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Lab 2: Design of a Three-Stage BJT Amplifier

INTRODUCTION:

In this lab we were given a cascode amplifier with an emitter follower as the third stage to design. The design was to meet certain specifications that will be laid out in the report with the data collected.

CALCULATIONS:

In this lab I used both hand calculations and an excel spread sheet to do most of my calculations. I've attached images of both documents however I've not included the base excel spread sheet as all of the material there was taken from the hand calculations for easier changes.

	C	D	E	F	G	H	I	J	K	L
	Beta	190		gm3	0.6			Rc^2	Rc	c
	Ve1	1		re3	1.666667		min	3597983	7009547	-1.04796E+14
	Vswi	1.5		Rin	3000		max	6366.667		
	Iq	0.015		gm1	0.013417					
	Af	0.983607		re1	74.53309		Q	31.63993		
	Ri3	19418.33								
	Ve2>	1.25	Ve2	1.25						
	Vx	3.55					(1-k)Rb	186929		
	k	0.34					kRb	96296.76		
	N	10								
	Rc	6000		Rc||Ri3	4583.699					
	Ic2	0.000335								
	RB	283225.8			2.012529					
	Re	2981.324								
						0.64				
	Rg	77.72709								
	75.75213									
	Ve3	2.2								
	Re3	33.33333								

Lab # 2

find V_{E4} st. $V_{E4} + V_{CE,sat} \leq V_{E3} - V_{out,0\text{ to peak}}$

$V_{E4} + 0.2 \leq V_{E3} - 1.5$

$0.5 + 0.2 + 1.5 \leq V_{E3}$

$2.2 \leq V_{E3}$

$R_{E3} = \frac{V_{E4}}{I_Q} = 33.3$

$I_a \cdot R_{E3} = V_{cc} \frac{R_{B6}}{R_{B5} + R_{B6}} - 0.7$

$R_{B6} = 10k\Omega$

$R_{B5} = 5.625k\Omega$

$R_{in\,val} = \frac{R_{in}}{R_{in} + R_{rest}}$

Lab #2

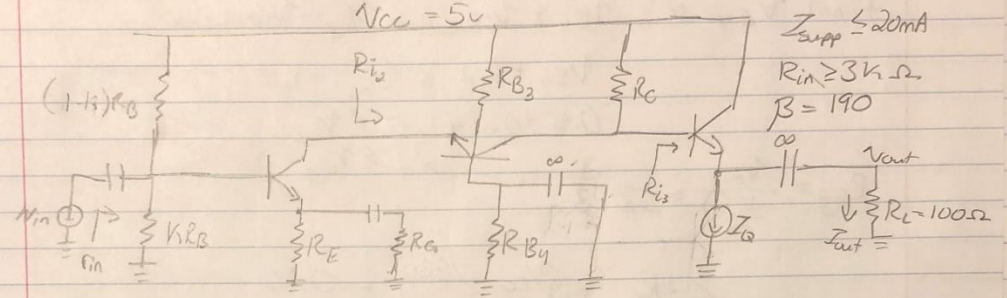
$|A_v| = 30$

$V_{cc} = 5v$

$I_{supp} \leq 20mA$

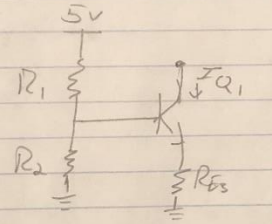
$R_{in} \geq 3k\Omega$

$\beta = 190$



$V_{E_1} \geq 1v \quad V_{E_4} \geq 0.5v \quad V_{swing} \geq 1.5v \quad$ Operation frequency $= 5kHz$

I_Q:



$I_Q \geq \frac{1.5v}{100\Omega} = 15mA$

$I_{C_3} = I_Q \Rightarrow A_F = \frac{V_{out}}{V_{E_3}} = \frac{R_L}{r_{e_3} + R_L} = 0.98$

$g_{m_3} = \frac{I_{C_3}}{V_t} = 0.6 \quad r_{e_3} = 1.667$

$R_{i_3} = (\beta+1)(r_{e_3} + R_L) = 19.418k\Omega$

$V_{E_1} = 1v$

$V_{E_2} \geq V_{E_1} + V_{CE,sat} + V_{i,max} \Rightarrow 1v + 0.2v + \frac{1.5}{30} \geq 1.25$

$V_{C_2} = 1.25$

$V_X = V_{CC} - V_{E_2} - V_{CE,sat} = 3.3v \quad K = \frac{(V_{E_1} + 0.7)}{V_{CC}} = 0.34 \quad N = 10$

$R_C^2(\beta R_{i_3} - R_{in,d}\frac{A_v}{A_F}) + R_C(2\beta R_{i_3} - 3R_{in,d}\frac{A_v}{A_F} - QR_{in,d}) - R_{i_3}^2 R_{in,d}(Q + 2\frac{A_v}{A_F}) \geq 0$

$Q = \frac{NV_X}{kT(1-k)\gamma_{bc}}$

$\min R_C \geq 5.39k\Omega$

$R_C \leq R_{i_3}(\frac{V_X A_F}{V_{sw}} - 2) \leq 6.366k\Omega \quad R_C = 6k\Omega$

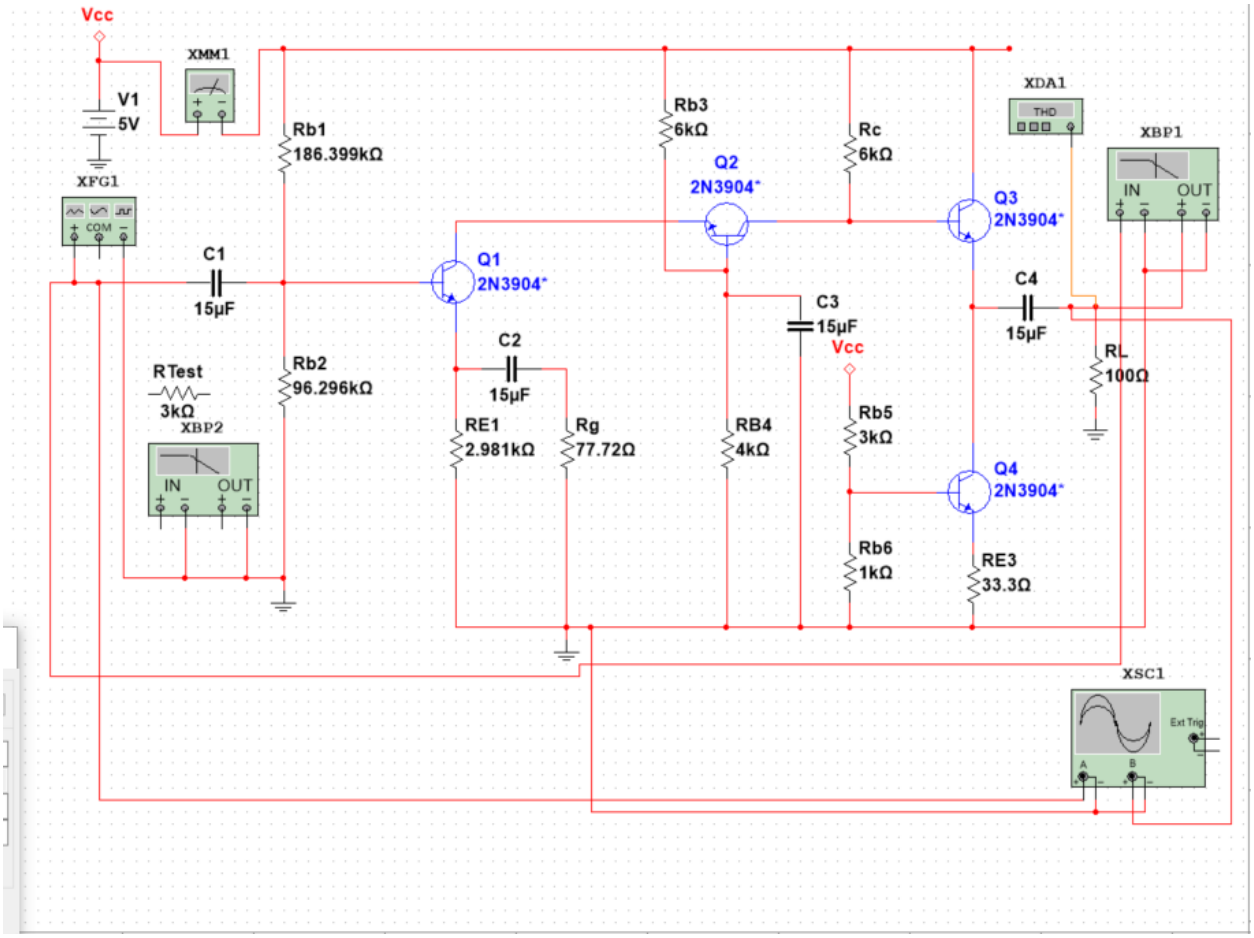
$I_{C_1} = I_{C_2} = \frac{V_X}{R_C + (R_C \| R_{i_3})} \quad R_B = \frac{\beta V_{CC}}{V_{E_1}} = 28k\Omega$

$R_E = \frac{V_E}{I_{C_1}} = 2.98k\Omega \quad R_A = \frac{1}{\frac{1}{\frac{R_C \| R_{i_3} A_F}{A_v} - r_{e_1}} - \frac{1}{R_E}} = 77.72\Omega$

$g_{m_1} = \frac{I_{C_1}}{V_t} = 0.0134$

CIRCUIT:

Below is the circuit used for both the simulations and measurement data collected:

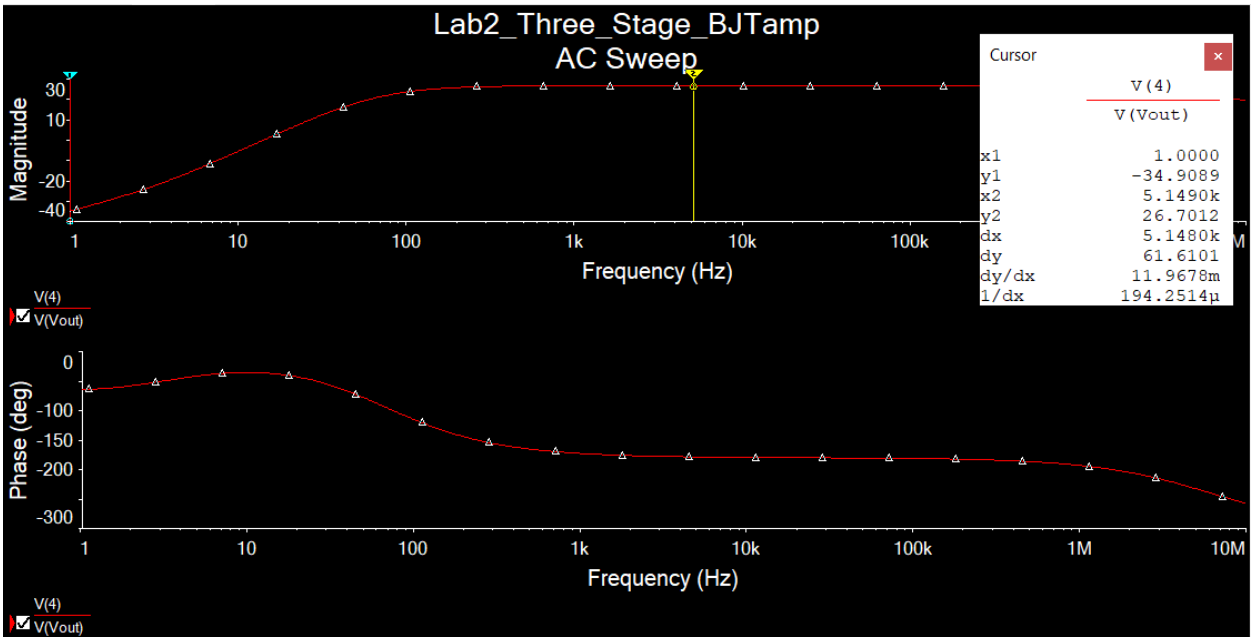


SIMULATION PLOTS:

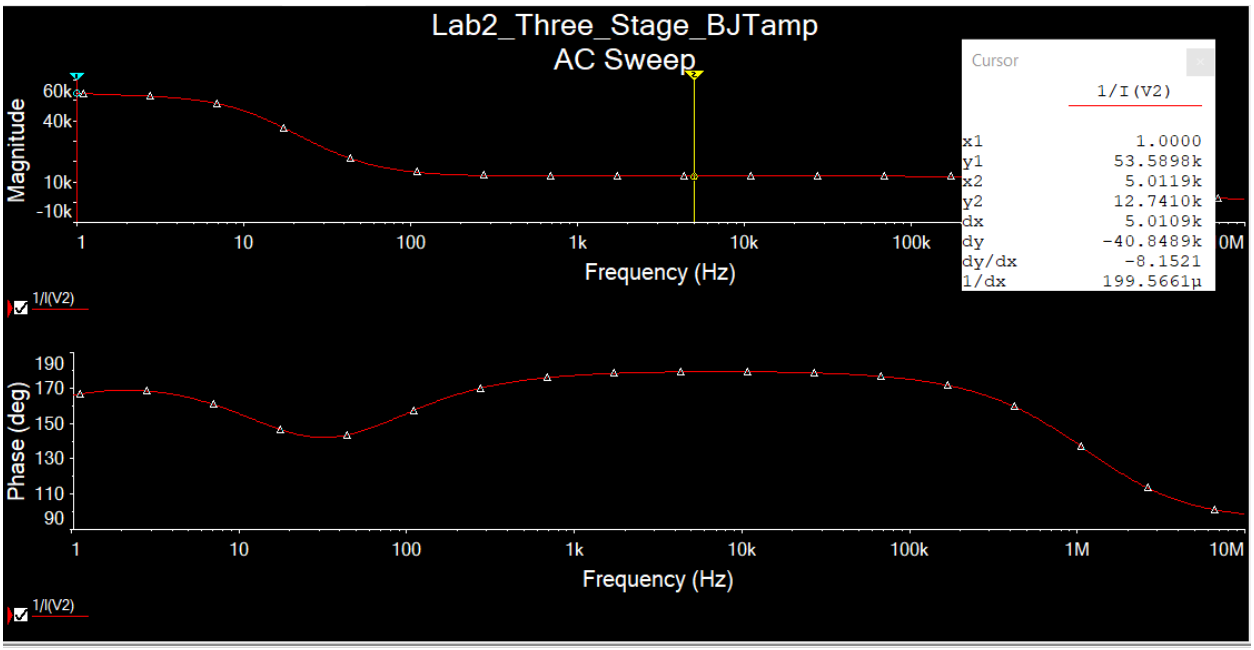
DC Operation Points:

	Variable	Operating point value
1	-I(Q1:C) | I(Ic1)	-283.99462 u
2	-I(Q2:C) | I(Ic2)	-280.69519 u
3	I(Q3:C) | I(Ic3)	12.47339 m
4	I(Q4:C) | I(Ic4)	12.59009 m
5	V(1) | V(Vb1)	1.48957
6	V(5) | V(Vb2)	1.99208
7	V(2) | V(Vb3)	2.61567
8	V(9) | V(Vb4)	1.15949
9	V(8) | V(Vc1)	1.35969
10	V(2) | V(Vc2)	2.61567
11	V(vcc) | V(Vc3)	5.00000
12	V(3) | V(Vc4)	1.88042
13	V(7) | V(Ve1)	856.61648 m
14	V(8) | V(Ve2)	1.35969
15	V(3) | V(Ve3)	1.88042
16	V(10) | V(Ve4)	423.26830 m
17	V(4) | V(Vout)	0.00000e+00

Gain:



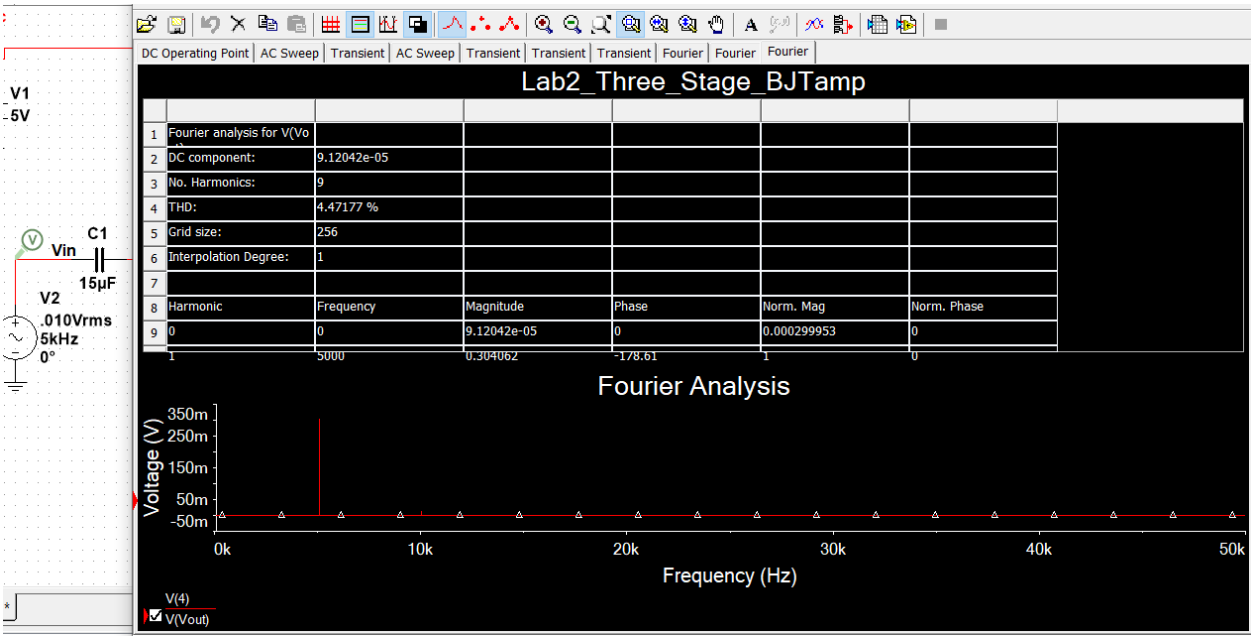
Rin:



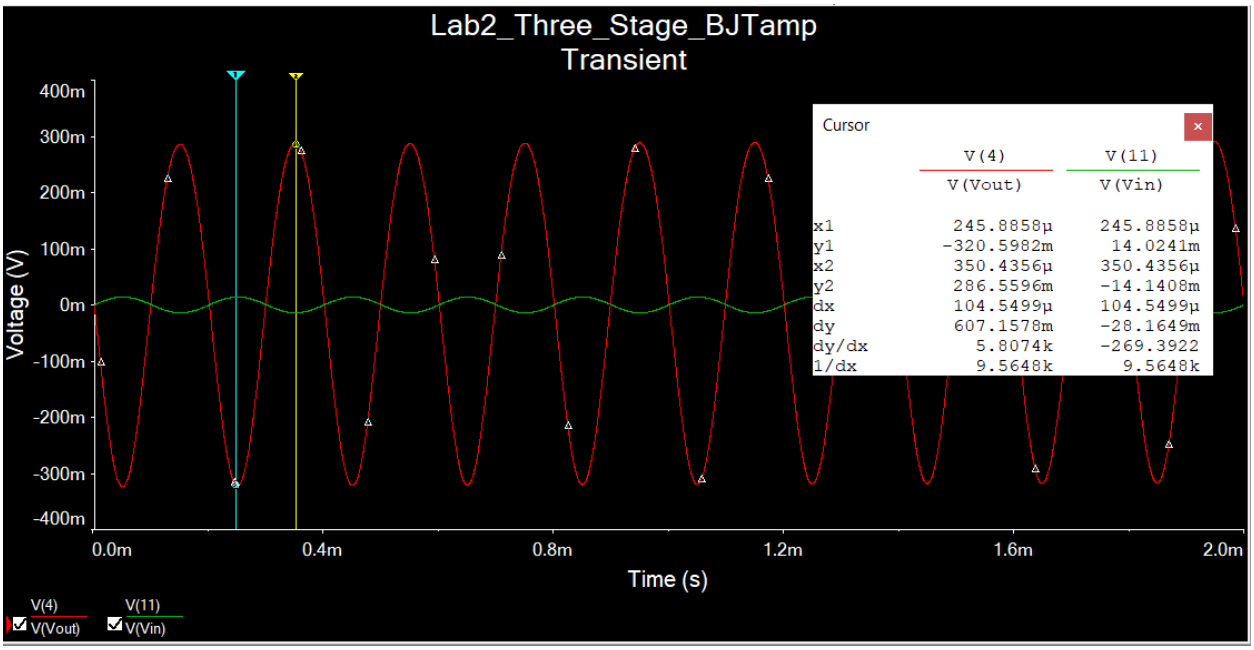
Isupply:

	Variable	Operating point value
1	-I(V1:1)-I(Rb5:1) | I(PR1)	13.39093 m

THD:



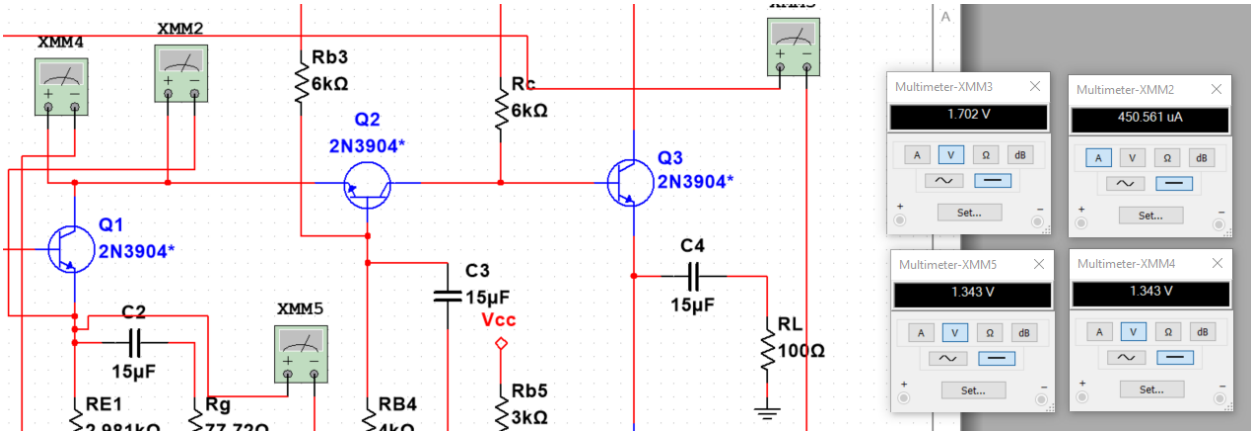
Waveform:



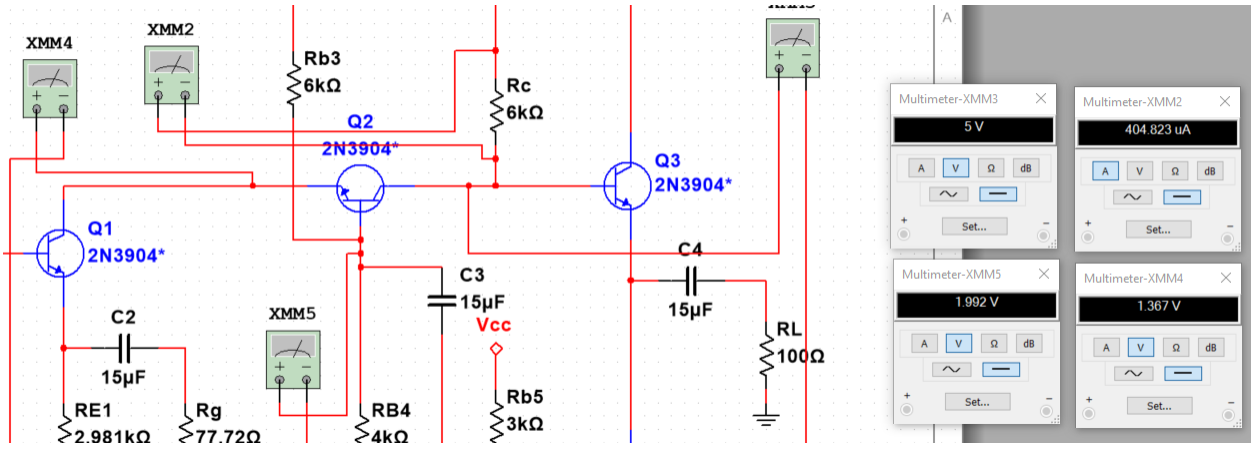
MEASUREMENT PLOTS:

DC Operation points of the relevant information shown below:

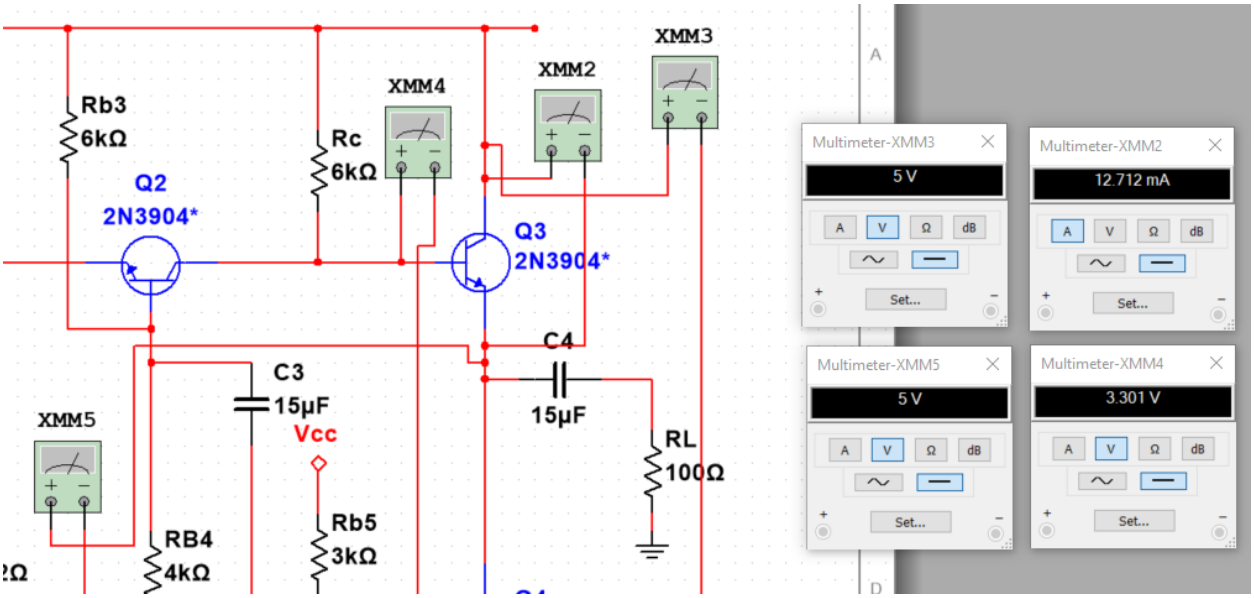
Q1:



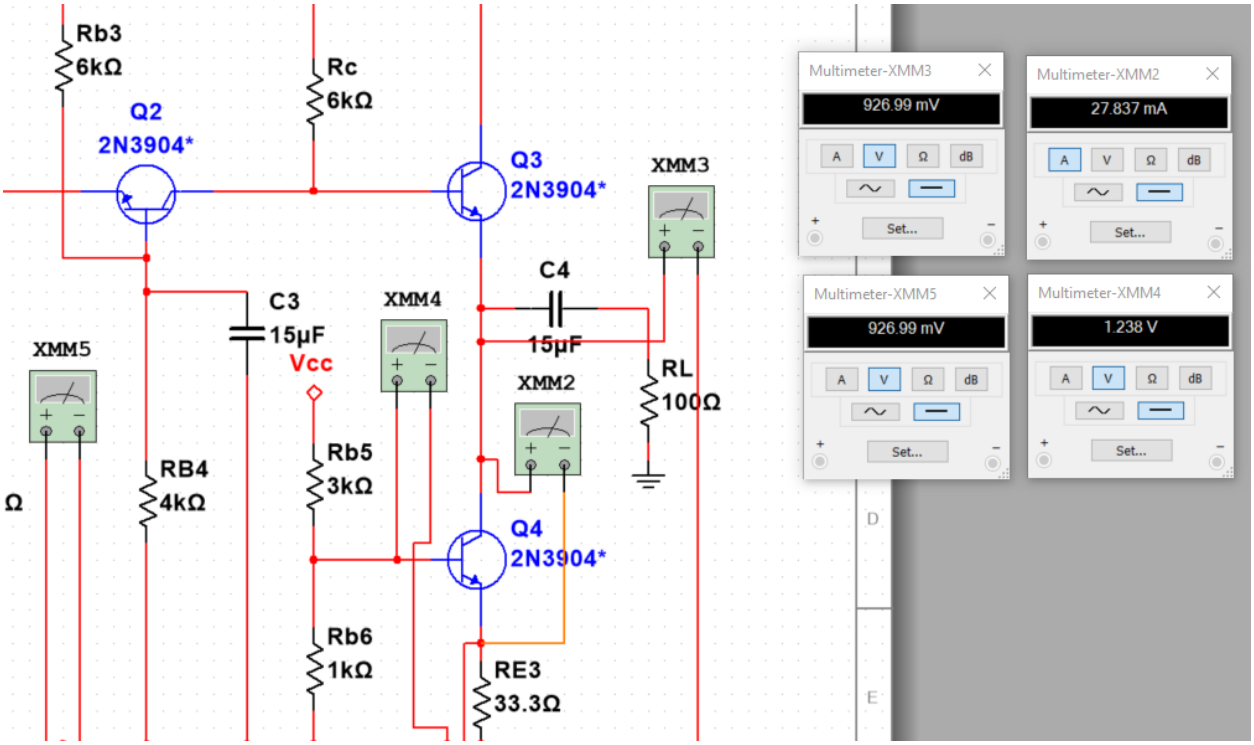
Q2:


XMM4
XMM2
Rb3
6kΩ
Rc
6kΩ
Q2
2N3904*
Q3
2N3904*
Q1
2N3904*
C4
15µF
C3
15µF
Vcc
C2
15µF
XMM5
RL
100Ω
RE1
2.981kΩ
Rg
77.72Ω
RB4
4kΩ
Rb5
3kΩ
Multimeter-XMM3
5 V
Multimeter-XMM2
404.823 uA
Multimeter-XMM5
1.992 V
Multimeter-XMM4
1.367 V

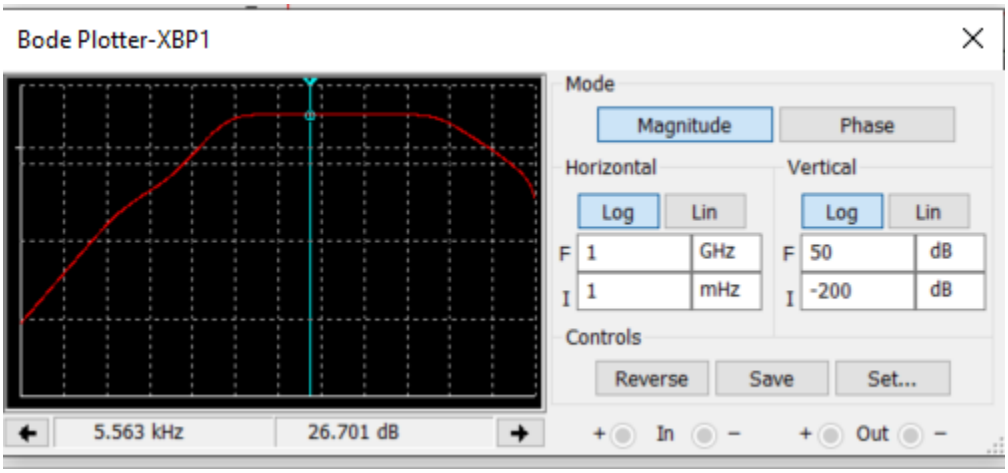
Q3:


XMM3
XMM2
XMM4
Rb3
6kΩ
Rc
6kΩ
Q2
2N3904*
Q3
2N3904*
C4
15µF
C3
15µF
Vcc
XMM5
RL
100Ω
RB4
4kΩ
Rb5
3kΩ
Multimeter-XMM3
5 V
Multimeter-XMM2
12.712 mA
Multimeter-XMM5
5 V
Multimeter-XMM4
3.301 V

Q4:

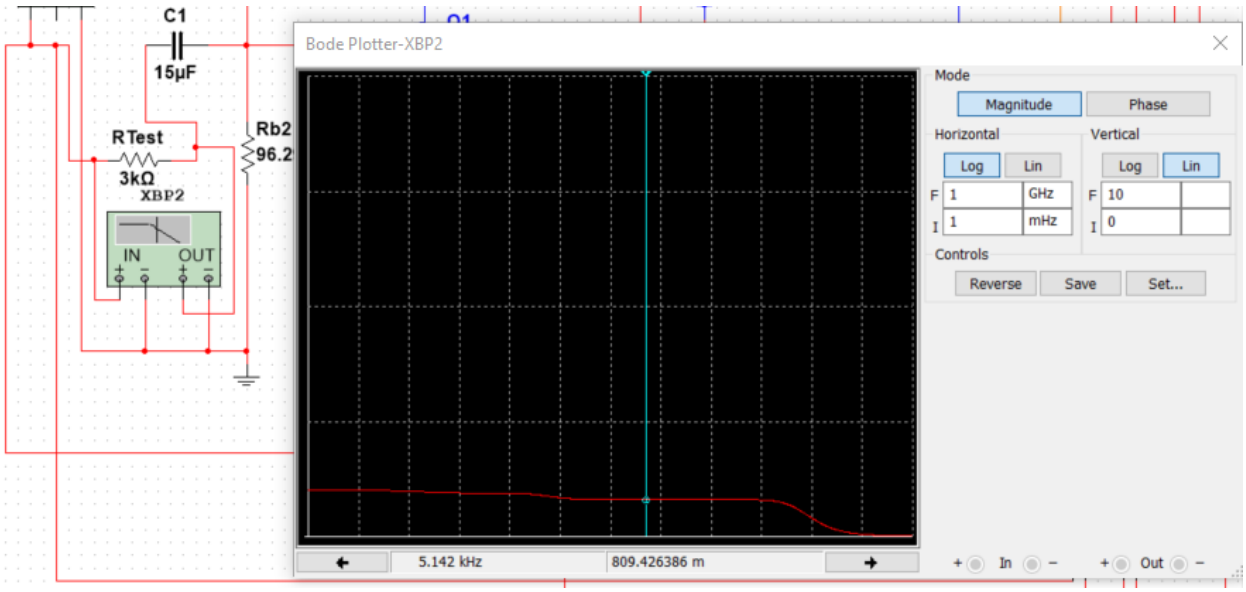


The gain is shown below:



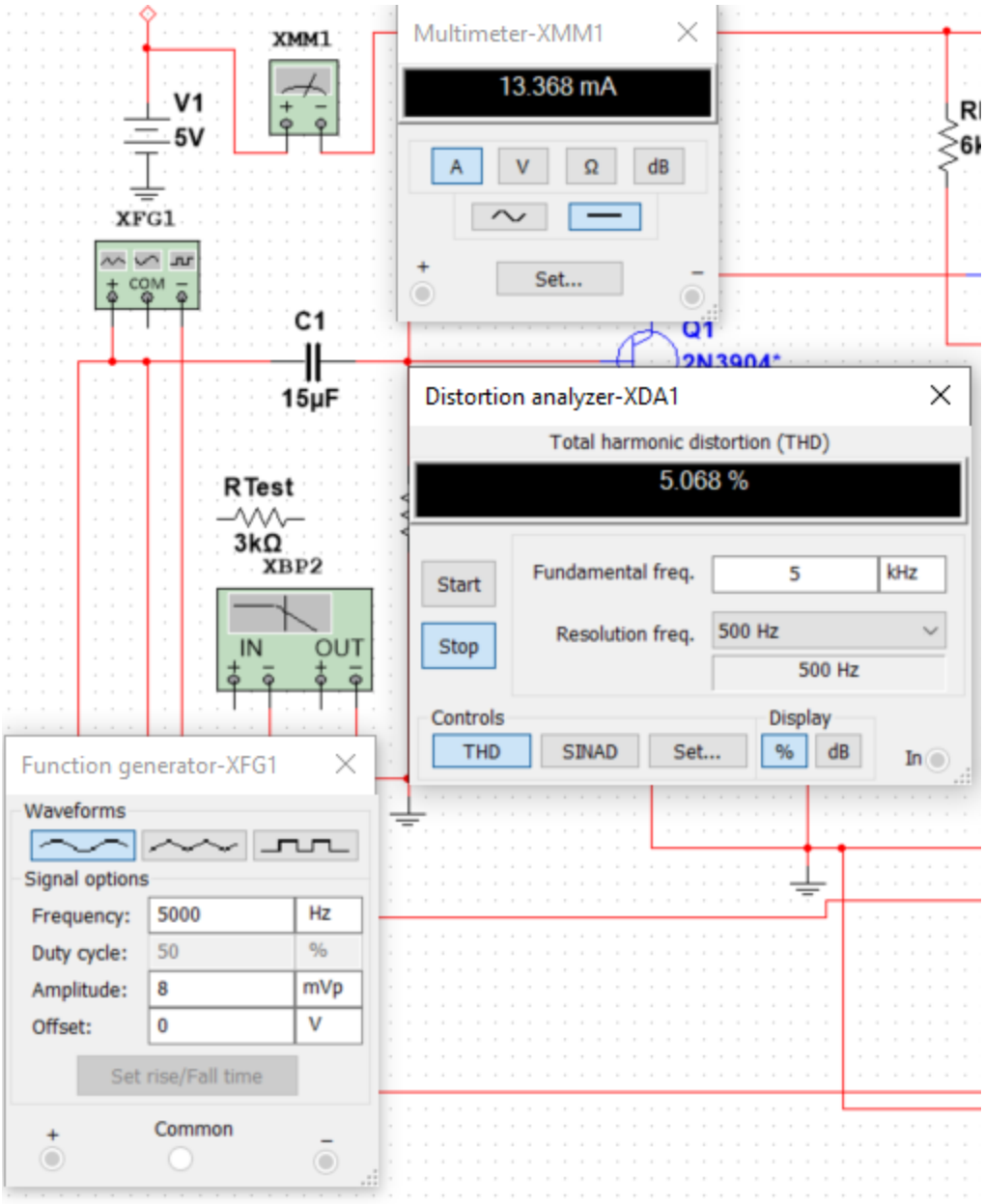
The gain is 26.7 dB

The measurement for Rin is shown below:

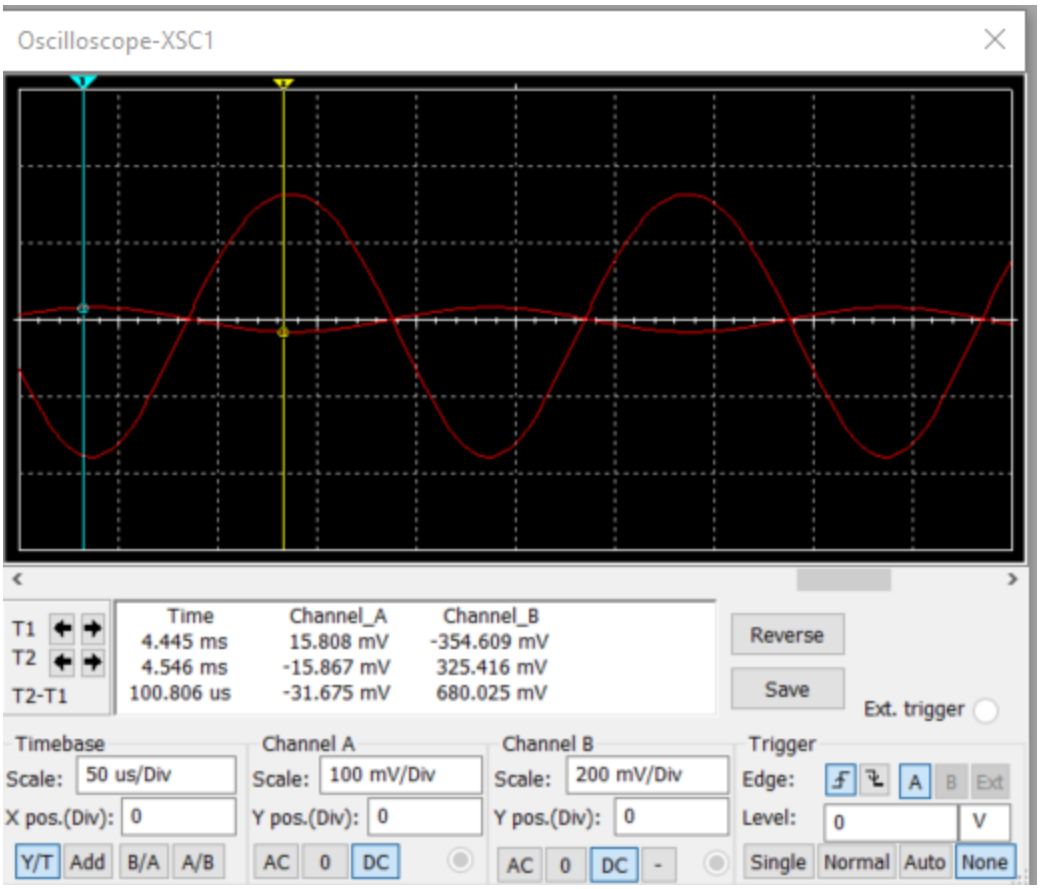


The difference was 0.809. When this value is plugged into the relevant equation from the calculations portion of the lab, the measured value of Rin becomes 12.706kΩ.

Below is the supply current measurement and the input information on the function generator that generated the 5% THD:

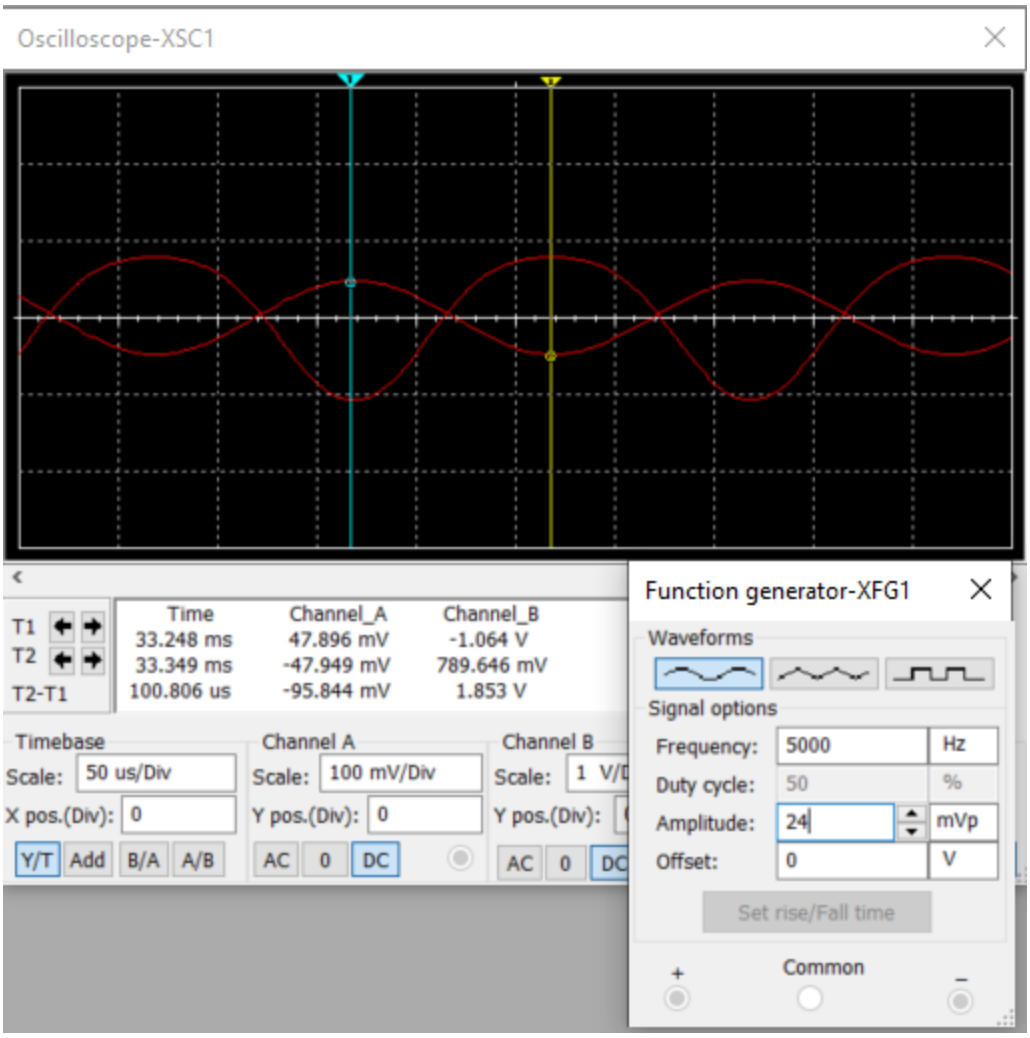


Below is the resultant oscilloscope information given the above information



This is the signal amplitude that resulted from the 5% THD shown in the previous data above. The peak-to-peak swing voltage is approximately 0.7 volts.

Below is the maximum unclipped voltage and relevant waveform information:


Oscilloscope-XSC1
T1
T2
T2-T1
Time
33.248 ms
33.349 ms
100.806 us
Channel_A
47.896 mV
-47.949 mV
-95.844 mV
Channel_B
-1.064 V
789.646 mV
1.853 V
Timebase
Scale: 50 us/Div
X pos.(Div): 0
Y/T
Add
B/A
A/B
Channel A
Scale: 100 mV/Div
Y pos.(Div): 0
AC
0
DC
Channel B
Scale: 1 V/
Y pos.(Div):
AC
0
DC
Function generator-XFG1
Waveforms
Signal options
Frequency: 5000 Hz
Duty cycle: 50 %
Amplitude: 24 mVp
Offset: 0 V
Set rise/Fall time
+
Common
–

Results Analyzed

	Calculated	Simulated	Measured
Vc1	1.25volts	1.3569 v	1.343v
Vc2	2.0125volts	2.6156 v	2.516v
Vc3	5volts	5 v	5v
Vc4	2.2volts	1.88 v	926mv
Vb1	1.7volts	1.4895 v	1.702v
Vb2	2volts	1.99 v	1.992v
Vb3	2.0125volts	2.615 v	3.301v
Vb4	1.25volts	1.159 v	1.238v
Ve1	1volt	0.856 v	1.343v
Ve2	1.25volts	1.3596 v	1.367v
Ve3	2.2volts	1.8804 v	2.6v
Ve4	0.55volts	0.423 v	926mV
Ic1	335uA	283uA	450uA
Ic2	335uA	280uA	404uA
Ic3	14.665mA	12.47mA	12.712mA
Ic4	15mA	12.59mA	27.837mA
Isupply	20mA	13.3903mA	13.368mA
Av	30dB	26.7012dB	26.701dB
Rin	3kΩ	12.741kΩ	12.706kΩ
Output Swing @ 5%	1.5volts	0.606volts	0.680volts

The above data is representative of the circuit operating to produce a gain that is slightly smaller than the required for this lab. The small gain leads to the smaller output swing which is almost half of the value required. These differences are most likely due to poor design choices on my initial base resistors being much higher than they need to be. A point of difference can also be found on the collector voltage for the fourth BJT. This value is most likely to Multisim doing something weird with the capacitor on the branch and causing the value to fluctuate wildly. The value should be 0.7 volts lower than the base voltage on BJT 3 however it’s not close.