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Faculty of Engineering & Architectural Science

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Objective

The objective of this lab is to create a two-stage coupled Amplifier that meets certain design parameters such as the small signal magnitude that maximizes output swing without clipping.

The Design Process

This is the final circuit designed which is a two-stage direct coupled Common-Emitter, Common-Collector Amplifier.

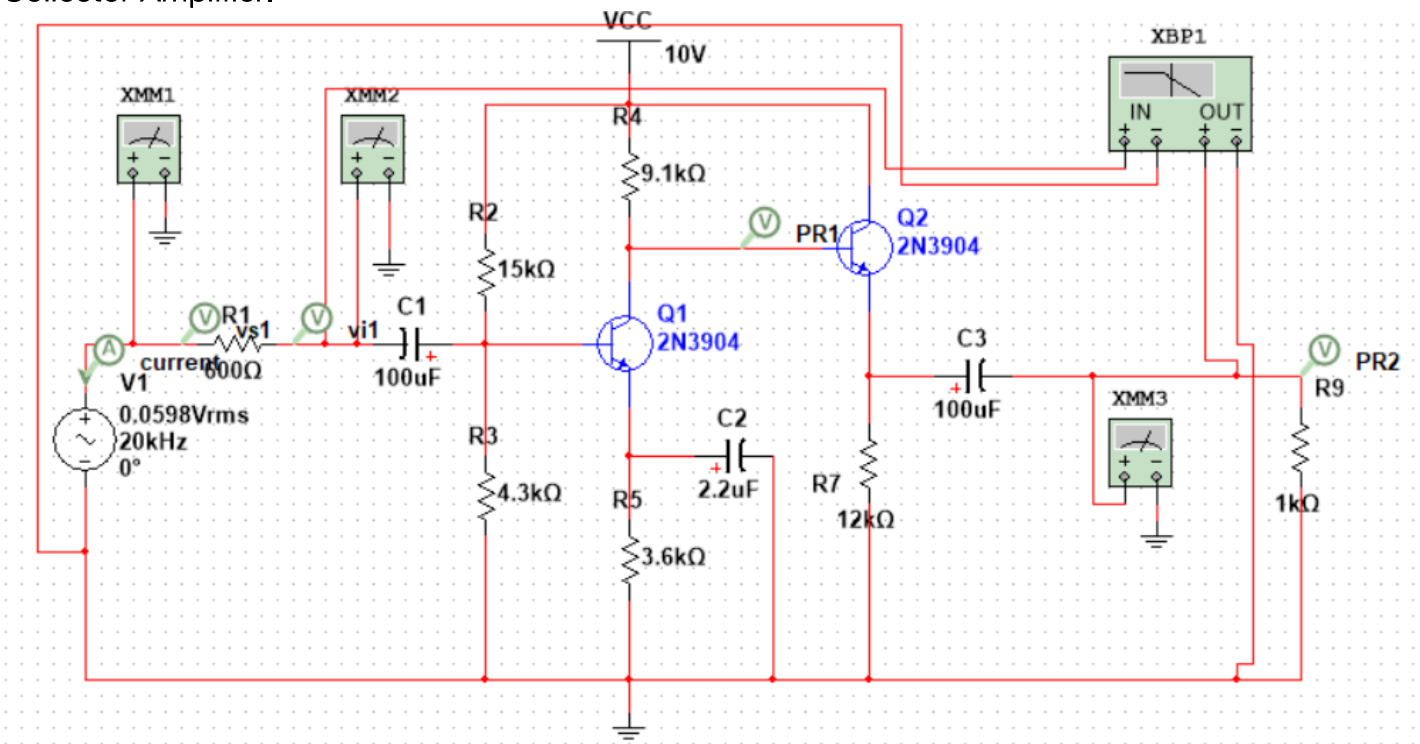
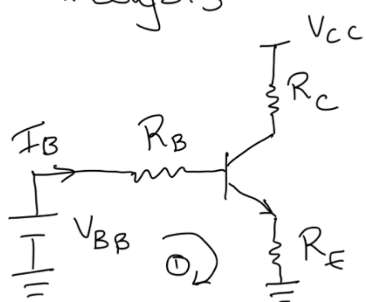


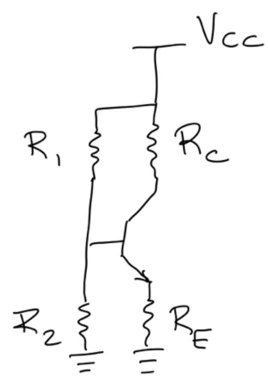
Figure 1: A Common-Emitter (CE) amplifier driving a buffered load.

I chose this design because it is relatively simple due to the fact that it is directly coupled and checks out the design parameters given. I chose a Common-Emitter as the first stage for its high voltage gain characteristic and connected it with an emitter follower which provides a gain of just less than one but outputs a low output resistance, which allows the amplifier to drive a low-resistance load (1kΩ) without losing voltage gain. I then chose passive loads instead of active loads to make it easier to test out the best values for meeting the design criteria. Overall, there was a lot of trial and error involved but using the calculations below I was able to design this circuit.

To analyze the direct-coupled 2 stage CE-CC amplifier we must first analyze the CE amplifier individually;

DC Analysis $\dashv\vdash \rightarrow --$





$$V_{BB} = V_{cc}\left(\frac{R_2}{R_1+R_2}\right)$$

$$= 10\left(\frac{15}{15+4.3}\right) = 7.77\,V \qquad R_B = R_1 // R_2$$

$$= 3.34\ k\Omega$$

KVL @ 1

$$-V_{BB} + I_B R_B + V_{BE} + I_E R_E = 0$$

$$-7.77 + I_B(3.34\ k) + 0.7 + (1+\beta) I_B (6.8k)$$

$$\Rightarrow \quad 1030140\, I_B = 7.07$$

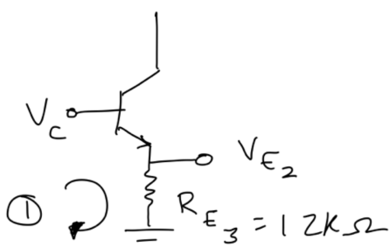
$$\Rightarrow I_B \simeq 6.86 \times 10^{-6} A \simeq 6.86\,\mu A$$

$$I_C = \beta I_B = 150(6.86\mu) = 1.0295\,mA$$

$$V_A = \beta / g_m = \frac{150}{I_C / r_1} = \frac{150\,(26mV)}{1.0295mA} = 3.788\,K$$

$$V_E = I_E R_E = 3.73\,V \qquad V_C = 10 - I_C R_C = 2.97\,V$$

DC-Analysis (2^{nd} Stage)



$$2.97 - V_{BE} - I_{E_2} R_{E_3} = 0$$

$$I_{E_2}\,(12K\Omega) = 2.97 - 0.7 = 2.27\,V$$

$$\Rightarrow I_{E_2} = 0.188mA$$

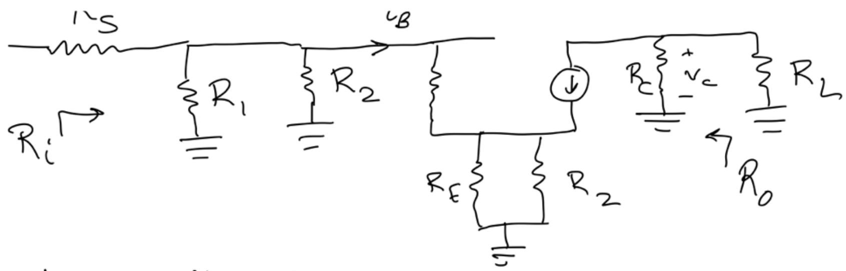
$$I_{E_2} = (1+\beta)\,I_B \;\Rightarrow\; I_{B_2} = \frac{I_{E_2}}{1+\beta} = 1.253\,\mu A$$

$$I_{C_2} = \beta I_B = 150\,(1.253\mu A) = 0.188\,mA$$

$$V_{E_2} = I_{E_2} - R_{E_3} = 9.44 \times 10^{-3} \times 12 \times 10^{3} = 1.52V$$

AC Analysis $\quad \dashv\vdash \rightarrow$ ——

R



A_v with R_L:

$$V_i = i_b r_\pi + (150+1) I_b \; (R_E \,//\, R_{E_2})$$
$$V_i = 35701.91 \; i_b$$

$$V_o = -150 \, i_b \, (R_C \,//\, R_L)$$
$$= -25312.5 \; i_b$$

$$A_v = \frac{V_o}{V_i} = \frac{-253125 \, i_b}{35701.91 \, i_b} = -0.709$$

A_v with R_s & R_L:

$$\frac{R_o'}{V} = \frac{r_1}{i_b} = 35.702K$$

$$R_{in} = -R_1 \,//\, (R_2 \,//\, R') = 5.612K$$

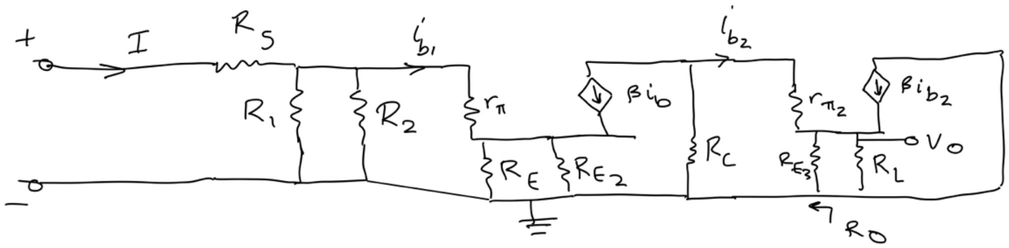
$$V_{in} = V_s \, (R_{in}) = 5.612 v_s$$

$$A_V = V_o \times V_{in} = -25312 i_L \times 0.99$$

$$\frac{}{v_{in}} \cdot \frac{}{V_s} = \frac{}{352016\, i_b}$$

$$A_v = -0.702$$

2 Stage



A_{v_o} (no load), $R_s = 600\,\Omega$

$$g_{m_1} = \left(\frac{I_C}{V_T}\right) = \frac{1.1mA}{25mA} = 44mV$$

$$r_{\pi_1} = \frac{\beta}{g_m} = \frac{150}{44\times10^{-3}} = 3.4k\Omega$$

$$g_{m_2} = \left(\frac{I_{C_2}}{V_T}\right) = \frac{9.37m}{25m} = 374.8mV$$

$$r_{\pi_2} = \frac{150}{374.8mV} = 400.2\Omega$$

$$v_i = i_{b_1} r_{\pi_1} + i_{b_1}(1+\beta)(R_E \,//\, R_{E_2})$$
$$= i_{b_1}(3.4K + (151)\,213.1) = i_{b_1}(35.57K)$$

$$V_o = R_{E_3}(i_{b_2} + \beta i_{b_2})$$
$$= i_{b_2}(1+\beta) R_{E_3}$$

$$A_{V_o} = \left|\frac{V_o}{V_i}\right| = \frac{151\,(1.2K)\, i_{b_2}}{(35.57K)\, i_{b_1}}$$
$$= \frac{181.2 \times 10^3 \times 62.5 \times 10^{-6}}{35.57 \times 10^3 \times 7.386 \times 10^{-6}}$$
$$\Rightarrow A_{V_o} = 54.61$$

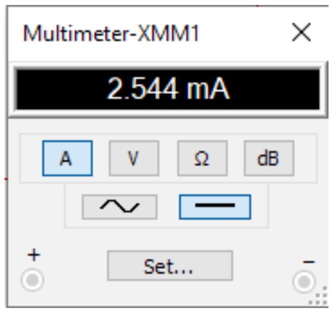
A_{V_o} (with load) $R_L = 1K\Omega$ $R_S = 600\,\Omega$

V_i is equal to the last part

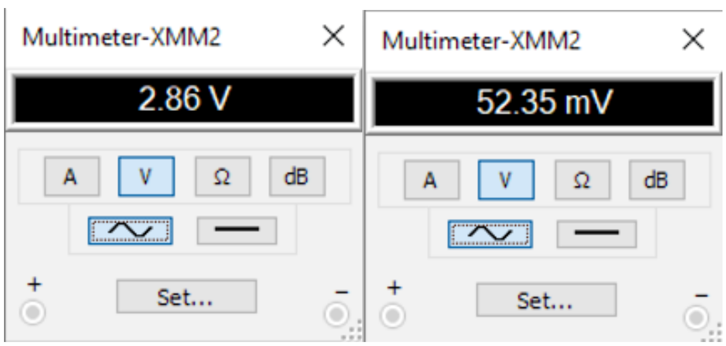
$$V_o = (R_{E_3} // R_2)(1+\beta)\, i_{b_2}$$
$$= (156.52)(151\,(625 \times 10^{-6})$$
$$\Rightarrow A_{V_o} = \frac{V_o}{V_i} = \frac{156.52 \times 151 \times 62.5 \times 10^{-6}}{35.57 \times 10^3 \times 7.386 \times 10^{-6}}$$
$$A_V = 52.44$$

The Design Criteria

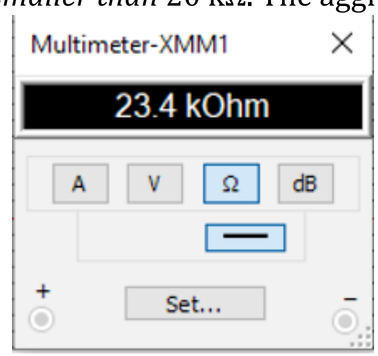
- Power supply: +10V relative to the ground; The DC Biasing Voltage Vcc=10V
- Quiescent current drawn from the power supply: *no larger than* 10 $\boldsymbol{m}$A. The current drawn is 2.544mA



- No-load voltage gain (at 1 kHz): $|A_{vo}|$ = $\mathbf{5}$0 (± 10%). The no-load voltage gain is 2.86V/52.35mV=54.63

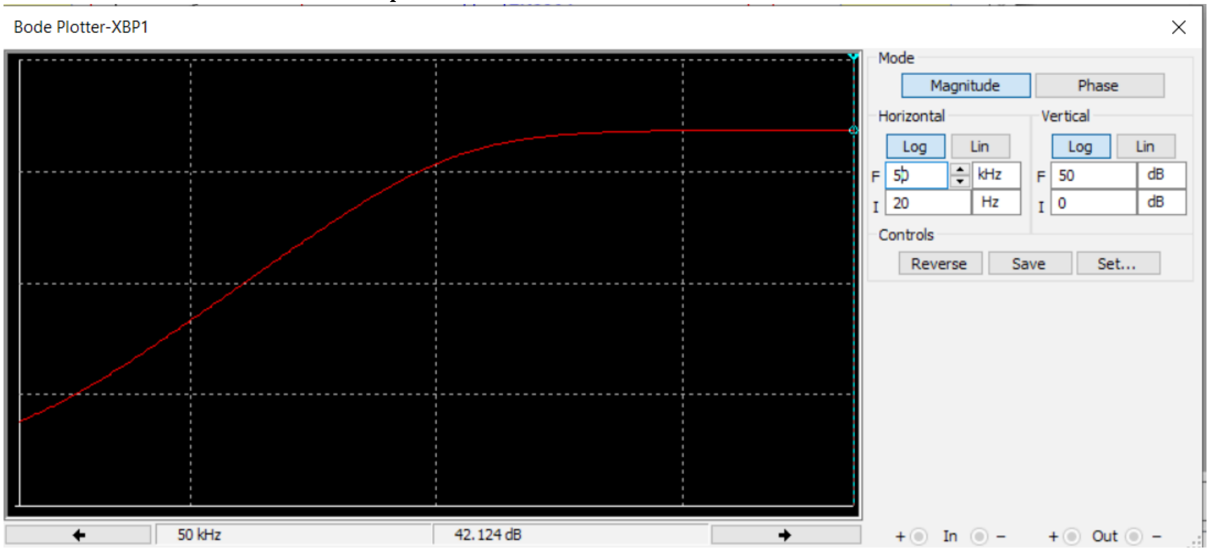


- Maximum no-load output voltage swing (at 1 kHz): *no smaller than 8 V peak to peak.* The no-load output voltage swing at 1 kHz is
- Loaded voltage gain (at 1 kHz and with R_L = 1 $k\Omega$): *no smaller than* 90% *of the no-load voltage gain.*
- Maximum loaded output voltage swing (at 1 kHz and R_L = 1 $k\Omega$): *no smaller than 4 V peak to peak.*
  - Input resistance (at 1 kHz): *no smaller than* 20 kΩ. The aggregate input resistance is 23.4kΩ



- Amplifier type: *inverting or non-inverting.* This is an inverting amplifier since the output waveform has a phase shift of 180 degrees

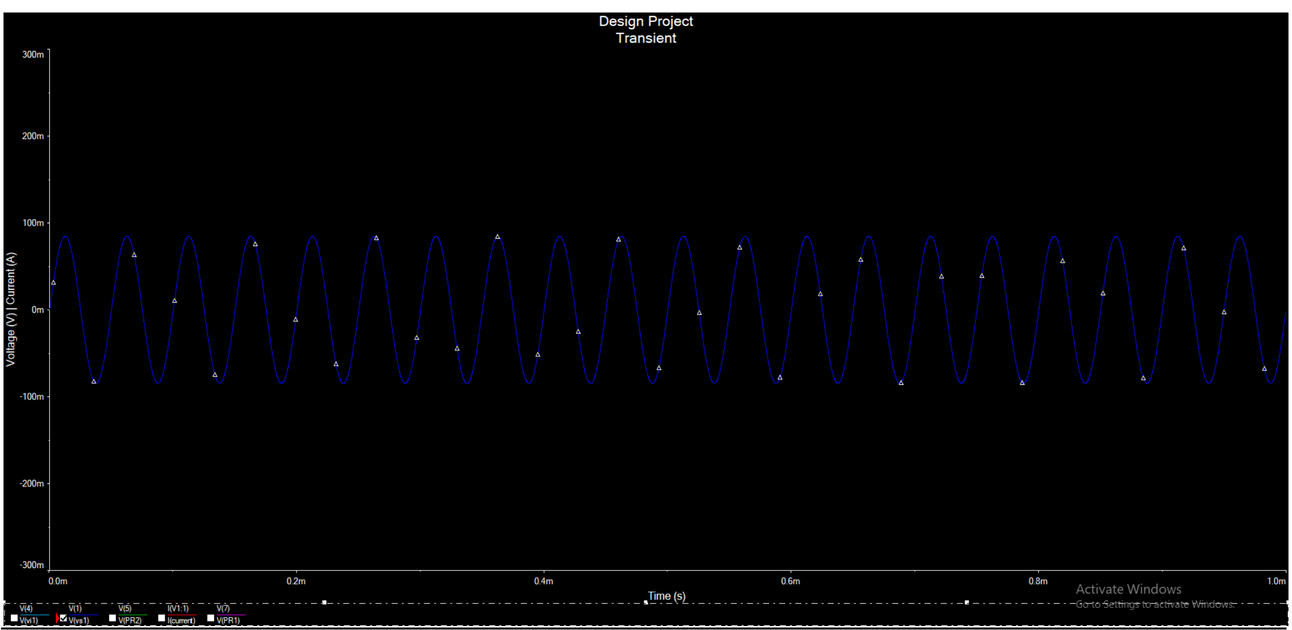
- Frequency response: *20 Hz to 50 kHz* ($-\mathbf{3dB}$ *response*); *The* bode plot covers frequencies from 20Hz to 50kHz but does not show a -3dB response

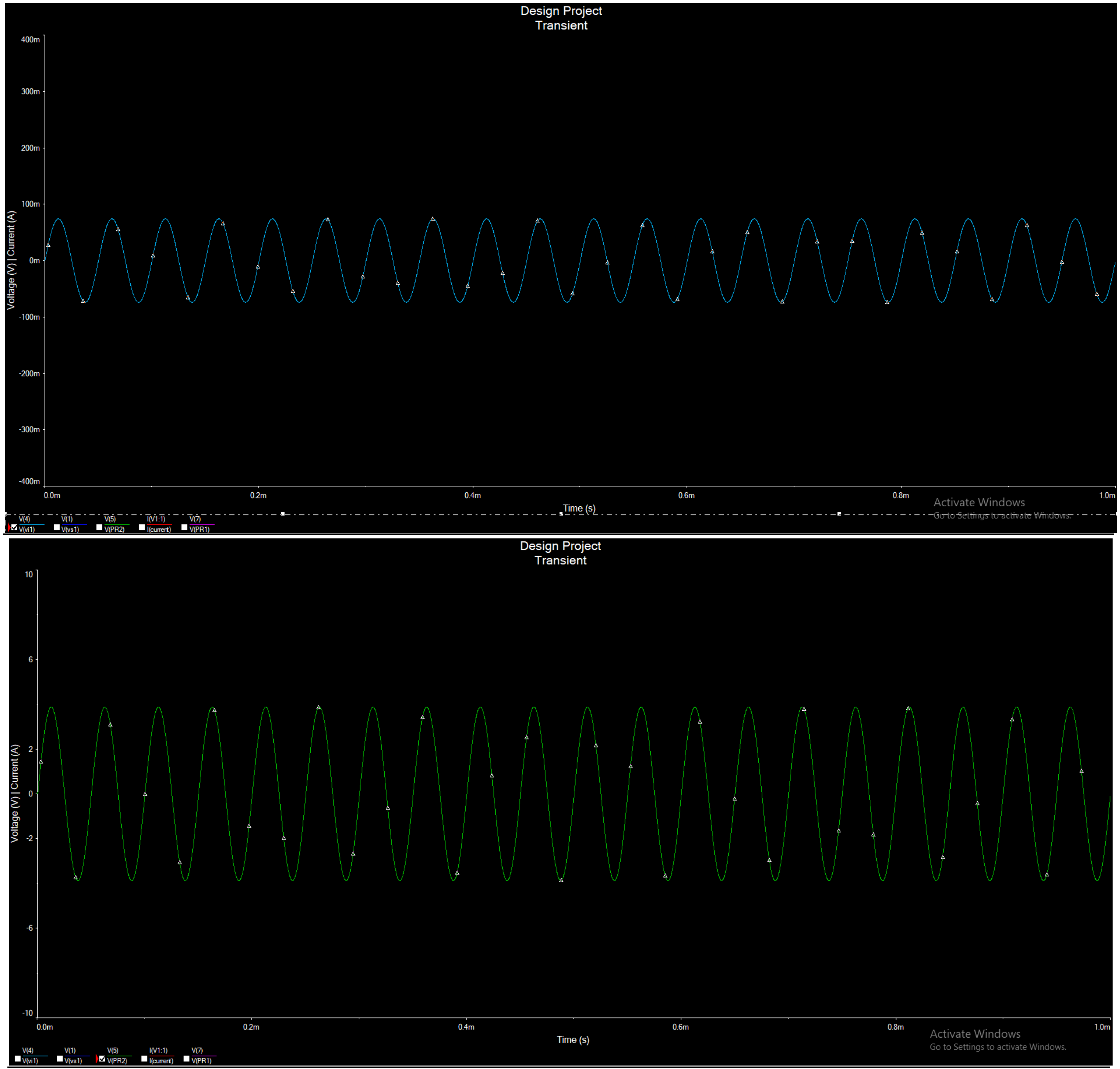


- Type of transistors: *BJT.* This circuit uses a 2N3904 BJT for both stages
- Number of transistors (stages): *no more than 3*. Only 2 transistors are used in the 2-stage design
- Resistances permitted: *values smaller than* 200 $k\Omega$ from *the E24 series*. Every resistor used is under 220 $k\Omega$ and is a value from the E24 series
- Capacitors permitted: $0.\mathbf{1}\ \boldsymbol{\mu F}$, $\mathbf{1}.0\ \boldsymbol{\mu F}$, $\mathbf{2.2}\ \boldsymbol{\mu F}$, $\mathbf{4.7}\ \boldsymbol{\mu F}$, $10\ \boldsymbol{\mu F}$, $\mathbf{47}\ \boldsymbol{\mu F}$, $\mathbf{100}\ \boldsymbol{\mu F}$, $\mathbf{22}0\ \boldsymbol{\mu F}$; The Capacitors used are within this set of values.
- Other components (BJTs, diodes, Zener diodes, etc.): *only from your ELE404 lab kit.* Only lab components are used in this design.

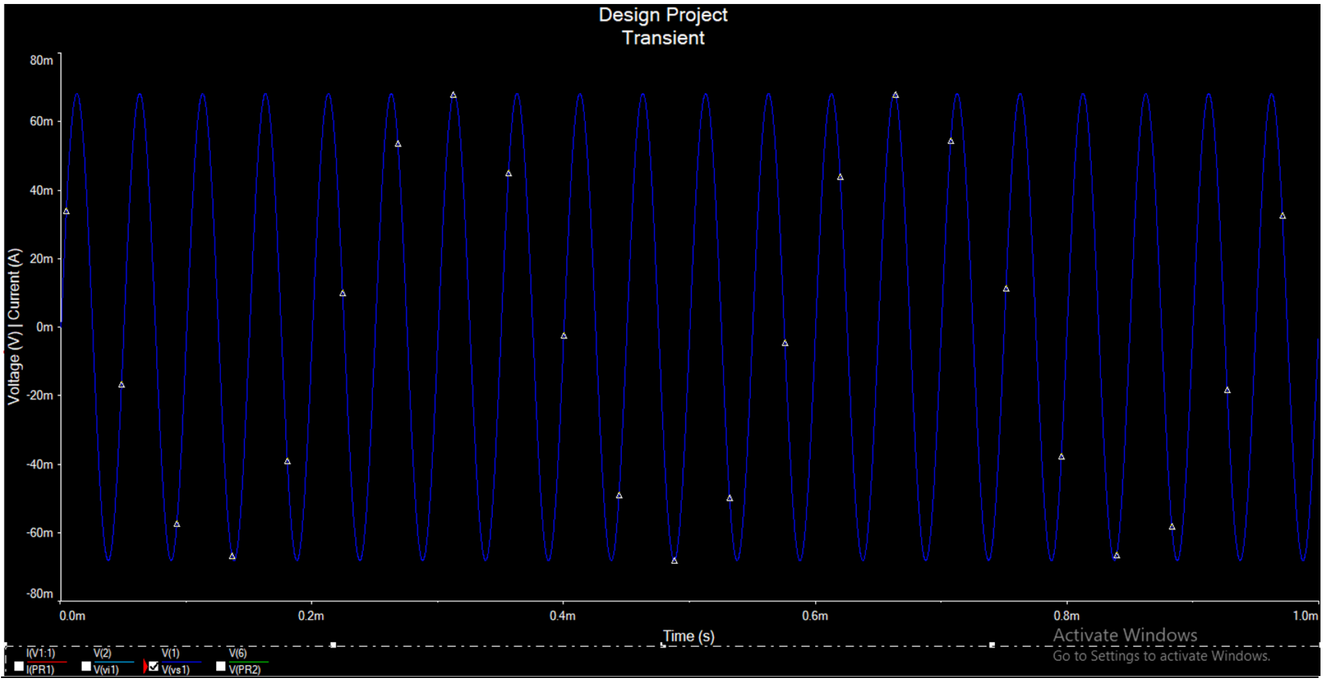
Conclusions and Results

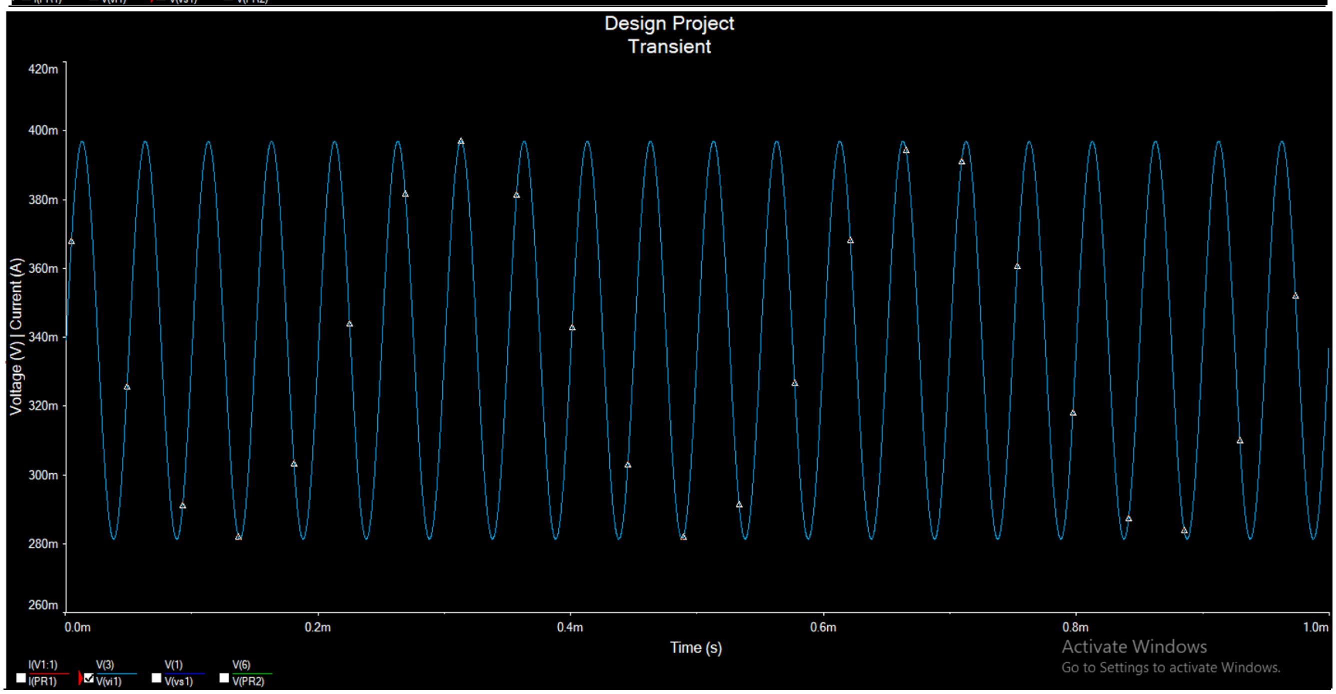
20Hz Waveforms:

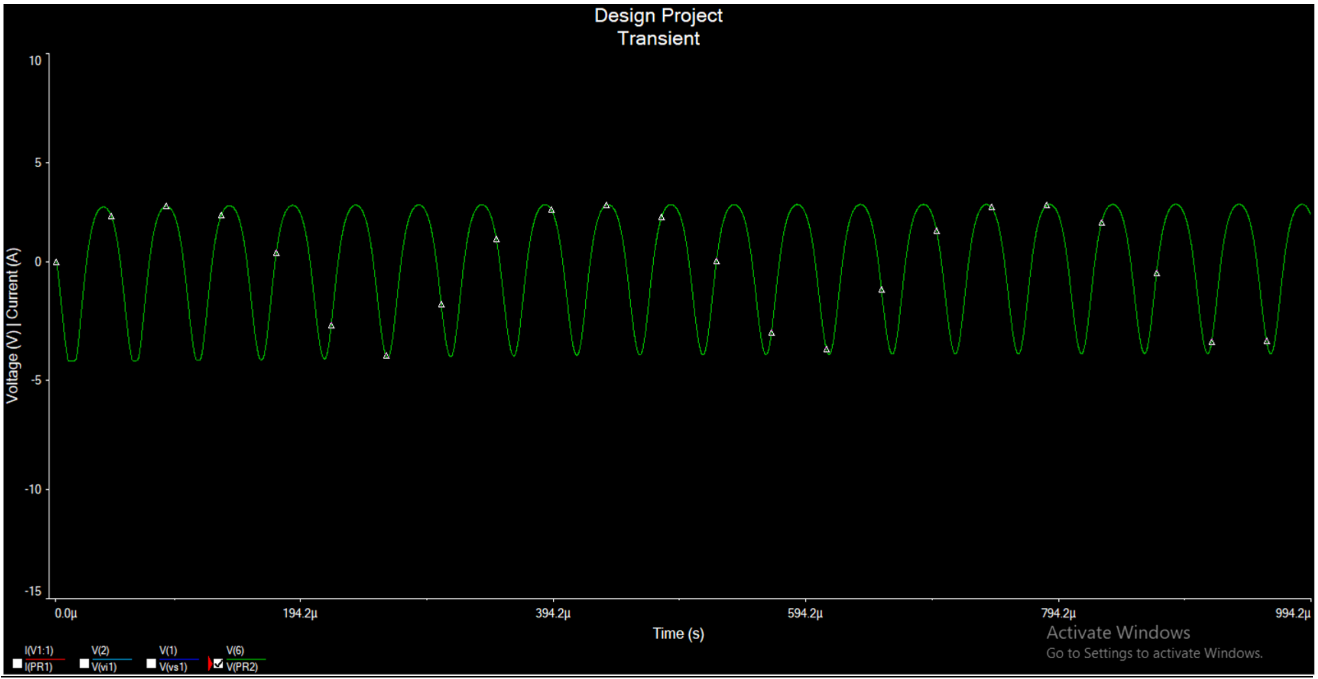




Graph 1: Source, Input and Output voltage Waveforms of the Amplifier of Figure 2, with R_s = 600Ω and no R_L.

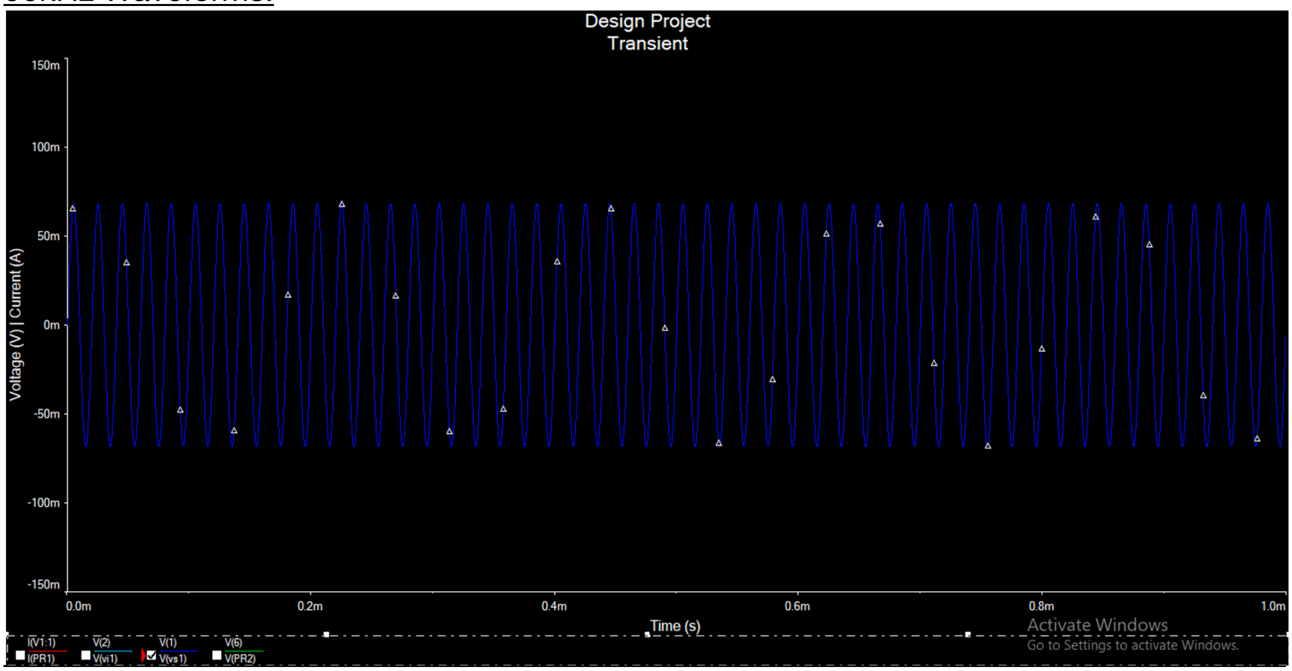

Design Project
Transient
80m
60m
40m
20m
0m
-20m
-40m
-60m
-80m
Voltage (V) | Current (A)
0.0m
0.2m
0.4m
0.6m
0.8m
1.0m
Time (s)
I(V1:1)
I(PR1)
V(2)
V(vi1)
V(1)
V(vs1)
V(6)
V(PR2)
Activate Windows
Go to Settings to activate Windows.

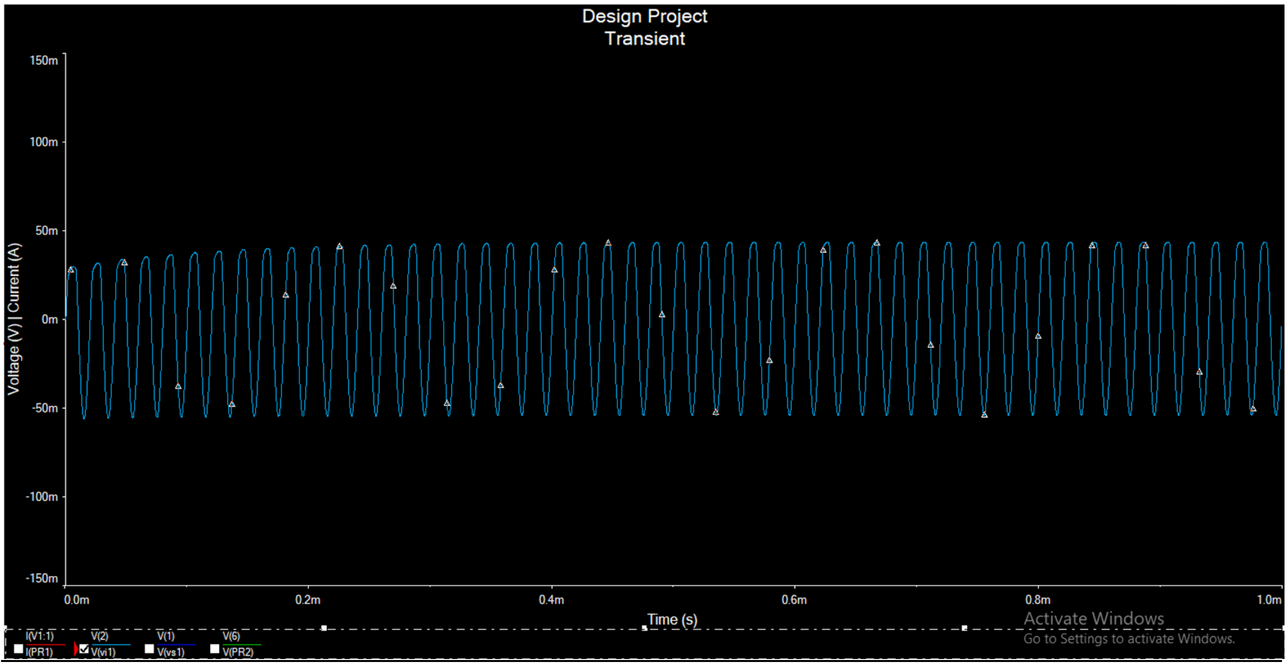

Design Project
Transient
420m
400m
380m
360m
340m
320m
300m
280m
260m
Voltage (V) | Current (A)
0.0m
0.2m
0.4m
0.6m
0.8m
1.0m
Time (s)
I(V1:1)
I(PR1)
V(3)
V(vi1)
V(1)
V(vs1)
V(6)
V(PR2)
Activate Windows
Go to Settings to activate Windows.

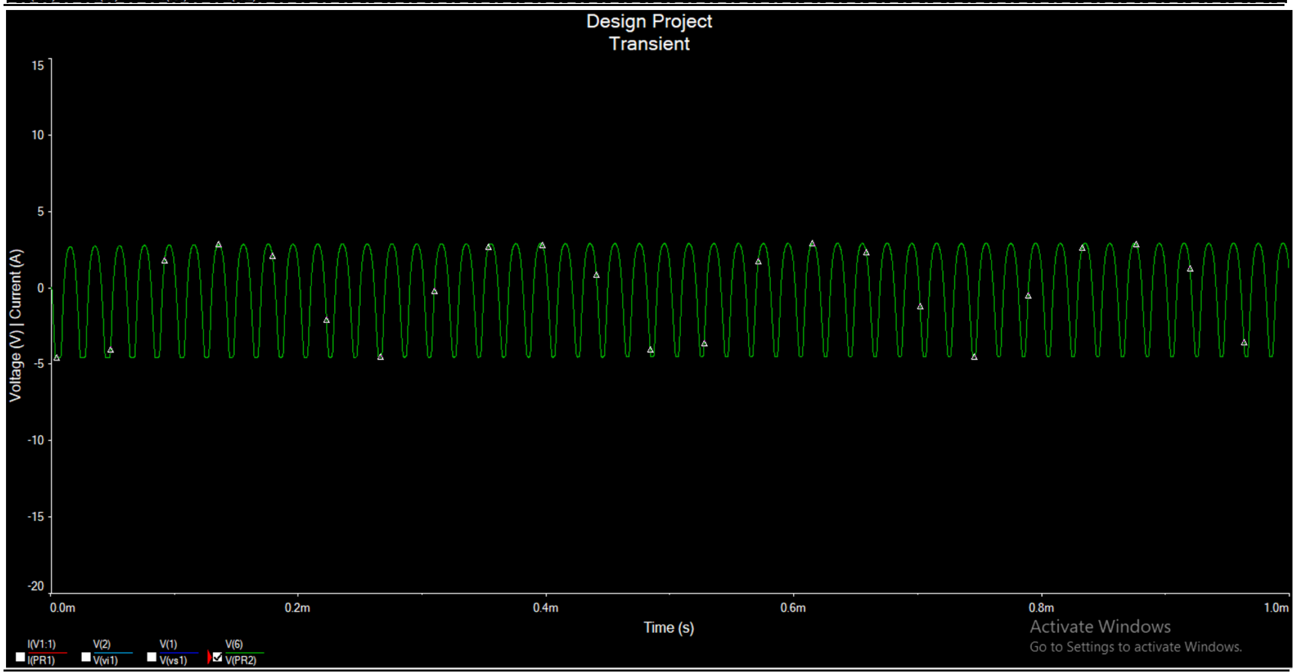


Graph 2: Source, Input and Output voltage Waveforms of the Amplifier of Figure 1, with $R_s = 600\Omega$ and $R_L = 1k\Omega$.

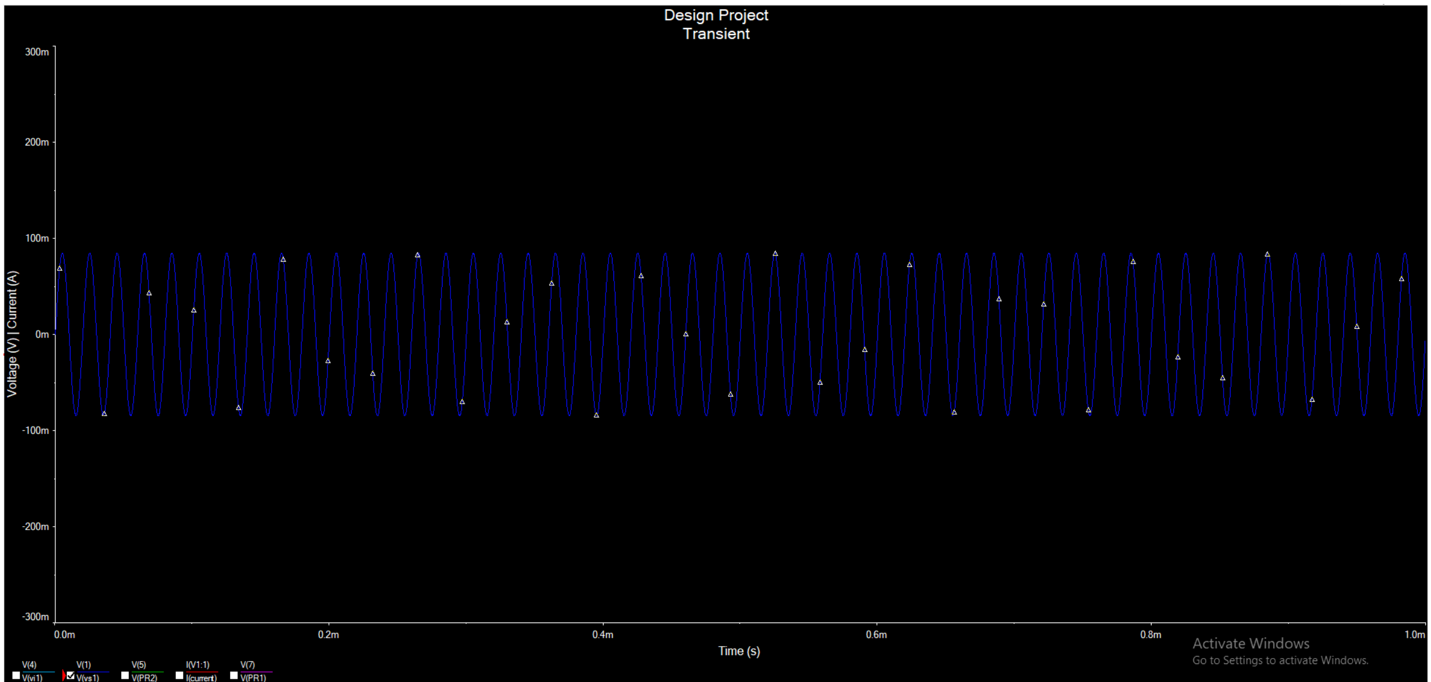
50kHz Waveforms:

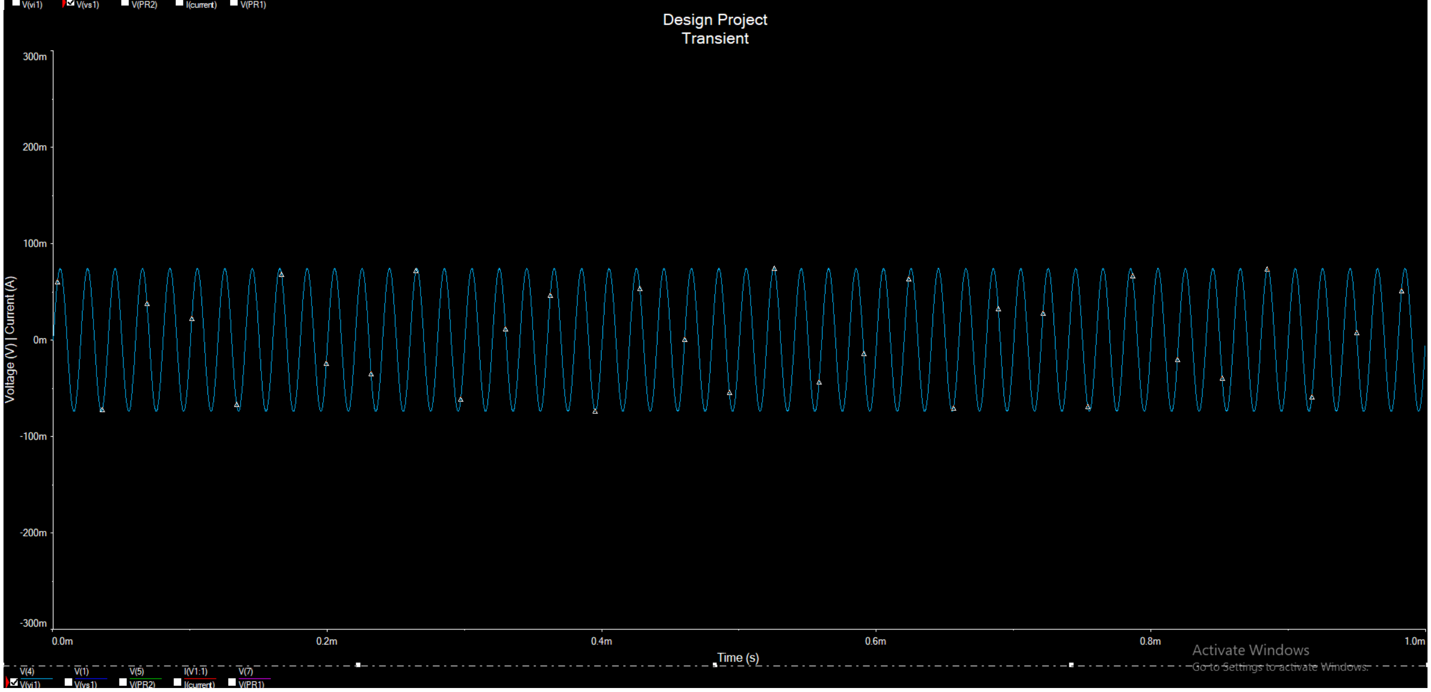


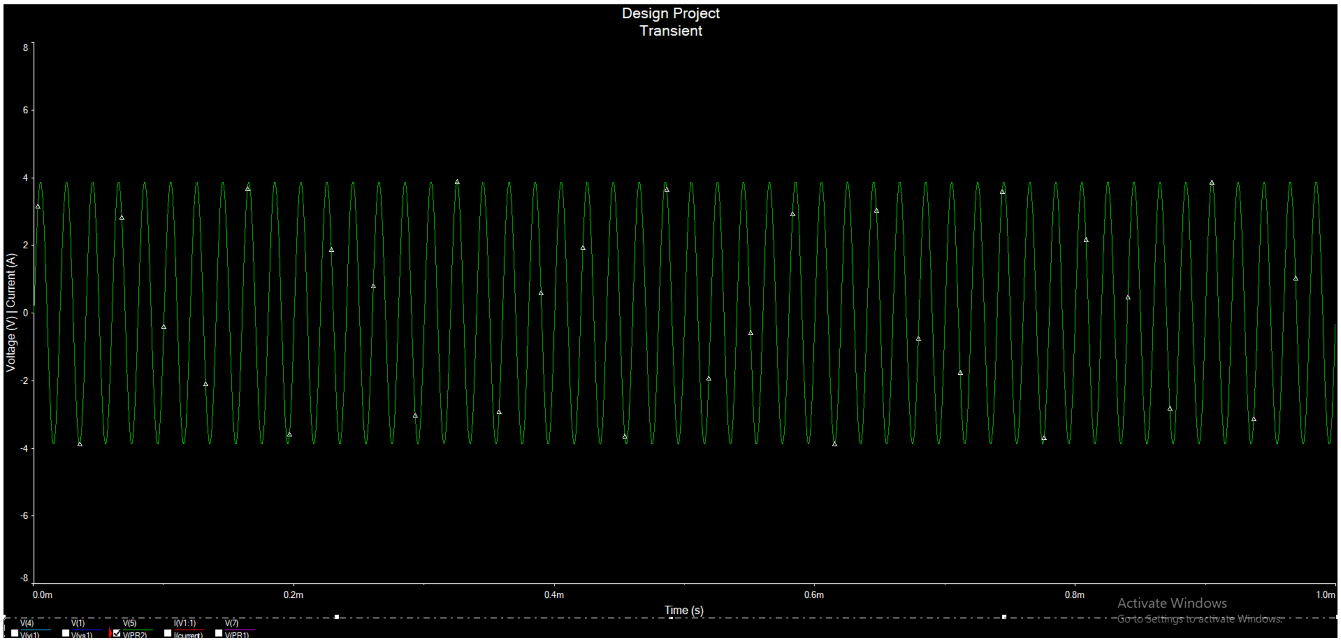




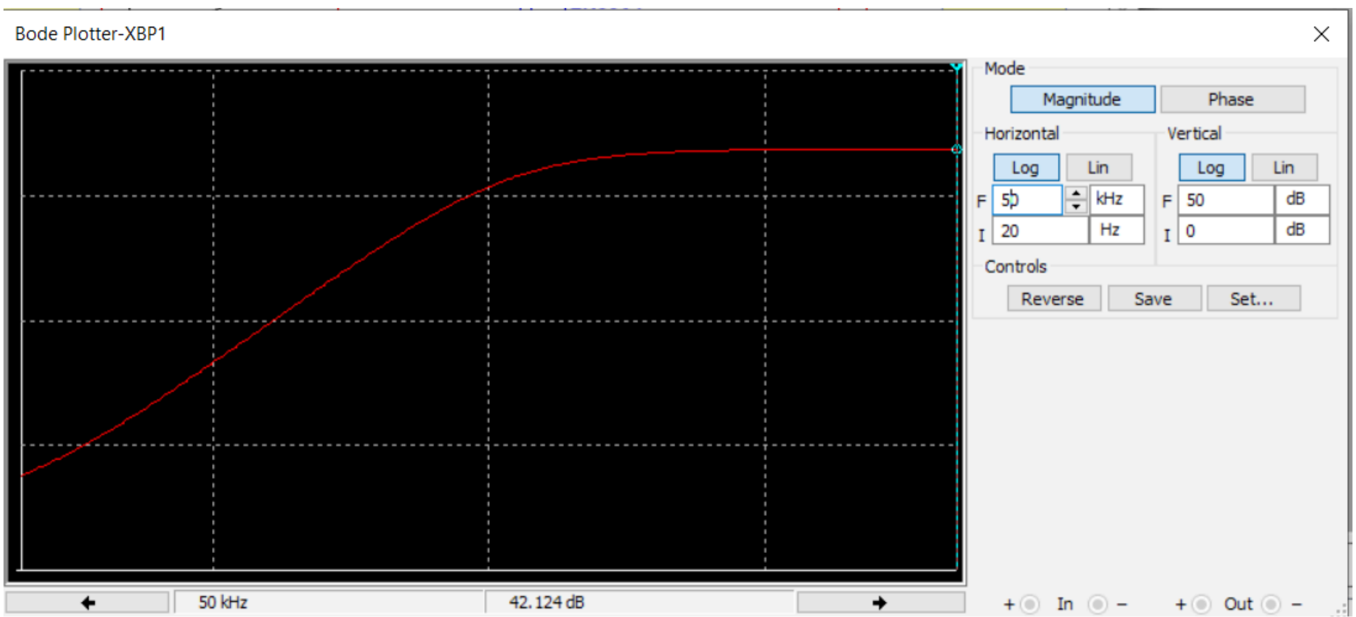
Graph 3: Source, Input and Output voltage Waveforms of the Amplifier of Figure 2, with $R_s = 600\Omega$ and no R_L.


Design Project
Transient
Voltage (V) | Current (A)
Time (s)
V(4) V(vi1)
V(1) V(vs1)
V(5) V(PR2)
I(V1:1) I(current)
V(7) V(PR1)
Activate Windows
Go to Settings to activate Windows.


Design Project
Transient
Voltage (V) | Current (A)
Time (s)
V(4) V(vi1)
V(1) V(vs1)
V(5) V(PR2)
I(V1:1) I(current)
V(7) V(PR1)
Activate Windows
Go to Settings to activate Windows.



Graph 4: Source, Input and Output voltage Waveforms of the Amplifier of Figure 1, with R_s = 600Ω and R_L=1kΩ.



Graph 5: Frequency Response of the 2-stage amplifier

In Conclusion, I chose the Common Emitter amplifier directly coupled with an emitter follower because the Common Emitter amplifier provided the high gain required and the emitter follower allowed a wide range of loads to be driven while maintaining the voltage gain. if I had more time I would focus on the Frequency Response to get the exact desired effect and try to minimize the design to make it more efficient.