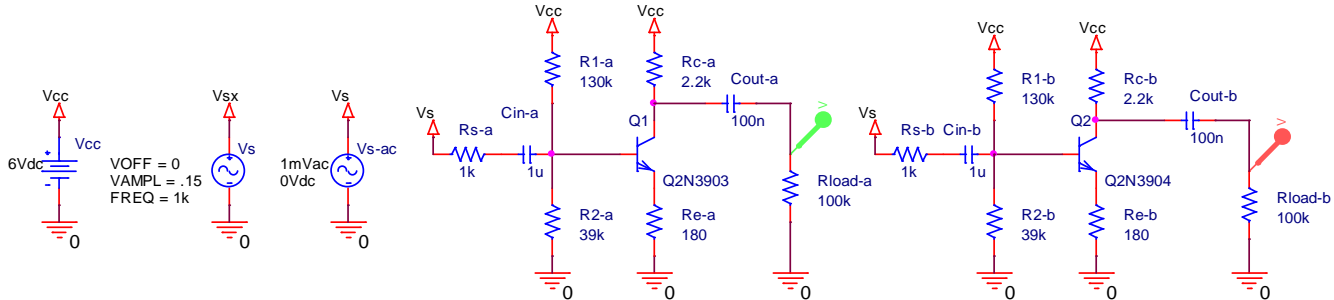


ECE 255
Fall 2009

ELECTRONIC ANALYSIS AND DESIGN
PSpice Design 2– Preliminary and Final Design Results

Hand-drawn schematic:



Intended operating point for preliminary design: $I_C = \underline{1.14 \text{ mA}}$, $V_{CE} = \underline{3.2 \text{ V}}$

Explanation of why this operating point was chosen:

We would like to have a $\pm 1.5 \text{ V}$ output voltage swing about the operating point, Q . Therefore, $V_C < 4.5 \text{ V} \Rightarrow I_C > .7 \text{ mA}$. Also we need to have $V_{CE} > 1.5 \text{ V} + V_0$ to ensure that the transistor remains in the active region. If we take $V_0 = .85 \text{ V}$ as the maximum from the data sheet we have $V_{CE} > 2.35 \text{ V}$. That leaves about 2.1 V for R_E . From the gain equation, we see that R_E is not going to be bigger than 200Ω , so the voltage drop across R_E is only going to be about $.2 \text{ V}$. Consequently, we have about 2 V of uncommitted voltage which we can distribute between R_C and V_{CE} .

Component values from preliminary design:

$R_C = \underline{2.2 \text{ k}\Omega}$, $R_E = \underline{180 \Omega}$, $R_1 = \underline{150 \text{ k}\Omega}$, $R_2 = \underline{39 \text{ k}\Omega}$, () = _____

Comments on the success (or failure) of your preliminary bias point calculations.

The circuit, as designed, was expected to have poor bias stability since R_E is too small to provide much negative feedback and the bias current, I_{R2} , is not much larger than I_B .
Decrease R_1 a bit to increase the gain.

Whether or not redesign is required, list the final values used in your simulation:

$R_C = \underline{2.2 \text{ k}\Omega}$, $R_E = \underline{180 \Omega}$, $R_1 = \underline{130 \text{ k}\Omega}$, $R_2 = \underline{39 \text{ k}\Omega}$, () = _____

Component values for external capacitors used:

$C_1 = \underline{1 \mu\text{F}}$, $C_2 = \underline{1 \mu\text{F}}$, () = _____

Final mid-frequency voltage gain $|A_{Vs}|$

2N3903 9.48 2N3904 10.24

(from transient output; AC simulation meets specs.)

PSpice Design 2

Solution – without bias point stabilization

Preliminary Design

Gain equation:
$$A_{V_s} = \frac{v_{out}}{v_s} = \frac{Z_{in}}{R_S + Z_{in}} \times \frac{g_m r_\pi (R_C \parallel R_{Load})}{r_\pi + g_m r_\pi R_E + R_E} = 10 \pm 0.5$$

Constraints:
$$\begin{aligned} Z_{in} &> 10 \text{ k}\Omega & R_S &= 1 \text{ k}\Omega & R_{Load} &= 100 \text{ k}\Omega \\ Z_{out} &\approx 2.2 \text{ k}\Omega & \Rightarrow & R_C &= 2.2 \text{ k}\Omega \end{aligned}$$

Substituting known values
$$A_{V_s} = \frac{10}{1+10} \times \frac{g_m r_\pi (2.15)}{r_\pi + (g_m r_\pi + 1) R_E} = 10 \pm 0.5$$

From the data sheet, β_0 is expected to be between 50 and 200 for $I_C = 1 \text{ mA}$.
Take $\beta_0 \approx 75$ (to be on the safe side)

$$\begin{aligned} \therefore \quad g_m r_\pi (2.15) &\approx 11 \times [r_\pi + (g_m r_\pi + 1) R_E] \\ \text{or} \quad 161 &\approx 11 \times [r_\pi + (76) R_E] \end{aligned}$$

Input impedance equation:
$$Z_{in} = R_1 \parallel R_2 \parallel [r_\pi (1 + g_m R_E)] > 10 \text{ k}\Omega$$

Considerations:

We would like to have a $\pm 1.5 \text{ V}$ output voltage swing about the operating point, Q .
Therefore, $V_C < 4.5 \text{ V} \Rightarrow I_C > .7 \text{ mA}$. Also we need to have $V_{CE} > 1.5 \text{ V} + V_0$ to ensure that the transistor remains in the active region. If we take $V_0 = .85 \text{ V}$ as the maximum from the data sheet we have $V_{CE} > 2.35 \text{ V}$. That leaves about 2.1 V for R_E . From the gain equation, we see that R_E is not going to be bigger than 200 Ω , so the voltage drop across R_E is only going to be about .2 V. Consequently, we have about 2 V of uncommitted voltage which we can distribute between R_C and V_{CE} .

Let's try making $V_C = 3.5 \text{ V}$ and $V_{CE} \approx 3.2 \text{ V}$.

Then
$$I_C = \frac{V_{CC} - V_C}{R_C} = \frac{6.0 - 3.5}{2.2 \text{ k}} = 1.14 \text{ mA} \quad \Rightarrow \quad g_m = \frac{q}{\eta k T} \times I_C = \frac{38.66}{1.2} \times 1.14 = 36.73 \text{ mS}$$

$$r_\pi \approx \frac{\beta_0}{g_m} \approx 2 \text{ k}\Omega \quad \text{for } \beta_0 \approx 75$$

From the gain equation, $161 \approx 11 \times [r_\pi + (76) R_E] \quad \Rightarrow \quad R_E = \frac{161 - 22}{11 \times 76} = .166 \text{ k}\Omega$

Try $R_E = 180 \Omega$

$$\text{Since } Z_{in} = R_1 \parallel R_2 \parallel [r_{\pi} (1 + g_m R_E)] = R_1 \parallel R_2 \parallel 15k\Omega > 10k\Omega \Rightarrow R_1 \parallel R_2 > 30k\Omega$$

Since R_1 will be much larger than R_2 , try $R_2 = 39k\Omega$

$$V_B \approx V_E + V_0 = |I_E| R_E + 0.7V \approx 0.9V \Rightarrow I_{R_2} \approx \frac{0.9V}{39k\Omega} = .023mA$$

$$\text{and } I_{R_1} = I_{R_2} + I_B = 0.023 + .011 = .034mA \therefore R_1 = \frac{5.1V}{.034mA} = 150k\Omega, \text{ use } 150k\Omega$$

Comments:

The circuit, as designed, is expected to have poor bias stability since R_E is too small to provide much negative feedback and the bias current, I_{R_2} , is not much larger than I_B .

Initial simulation results show $|A_{Vs}|_{min} \approx 9.26$. Let's decrease R_1 a bit to increase the gain, try $R_1 = 130k\Omega$.

Simulation results:

	V_{CE}	I_C	R_{in}	$ A_{Vs} $
2N3903	3.23 V	1.16 mA	10.3 k Ω	9.53
2N3904	1.70 V	1.81 mA	15.1 k Ω	10.26

Capacitor selection:

The minimum impedance that the input coupling capacitor sees is

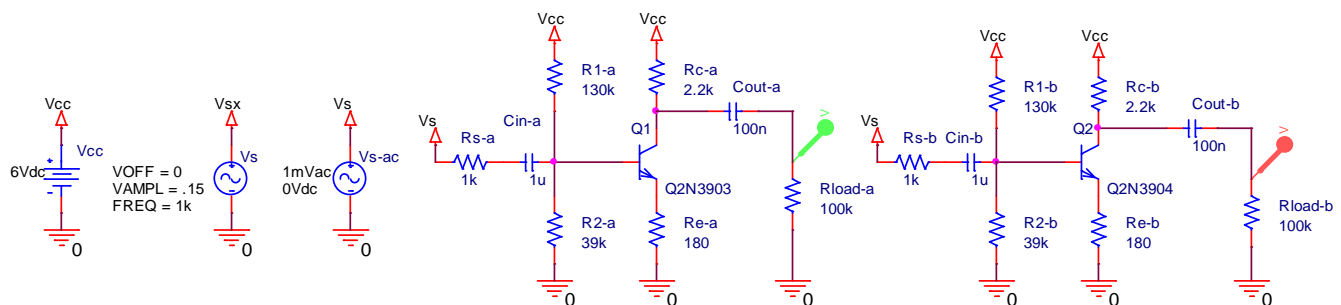
$$R_{C_{in}} = R_S + R_{in} = 1k\Omega + 10k\Omega = 11k\Omega \Rightarrow C_{in} > \frac{1}{2\pi \times 30 \times 11k} = 490nF$$

The minimum impedance that the output coupling capacitor sees is

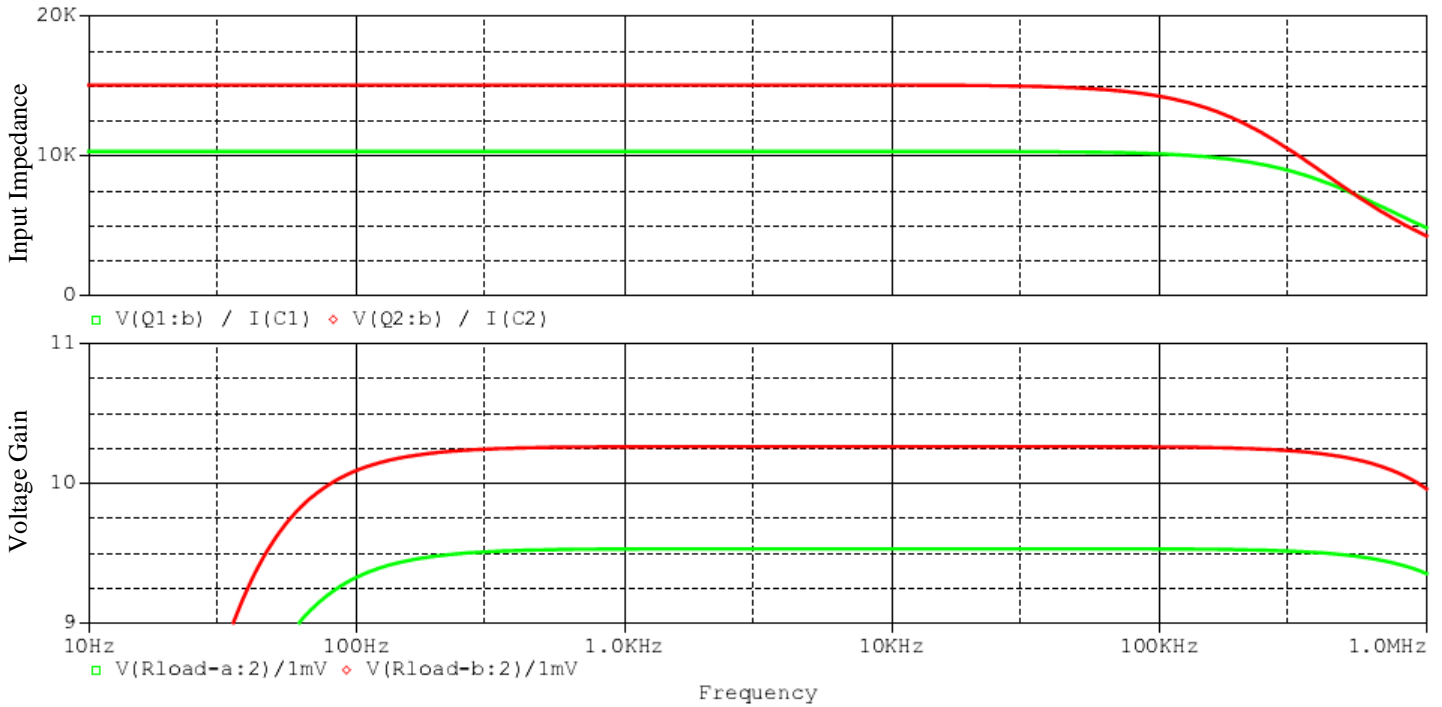
$$R_{C_{out}} \approx R_C + R_{Load} = 2.2k\Omega + 100k\Omega = 102k\Omega \Rightarrow C_{out} > \frac{1}{2\pi \times 30 \times 102k} = 52nF$$

Since the low frequency cut-off (-3 dB point), $max\{\omega's\} < \omega_L < \Sigma \omega's$, set $C_{in} = 1\mu F$ and $C_{out} = 100nF$. (Larger values will also work.)

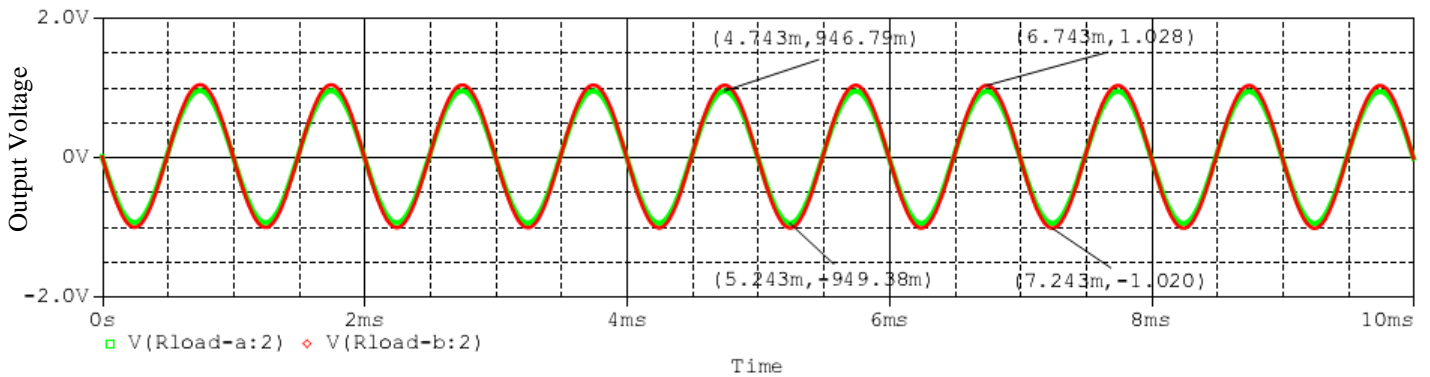
Circuits used in simulations



A.C. Simulation

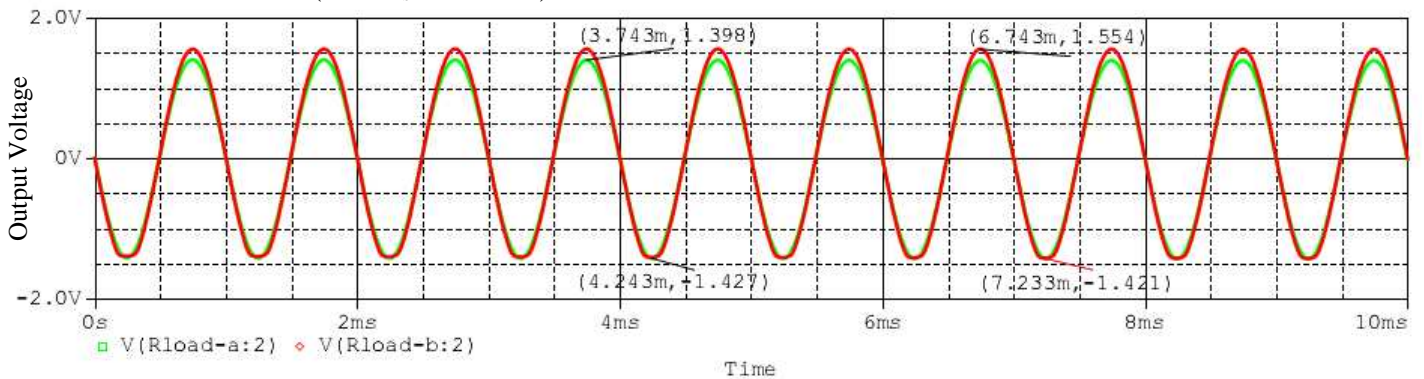


Transient Simulation (with $v_s = 0.2 V_{PP}$)



For the 2N3903, $V_{out-PP} = 1.896 V \Rightarrow |A_{Vs}| = 9.48$ and for the 2N3904, $V_{out-PP} = 2.048 V \Rightarrow |A_{Vs}| = 10.24$

Transient Simulation (with $v_s = 0.3 V_{PP}$)



For the 2N3903, $V_{out-PP} = 2.825 V \Rightarrow |A_{Vs}| = 9.42$ and for the 2N3904, $V_{out-PP} = 2.975 V \Rightarrow |A_{Vs}| = 9.92$
 Note the distortion at the bottom of the waveform.