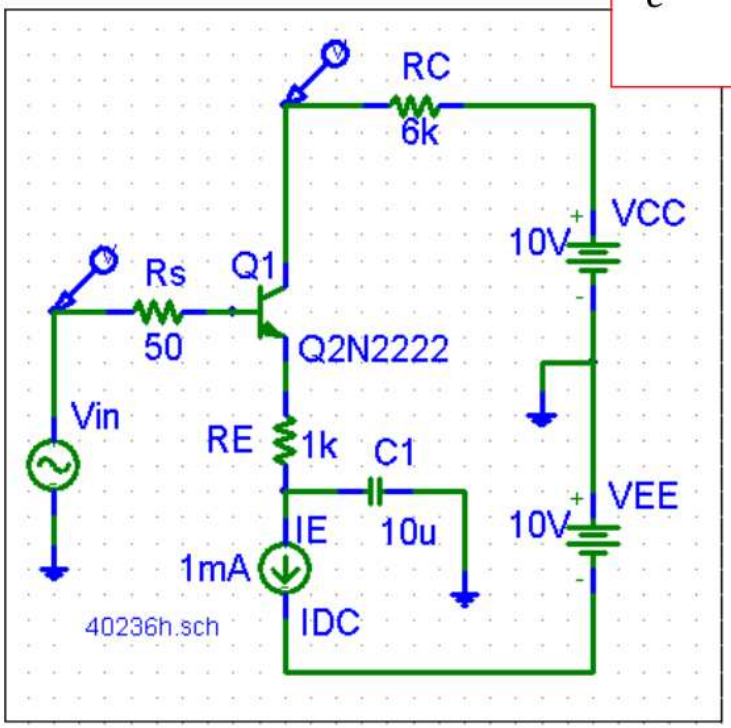
BJT Amplifier Parameters

	Voltage Gain	Current Gain	Input Resistance	Output Resistance
CE	$-\dfrac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + \dfrac{(\beta+1)V_T}{I_E^{(DC)}}}$	$-\beta\dfrac{R_C \parallel R_0}{(R_C \parallel R_0)+R_L}$	$(\beta+1)\dfrac{V_T}{I_E^{(DC)}}$	$R_C \parallel R_0$
	$-\dfrac{(R_C \parallel R_L)I_E^{(DC)}}{V_T}$	$-\beta\dfrac{R_C}{R_C+R_L}$		
	$-\dfrac{R_C/2}{25\Omega}$	$-\dfrac{100}{2}$	2500	R_C
CER				
CB				
CC				

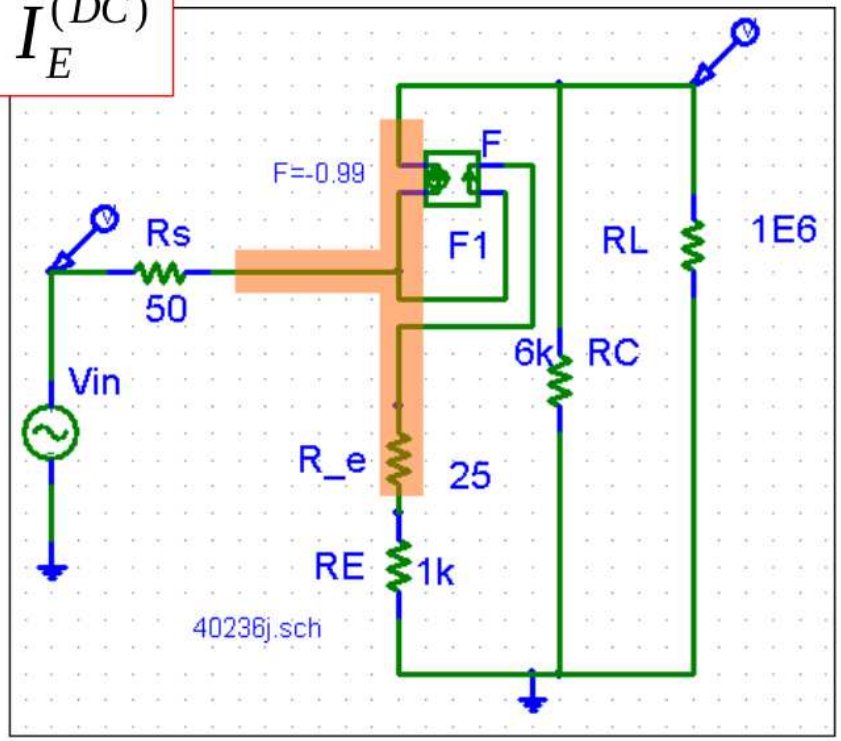
CE Amp with Emitter Resistor

$$r_e = \frac{V_T}{I_E^{(DC)}}$$

Circuit



AC Tee Model with Load



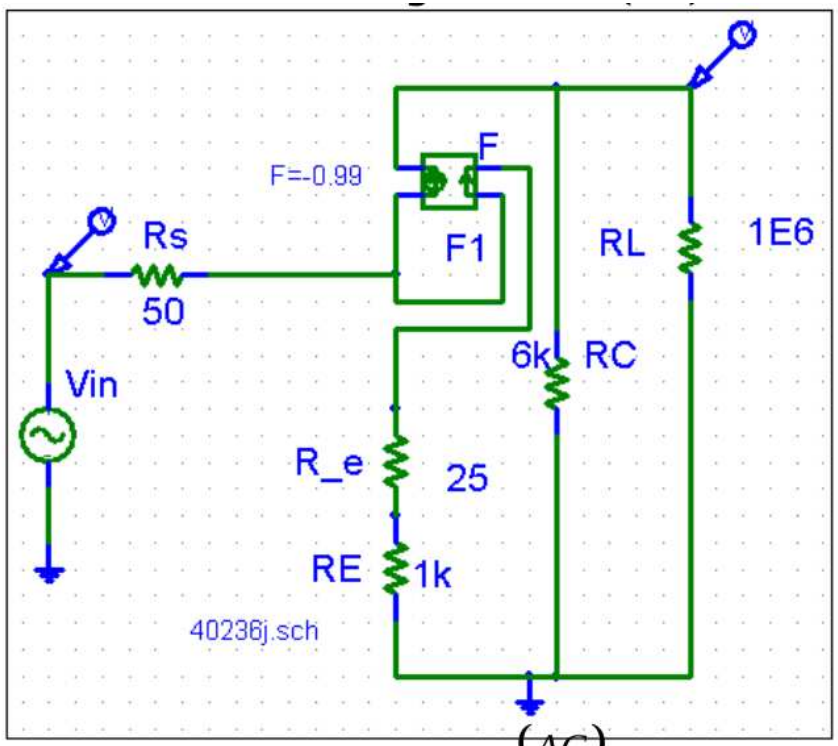
CE/R: Circuit Analysis (1)

Input Impedance

$$v_b^{(AC)} = i_e^{(AC)}(r_e + R_E)$$

$$i_b^{(AC)} = (1-\alpha) i_e^{(AC)} = \frac{i_e^{(AC)}}{\beta+1}$$

$$r_{in} = \frac{v_b^{(AC)}}{i_b^{(AC)}} = (\beta+1)(r_e + R_E)$$



Gain

$$v_{out}^{(AC)} = -i_c^{(AC)}(R_C \parallel R_L) = -\alpha i_e^{(AC)}(R_C \parallel R_L) = -\alpha \frac{v_b^{(AC)}}{r_e + R_E}(R_C \parallel R_L)$$

CE/R: Circuit Analysis (2)

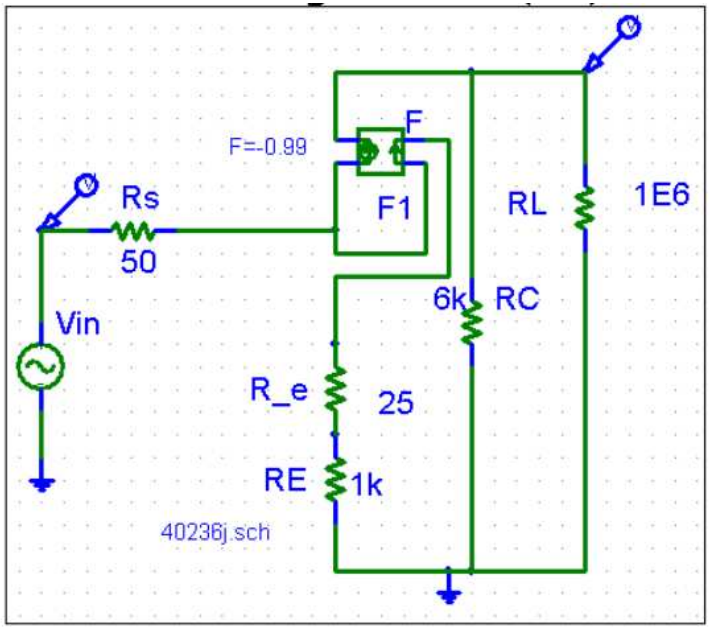
Gain

$$v_{out}^{(AC)} = -\alpha \frac{v_b^{(AC)}}{r_e + R_E}(R_C \parallel R_L)$$

$$A_v = -\frac{\beta}{\beta+1}\frac{R_C \parallel R_L}{r_e + R_E}$$

Alternative (We will use it here):

$$A_v = -\frac{\beta}{\beta+1}\frac{R_C \parallel R_L}{R_S + r_e + R_E}$$



Use this if R_s is part of the amplifier, rather than of the source.

Output Impedance: $r_{out} = R_C$

Why not $R_C||(r_e+R_E)$?

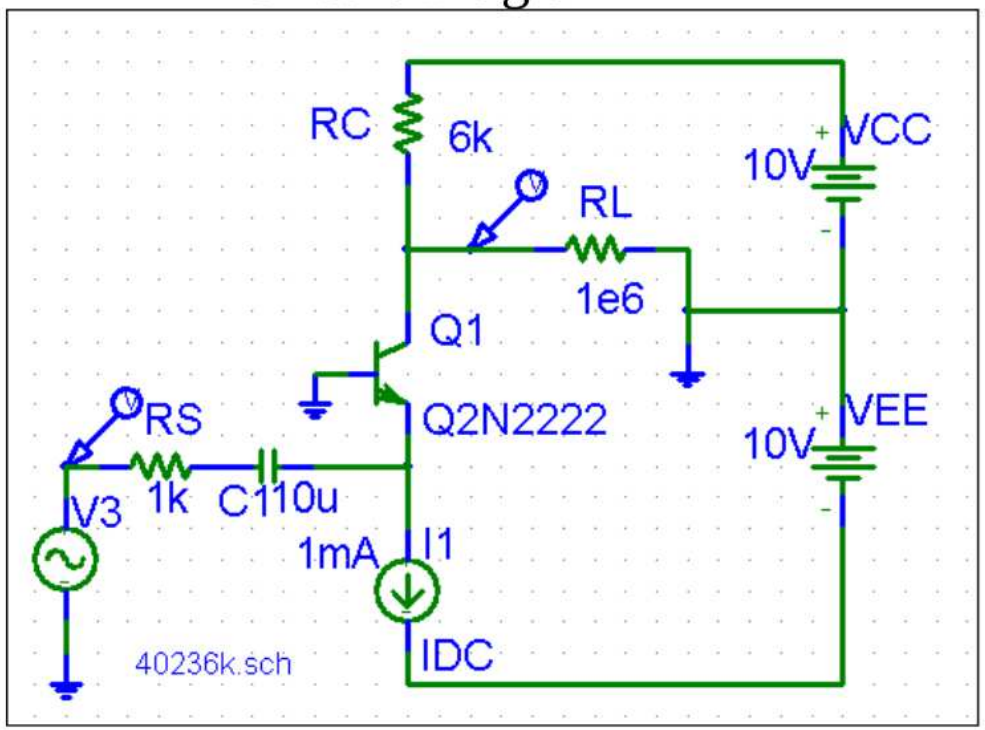
What about R_0?

BJT Amplifier Parameters

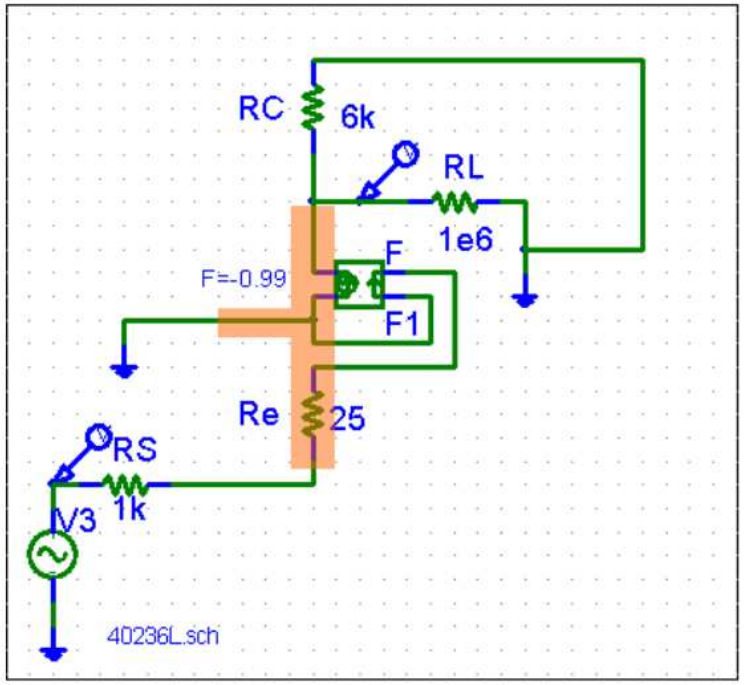
	Voltage Gain	Current Gain	Input Resistance	Output Resistance
CE	$-\dfrac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + \dfrac{(\beta+1)V_T}{I_E^{(DC)}}}$	$-\beta\dfrac{R_C \parallel R_0}{(R_C \parallel R_0)+R_L}$	$(\beta+1)\dfrac{V_T}{I_E^{(DC)}}$	$R_C \parallel R_0$
CER	$-\dfrac{\beta}{\beta+1}\dfrac{R_C \parallel R_L}{R_S + \dfrac{V_T}{I_E^{(DC)}} + R_E}$	$-\beta\dfrac{R_C}{R_C+R_L}$	$(\beta+1)\left(\dfrac{V_T}{I_E^{(DC)}} + R_E\right)$	R_C
CB				
CC				

Common Base Amplifier

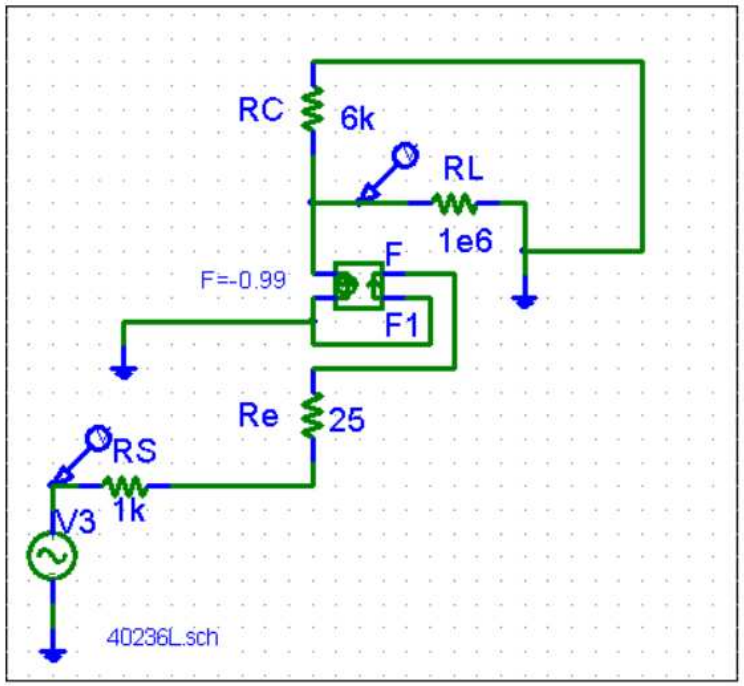
Circuit Diagram

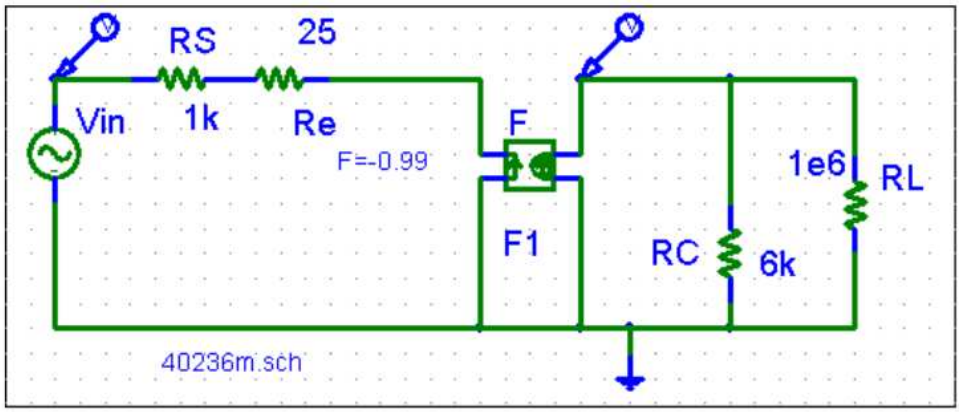


AC Tee Model



CB Amp: Simplified AC Model (1)





Input Impedance

$$r_{in} = r_e = \frac{V_T}{I_E^{(DC)}}$$

Low: Not a good voltage amplifier

CB Amp: Simplified AC Model (2)

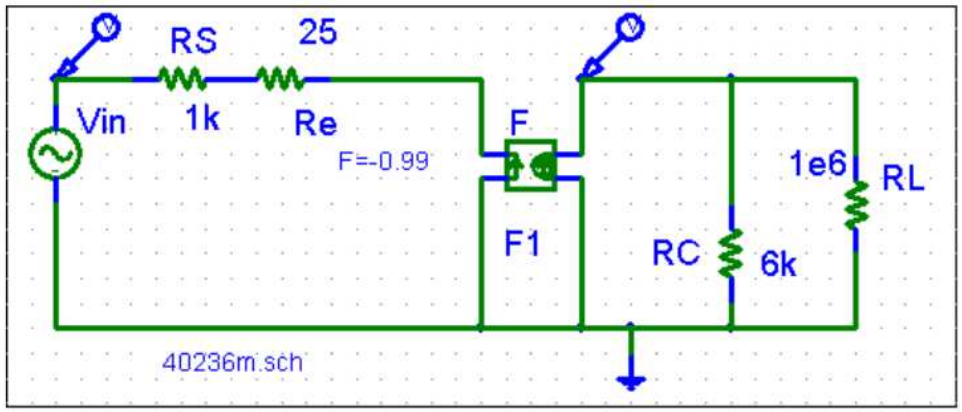
Voltage Gain

$$v_{out}^{(AC)} = -\alpha i_e^{(AC)} (R_C \parallel R_L)$$

$$v_{out}^{(AC)} = -\alpha \left(- \frac{v_{in}^{(AC)}}{r_e + R_s} \right) (R_C \parallel R_L)$$

$$A_V = \alpha \frac{R_C \parallel R_L}{r_e + R_s}$$

$$A_V = \frac{\beta}{\beta + 1} \frac{R_C \parallel R_L}{R_s + \frac{V_T}{I_E^{(DC)}}}$$



Current Gain

$$A_i = \frac{\beta}{\beta + 1} \frac{R_C}{R_L + R_C}$$

$$A_i \xrightarrow{R_L \to 0} 1$$

Output Impedance

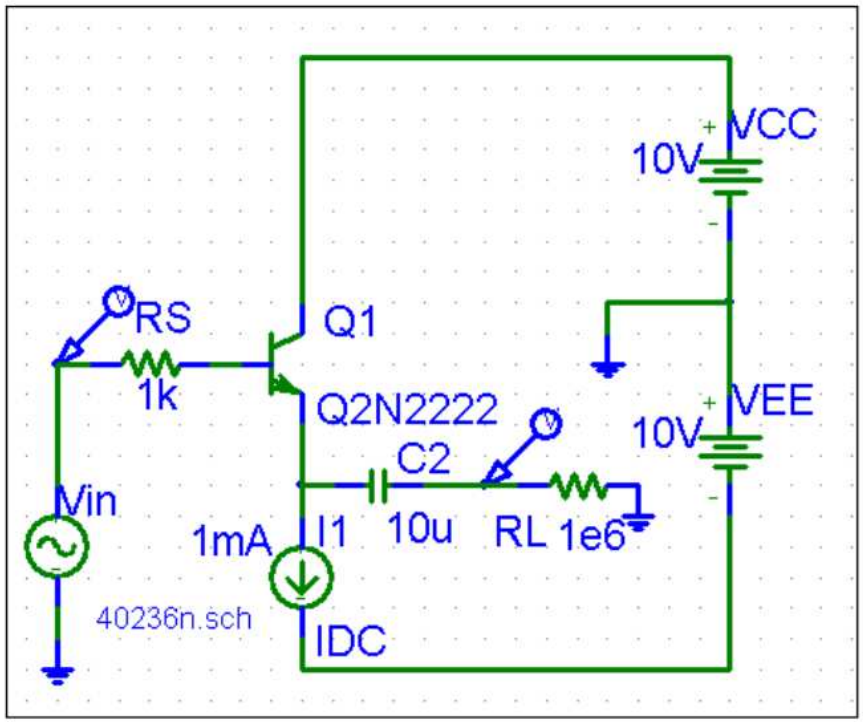
$$R_{out} = R_C$$

BJT Amplifier Parameters

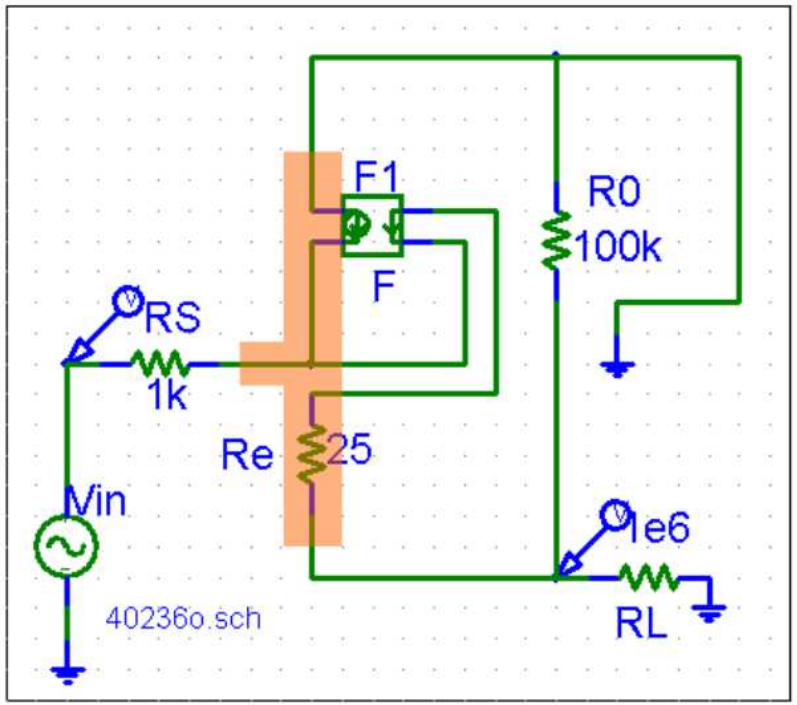
	Voltage Gain	Current Gain	Input Resistance	Output Resistance
CE	$-\dfrac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + \dfrac{(\beta+1)V_T}{I_E^{(DC)}}}$	$-\beta\dfrac{R_C \parallel R_0}{(R_C \parallel R_0)+R_L}$	$(\beta+1)\dfrac{V_T}{I_E^{(DC)}}$	$R_C \parallel R_0$
CER	$-\dfrac{\beta}{\beta+1}\dfrac{R_C \parallel R_L}{R_S + \dfrac{V_T}{I_E^{(DC)}} + R_E}$	$-\beta\dfrac{R_C}{R_C+R_L}$	$(\beta+1)\left(\dfrac{V_T}{I_E^{(DC)}} + R_E\right)$	R_C
CB	$\dfrac{\beta}{\beta+1}\dfrac{R_C \parallel R_L}{R_s + \dfrac{V_T}{I_E^{(DC)}}}$	$\dfrac{\beta}{\beta+1}\dfrac{R_C}{R_L+R_C}$	$\dfrac{V_T}{I_E^{(DC)}}$	R_C
CC				

Common Collector Amplifier

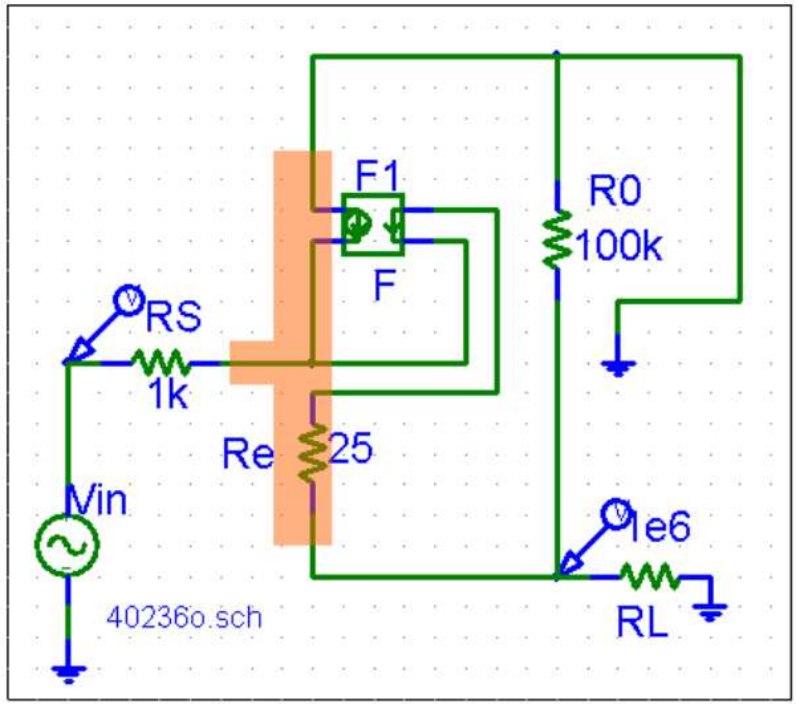
Circuit Diagram

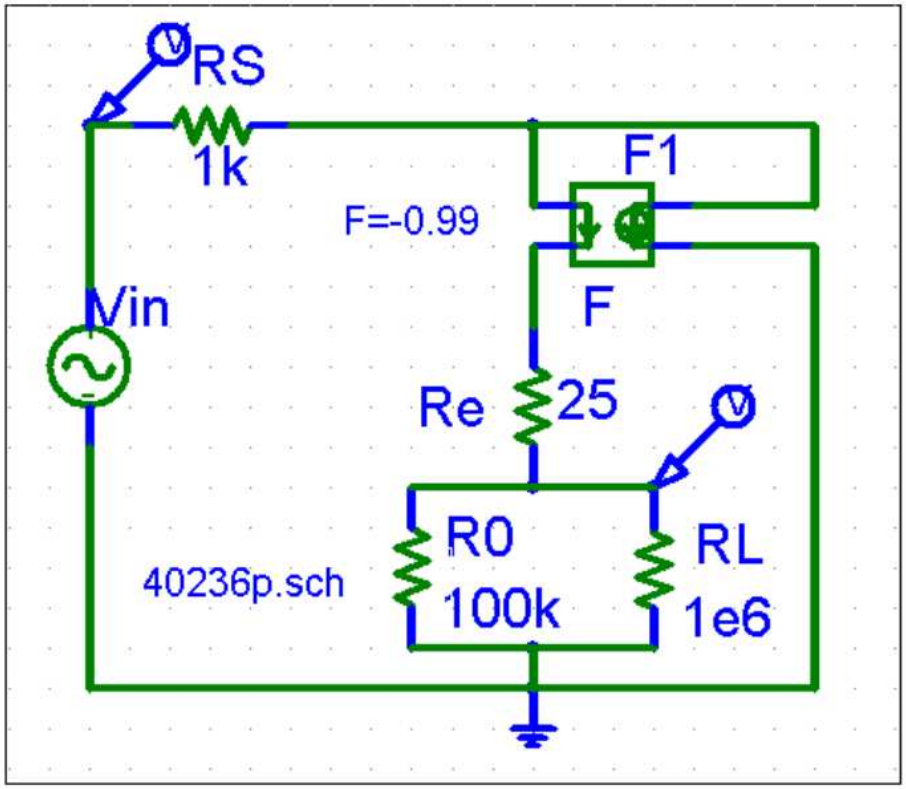


AC Tee Model



CC Amp: Simplified AC Model





CC Amp: Input Impedance

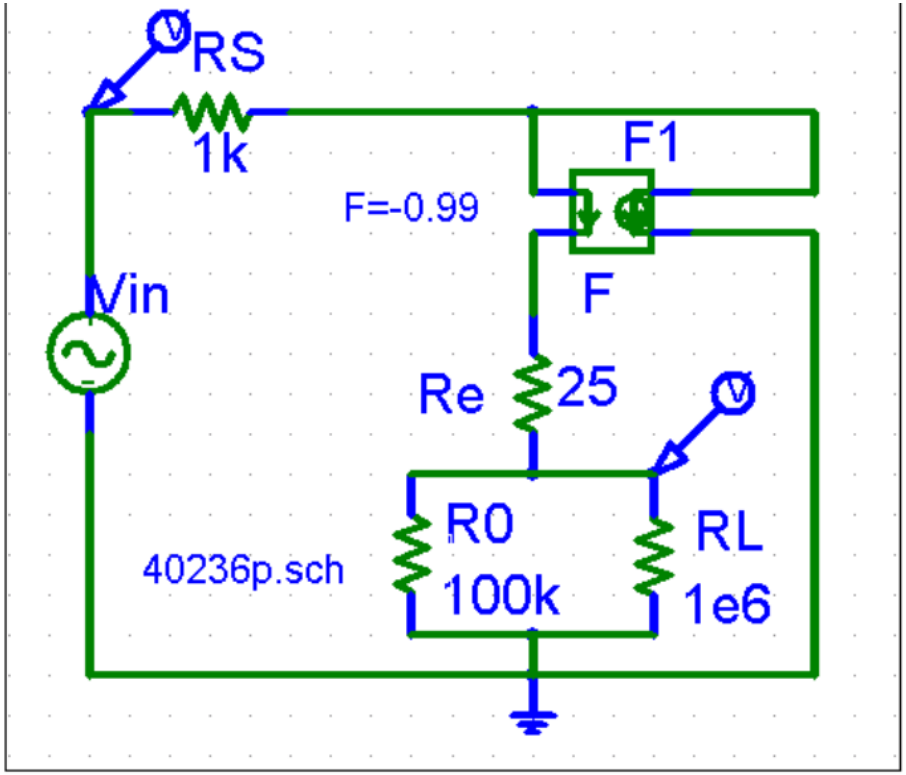
$$r_{in} = \frac{v_{in}^{(AC)}}{i_{in}^{(AC)}}$$

Base Loop:

$$0 = v_{in}^{(AC)} - i_{in}^{(AC)} R_s - \left[(\beta+1) i_{in}^{(AC)}\right]\left[r_e + (R_0 \parallel R_L)\right]$$

$$r_{in} = R_s + (\beta+1)\left[r_e + (R_0 \parallel R_L)\right]$$

$$r_{in} = R_s + (\beta+1)\left[\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L)\right]$$



$$r_{in} \approx 0 + (\beta+1)\left[0 + (\infty \parallel R_L)\right] = (\beta+1) R_L$$

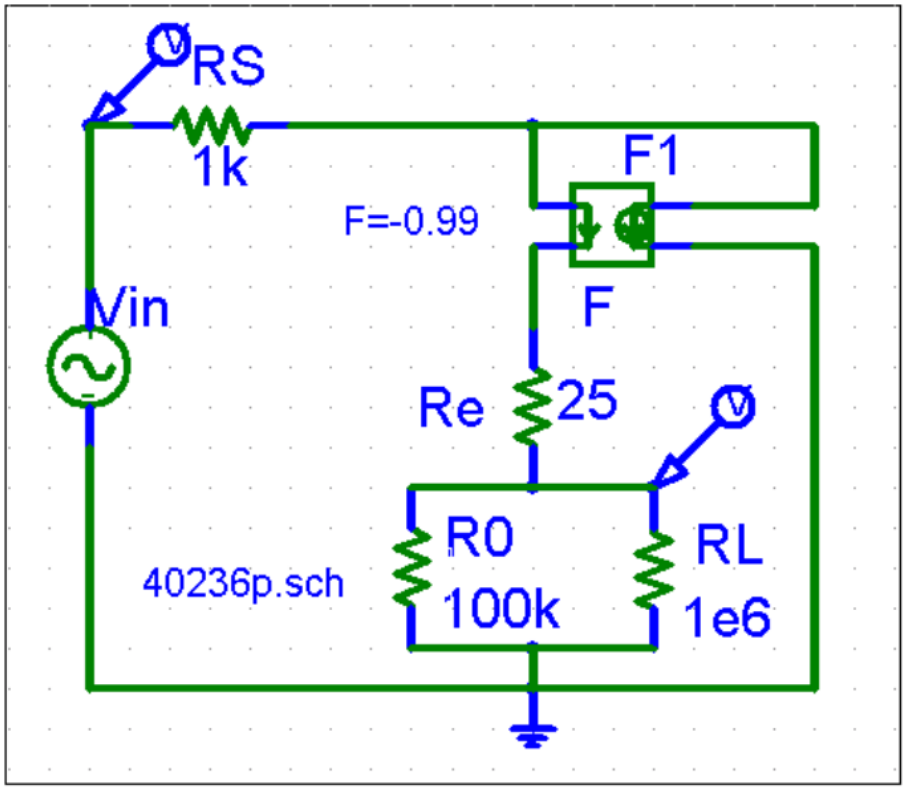
CC Amp: Voltage Gain (1)

$$v_b^{(AC)} = v_{in}^{(AC)} \frac{r_{in}}{r_{in} + R_s}$$

$$v_{out}^{(AC)} = v_b^{(AC)} \frac{R_0 \parallel R_L}{r_e + R_0 \parallel R_L}$$

$$A_v = \frac{v_{out}^{(AC)}}{v_{in}^{(AC)}} =$$

$$\frac{r_{in}}{r_{in} + R_s} \frac{R_0 \parallel R_L}{r_e + R_0 \parallel R_L}$$



CC Amp: Voltage Gain (2)

$$A_v = \frac{r_{in}}{r_{in} + R_s} \frac{R_0 \parallel R_L}{r_e + R_0 \parallel R_L} \qquad r_{in} = (\beta + 1)\left[\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L)\right]$$

$$A_v = \frac{(\beta + 1)\left[\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L)\right]}{(\beta + 1)\left[\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L)\right] + R_s} \frac{R_0 \parallel R_L}{\frac{V_T}{I_E^{(DC)}} + R_0 \parallel R_L}$$

$$A_v = \frac{R_0 \parallel R_L}{\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L) + \frac{R_s}{(\beta + 1)}}$$

CC Amp: Voltage Gain (3)

$$A_v = \frac{R_0 \parallel R_L}{\frac{V_T}{I_E^{(DC)}} + (R_0 \parallel R_L) + \frac{R_s}{(\beta + 1)}}$$

$$A_v \approx \frac{R_0 \parallel R_L}{0 + (R_0 \parallel R_L) + 0} = 1$$

Typical Application is a Unity Voltage Gain Buffer Amplifier

Recall that...

$$r_{in} \approx 0 + (\beta + 1)\left[0 + (\infty \parallel R_L)\right] = (\beta + 1)R_L$$

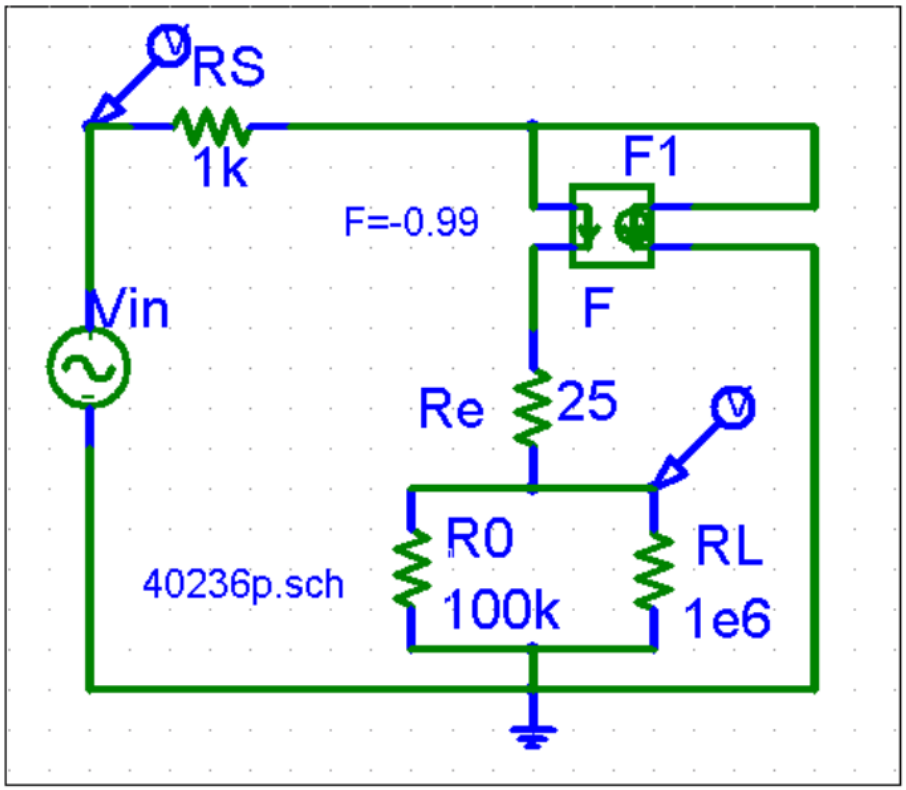
CC Amp: Output Impedance

$$r_{out} = R_0 \parallel \left(r_e + \frac{R_s}{\beta + 1} \right)$$

Use Resistance Reflection Rule (or trust me!)

$$r_{out} = R_0 \parallel \left(\frac{V_T}{I_e^{(DC)}} + \frac{R_s}{\beta + 1} \right)$$

$$r_{out} \approx \infty \parallel \left(0 + \frac{R_s}{\beta + 1} \right) = \frac{R_s}{\beta + 1}$$



CC Amp: Summary

Current Gain:

$$i_{out}^{(AC)} = i_{in}^{(AC)}(\beta + 1)$$

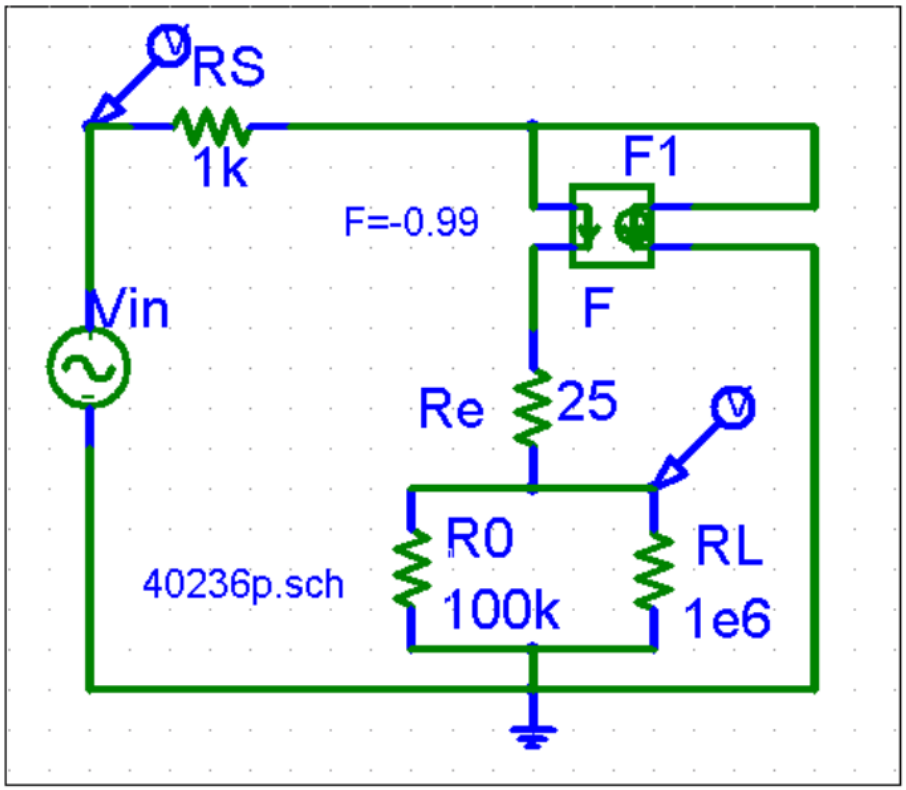
Results from Earlier Pages

$$A_v \approx 1$$

$$r_{in} \approx (\beta + 1) R_L$$

$$r_{out} \approx \frac{R_s}{\beta + 1}$$

Voltage Buffer Amplifier



BJT Amplifier Parameters

	Voltage Gain	Current Gain	Input Resistance	Output Resistance
CE	$-\dfrac{\beta(R_C \parallel R_0 \parallel R_L)}{R_s + \dfrac{(\beta+1)V_T}{I_E^{(DC)}}}$	$-\beta\dfrac{R_C \parallel R_0}{(R_C \parallel R_0)+R_L}$	$(\beta+1)\dfrac{V_T}{I_E^{(DC)}}$	$R_C \parallel R_0$
CER	$-\dfrac{\beta}{\beta+1}\dfrac{R_C \parallel R_L}{R_S + \dfrac{V_T}{I_E^{(DC)}} + R_E}$	$-\beta\dfrac{R_C}{R_C+R_L}$	$(\beta+1)\left(\dfrac{V_T}{I_E^{(DC)}}+R_E\right)$	R_C
CB	$\dfrac{\beta}{\beta+1}\dfrac{R_C \parallel R_L}{R_s + \dfrac{V_T}{I_E^{(DC)}}}$	$\dfrac{\beta}{\beta+1}\dfrac{R_C}{R_L+R_C}$	$\dfrac{V_T}{I_E^{(DC)}}$	R_C
CC	$\dfrac{R_0 \parallel R_L}{\dfrac{V_T}{I_E^{(DC)}}+(R_0 \parallel R_L)+\dfrac{R_s}{(\beta+1)}}$	$\beta+1$	$(\beta+1)\left[\dfrac{V_T}{I_E^{(DC)}}+(R_0 \parallel R_L)\right]$	$R_0 \parallel \left(\dfrac{V_T}{I_e^{(DC)}}+\dfrac{R_s}{\beta+1}\right)$

Approximations

	Voltage Gain	Current Gain	Input Resistance	Output Resistance	
CE	$-\frac{\beta}{(\beta+1)}\frac{(R_C \parallel R_L)I_E^{(DC)}}{V_T}$	$-\beta\frac{R_C}{R_C+R_L}$	$(\beta+1)\frac{V_T}{I_E^{(DC)}}$	R_C	$R_0 \to \infty$
CER	$-\frac{\beta}{\beta+1}\frac{R_C \parallel R_L}{\frac{V_T}{I_E^{(DC)}}+R_E}$	$-\beta\frac{R_C}{R_C+R_L}$	$(\beta+1)\left(\frac{V_T}{I_E^{(DC)}}+R_E\right)$	R_C	$R_0 \to \infty$
CB	$\frac{\beta}{\beta+1}\frac{I_e^{(DC)}R_L}{V_T}$	$\frac{\beta}{\beta+1}$	$\frac{V_T}{I_E^{(DC)}}$	R_C	$R_L \to 0$
CC	1	$\beta+1$	$(\beta+1)R_L$	$\frac{R_s}{\beta+1}$	$R_L \to 0$ $R_0 \to \infty$

Some Rough Numbers

	Voltage Gain	Current Gain	Input Resistance	Output Resistance
CE	$-\frac{(10^4\Omega \parallel R_L)}{25\Omega}$	$-\frac{10^6\Omega}{10^4\Omega + R_L}$	$2.5k\Omega$	$10^4\Omega$
CER	$-\frac{(10^4\Omega \parallel R_L)}{25\Omega + R_E}$	$-\frac{10^6\Omega}{10^4\Omega + R_L}$	$(2500\Omega + 100R_E)$	$10^4\Omega$
CB	$\frac{R_L}{25\Omega}$	1	25Ω	$10^4\Omega$
CC	1	100	$100R_L$	$\frac{R_s}{100}$

Typical Applications

CE

High Gain

CER

Lower Gain, Higher Inputs

CB

Current Buffer: Input looks like a short, output like a current source

CC

Voltage Buffer: Input looks like $R_L\ \beta$, Output like $R_s/\ \beta$