Department of Electronics & Telecommunication Engineering

University of Moratuwa

Course: B.Sc. (Eng.), Semester 04	
Subject: Electronics III	Subject code: EN2110
Simulation Assignment: Power Amplifiers	
Names: P.M.N.S. Bandara A.U.P.H. Athukorala S.S. Hettiarachchi	Admission Numbers: 180066F 180051F 180237G
Group: 10	Date of Submission: 25/06/2021

Objectives: To study the behavior of standard types of power amplifiers using simulations.

Software: LTSpice

Note: You may modify the word document accordingly to insert the figures of simulation outputs.

Use the following SPICE directives for the transistor models, BC639 and BC640. These parameters are extracted from: http://ltwiki.org/index.php?title=Standard.bjt.

BC639

```
.MODEL BC639 NPN IS=6.119E-14 NF=0.9948 ISE=5.844f NE=1.469 BF=130.4
IKF=0.8 VAF=54.27 NR=0.9905 ISC=1.342E-13 NC=1.183 BR=14.53 IKR=0.2049
VAR=30 RB=0.5 IRB=1E-06 RBM=0.5 RE=0.1114 RC=0.082 XTB=0 EG=1.11 XTI=3
CJE=1.234E-10 VJE=0.6917 MJE=0.338 TF=6.543E-10 XTF=223.8 VTF=1.892 ITF=10
CJC=3.49E-11 VJC=0.5 MJC=0.388 XCJC=0.15 TR=10n FC=0.9232
```

BC640

```
.MODEL BC640 PNP IS=6.1530E-14 NF=0.9911 ISE=1.382E-16 NE=1.089 BF=150.8
IKF=1.225 VAF=105.4 NR=0.9965 ISC=6.480f NC=1.022 BR=8.074 IKR=0.3627
VAR=18.20 RB=2 IRB=1E-06 RBM=2 RE=5.562E-02 RC=0.1449 XTB=0 EG=1.11 XTI=3
CJE=1.157E-10 VJE=0.7300 MJE=0.3751 TF=8.666E-10 XTF=1.231 VTF=3.008
ITF=0.4581 CJC=5.264E-11 VJC=0.6591 MJC=0.4533 XCJC=0.4401 TR=2.75E-07
FC=0.9427
```

PROCEDURE:

Simulation 1: Class '**A**' Amplifier

a) Connect the circuit as shown in figure 1 and paste your circuit diagram.

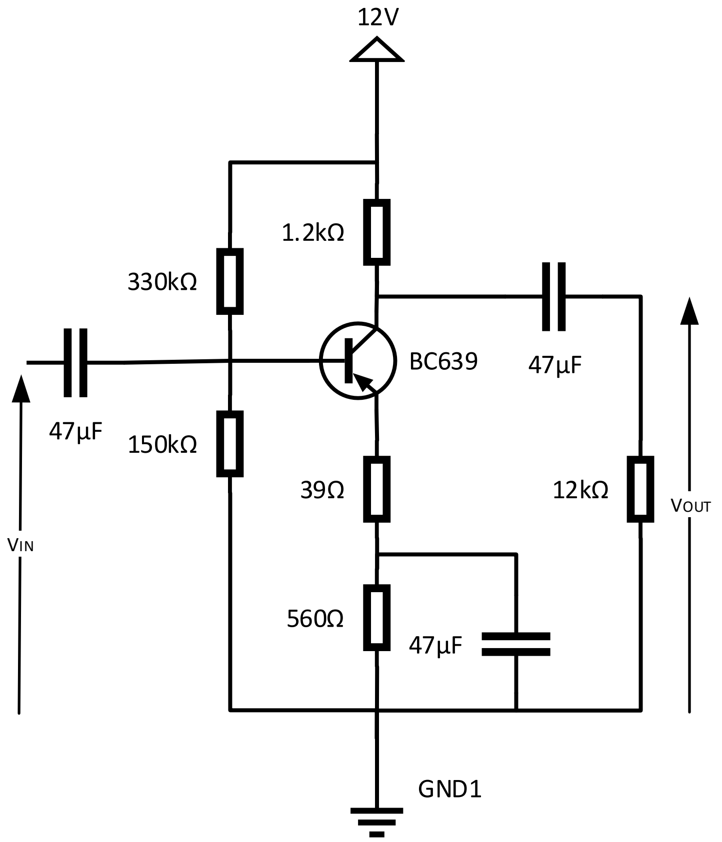


Figure1.1

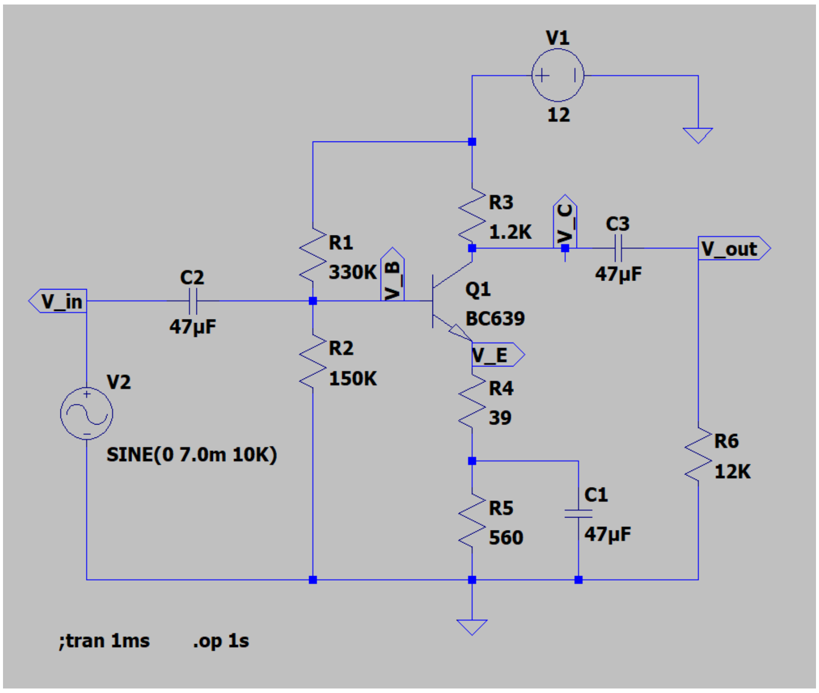
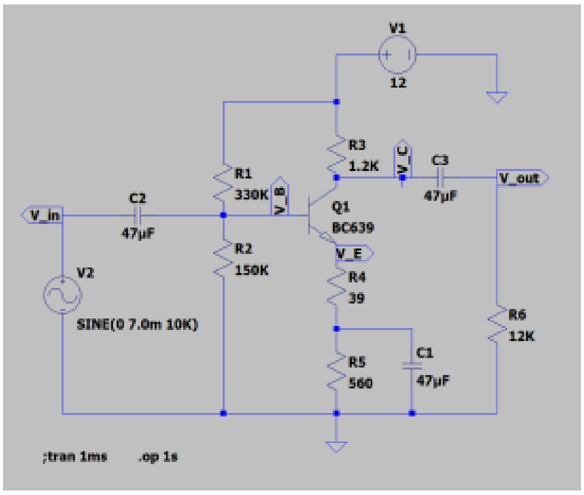


Figure 1.2: LTSpice based circuit diagram

b) Using the operating point simulations, obtain the DC bias voltages

$$V_B = 2.0519V$$
$$V_E = 1.42698V$$
$$V_C = 9.16103V$$

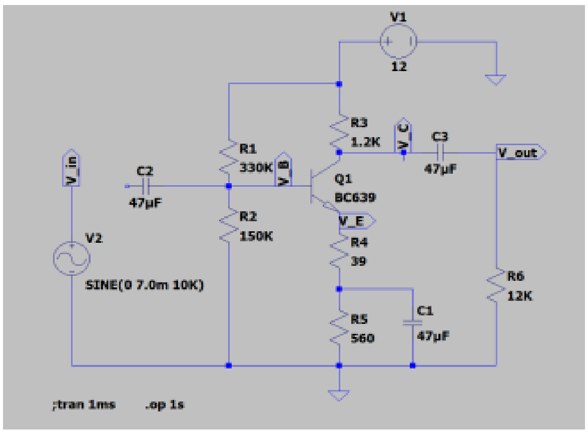
c) Paste a screen capture of operating point simulation output window.




```
* C:\Users\HP\Documents\LTspiceXVII\Simulation1.asc
       --- Operating Point ---

V(n001):      12              voltage
V(v_b):       2.0519          voltage
V(v_c):       9.16103         voltage
V(v_e):       1.42698         voltage
V(n002):      1.33408         voltage
V(v_out):     5.16682e-012    voltage
V(v_in):      0               voltage
Ic(Q1):       0.00236581      device_current
Ib(Q1):       1.64664e-005    device_current
Ie(Q1):       -0.00238228     device_current
I(C3):        4.30568e-016    device_current
I(C2):        9.64393e-017    device_current
I(C1):        6.27016e-017    device_current
I(R6):        4.30568e-016    device_current
I(R5):        0.00238228      device_current
I(R4):        0.00238228      device_current
I(R3):        0.00236581      device_current
I(R2):        1.36793e-005    device_current
I(R1):        3.01458e-005    device_current
I(V2):        9.64393e-017    device_current
I(V1):        -0.00239596     device_current
```

Figure 1.3: Operating point simulation output window (when input signal source is connected: including small internal current in V2 signal source)




```
* C:\Users\HP\Documents\LTspiceXVII\Simulation1.asc
       --- Operating Point ---

V(n001):      12              voltage
V(v_b):       2.0519          voltage
V(v_c):       9.16103         voltage
V(v_e):       1.42698         voltage
V(n002):      1.33408         voltage
V(v_out):     5.16682e-012    voltage
V(nc_01):     9.64348e-005    voltage
V(v_in):      0               voltage
Ic(Q1):       0.00236581      device_current
Ib(Q1):       1.64664e-005    device_current
Ie(Q1):       -0.00238228     device_current
I(C3):        4.30568e-016    device_current
I(C2):        9.64348e-017    device_current
I(C1):        6.27016e-017    device_current
I(R6):        4.30568e-016    device_current
I(R5):        0.00238228      device_current
I(R4):        0.00238228      device_current
I(R3):        0.00236581      device_current
I(R2):        1.36793e-005    device_current
I(R1):        3.01458e-005    device_current
I(V2):        0               device_current
I(V1):        -0.00239596     device_current
```

Figure 1.4: Operating point simulation output window (when input signal source is isolated: no current is drawn from the input signal source)

Figure 1.3 and Figure 1.4 clearly indicates that the connection of the input signal source to the circuit has no effect on the dc biasing of the class A amplifier.

d) Using the "signal" block, adjust the input signal at 10 kHz to the maximum output possible without clipping or distortion. Use probe options to measure and note down the maximum input & output values.

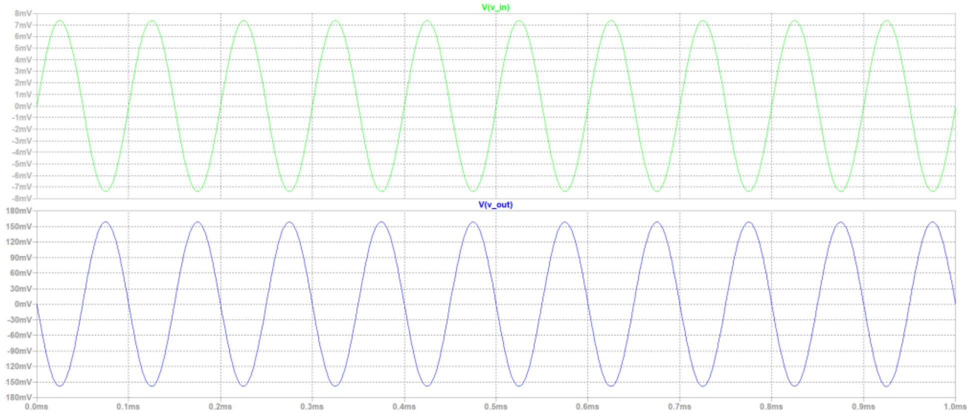


Figure 1.5: Input and output signals when $V_{I\text{-}Peak}$=7.4 mV

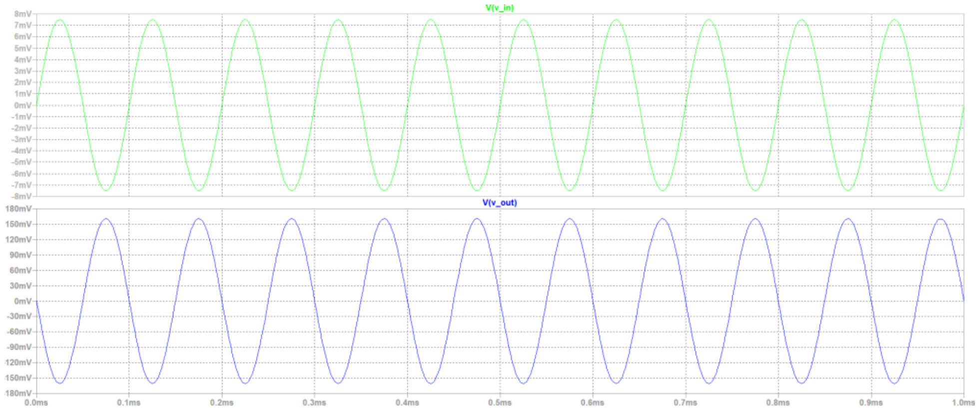


Figure 1.6: Input and output signals when $V_{I\text{-}Peak}$=7.5 mV

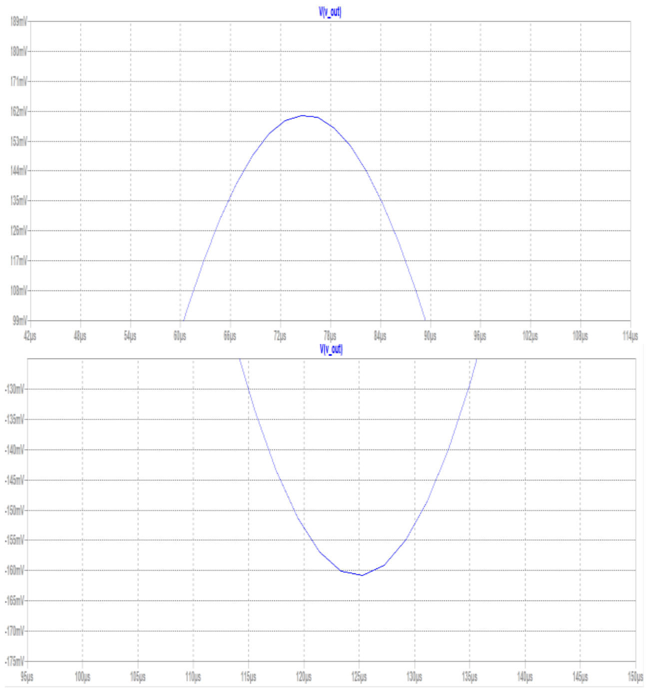


Figure 1.7: Upper peak (average value of 160.67 mV) and lower peak (average value of -160.81 mv) of the output signal when $V_{I\text{-}Peak}$=7.5 mV

Figure 1.7 conveys that, when $V_{I\text{-}Peak}$=7.5 mV, the upper and lower peaks of the output signal do not refer the output signal to be sinusoidal. This indicates that the output signal is seemingly distorted when $V_{I\text{-}Peak}$=7.5 mV. Therefore, the maximum values at which the output signal is not distorted or clipped are,

$$V_I\ (\text{max}) = 7.4\ \text{mV}$$
$$V_O\ (\text{max}) = 158.68\ \text{mV}$$

e) Paste the simulation output waveforms in both Y-T and X-Y modes.

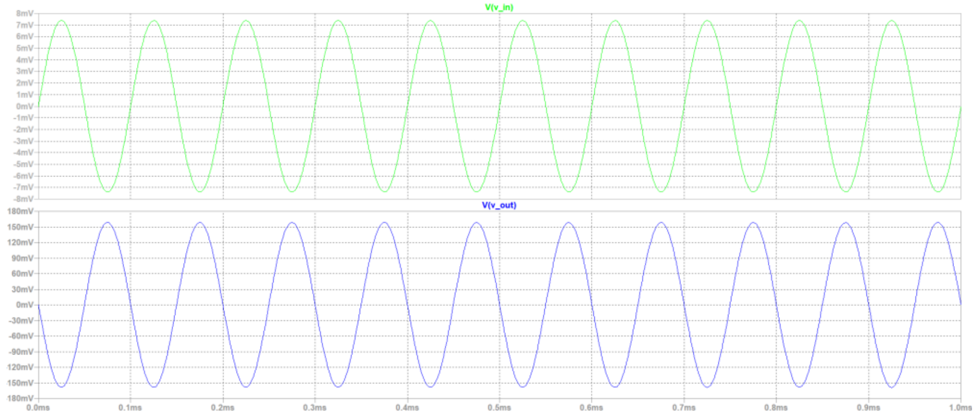


Figure 1.8: V_I (V) vs time (s) and V_O (V) vs time (s) when $V_{I\text{-}Peak}$=7.4 mV (in Y-T simulation format)

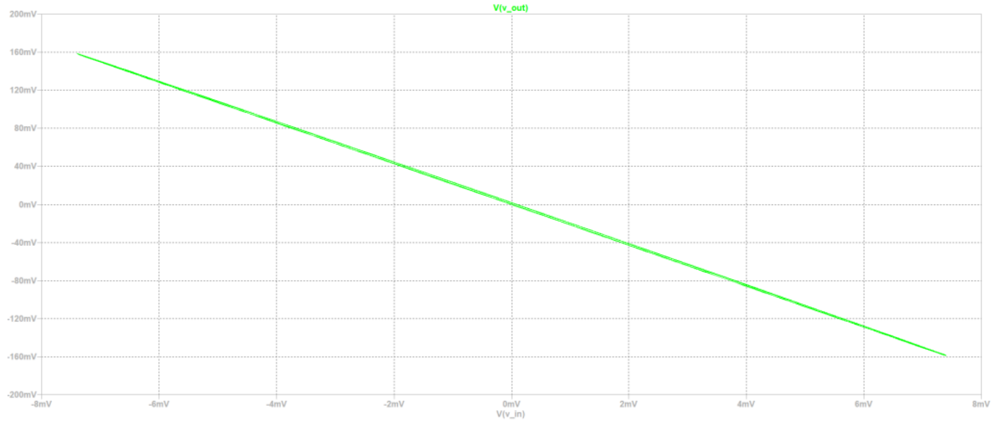


Figure 1.9: V_O (V) vs V_I (V) when $V_{I\text{-}Peak}$=7.4 mV (in X-Y simulation format)

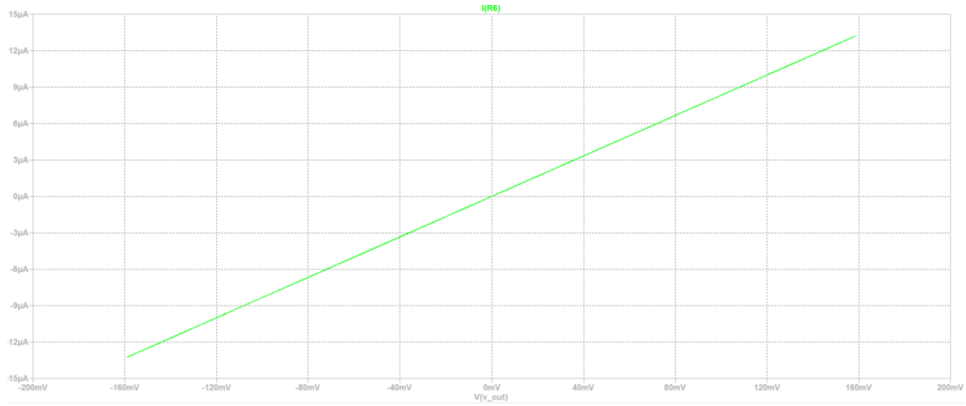


Figure 1.10: I_O (A) vs V_O (V) when $V_{I\text{-}Peak}$=7.4 mV (in X-Y simulation format)

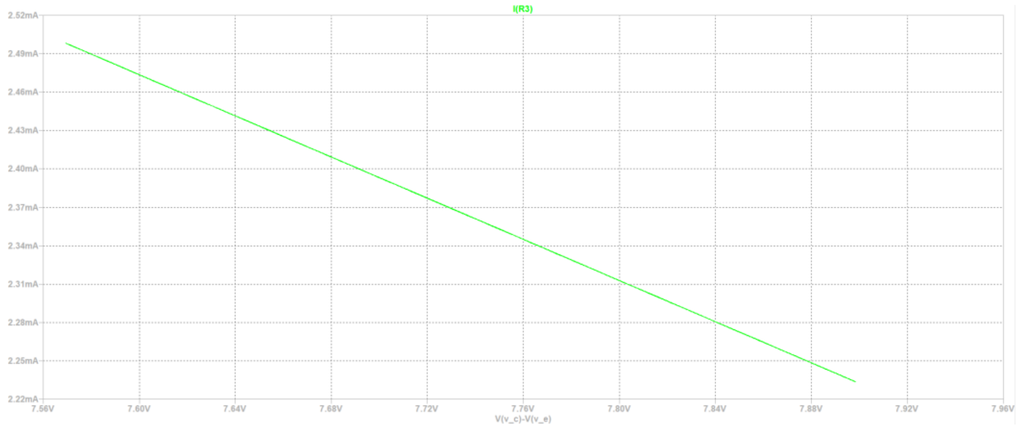


Figure 1.11: I_C (A) vs ($V_C - V_E$) (V) when $V_{I\text{-}Peak}$=7.4 mV (in X-Y simulation format)

f) Calculate the efficiency of the amplifier at this input level.

$$Efficiency\ \% = \frac{Amplifier's\ output\ ac\ power\ delivered\ to\ the\ load}{Total\ power\ supplied\ by\ the\ DC\ power\ supply} * 100$$

$$Efficiency = \frac{P_{L,ac}}{P_{T,in}} * 100$$

Since the current through R1 is negligible (compared to I_C),

$$Efficiency = \frac{{V^2}_{O-Peak}/_{2R_L}}{V_{CC} * I_C} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots[1]$$

$$Efficiency = \frac{(158.68 * 10^{-3})^2/_{2 * 12 * 10^3}}{12 * 2.37 * 10^{-3}} * 100$$

$$Efficiency = 3.689 * 10^{-3}\%$$

g) Reduce the input signal to the half of the signal level of step(c). Measure and note down the voltage values.

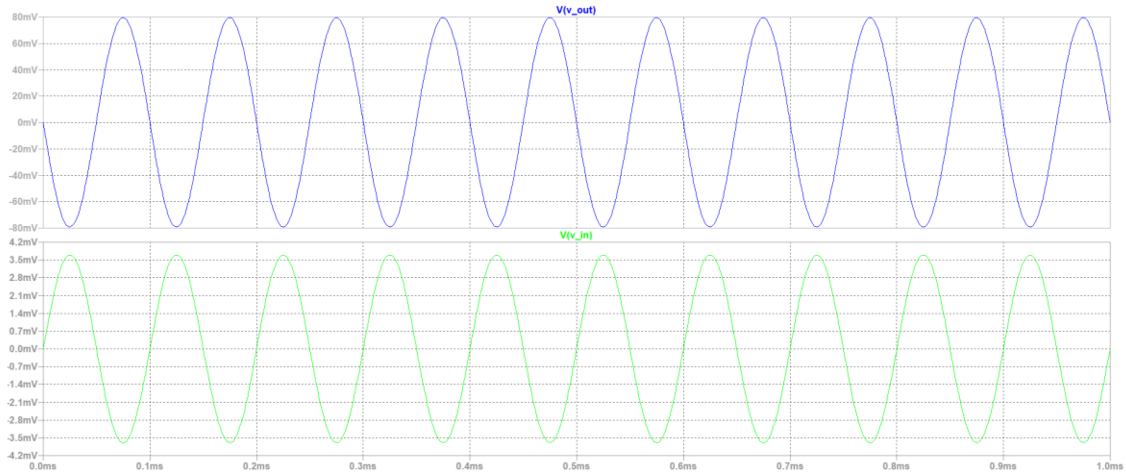


Figure 1.12: V_I (V) vs time (s) and V_O (V) vs time (s) when $V_{I\text{-}Peak}$=3.7 mV

New input signal voltage (peak value) = $\frac{7.4\ mV}{2}$ = 3.7 mV

Corresponding output signal voltage (peak value) = 79.38 mV

h) Calculate the efficiency of the amplifier at this input signal level.

$$Efficiency = \frac{{V^2}_{O-Peak}/_{2R_L}}{V_{CC} * I_C} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots[1]$$

$$Efficiency = \frac{(79.48 * 10^{-3})^2/_{2 * 12 * 10^3}}{12 * 2.37 * 10^{-3}} * 100$$

$$Efficiency = 9.255 * 10^{-4}\%$$

Simulation 2: Class ‘**B**’ Amplifier

Class ‘B’ push-pull amplifier with two symmetric power supplies. (complementary symmetry)

a) Connect the push-pull (complementary symmetry) class ‘B’ power amplifier shown in figure 2. Paste your circuit diagram.

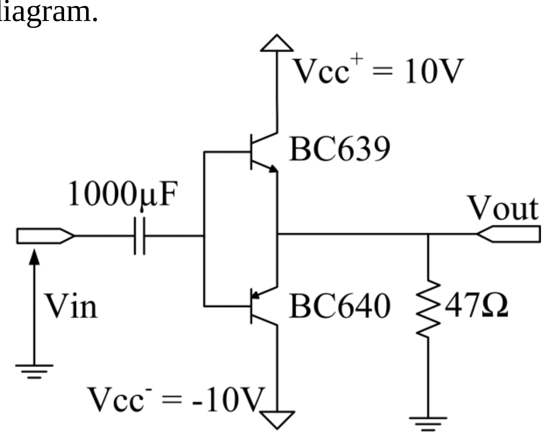


Figure 2

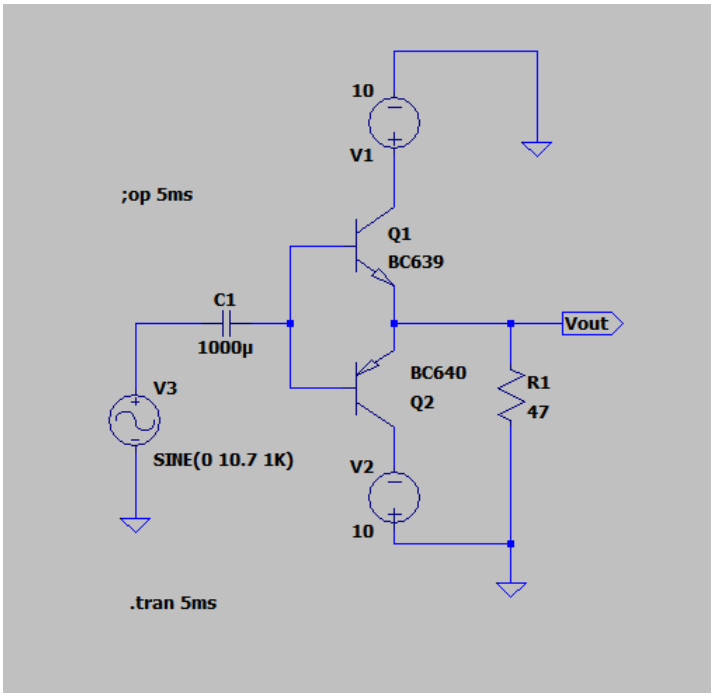


Figure 2.1: Circuit Diagram

b) Increase the input voltage to the clipping limit & measure the maximum input and output values

V_I (max) = 10.70V
V_O (max) = 9.92V

c) Calculate the efficiency of the amplifier.

We can write the output signals $V_{out}(t)$ and $I_{out}(t)$ as follows,

$$V_{out}(t) = V_0 + v_{out}(t)$$

$$I_{out}(t) = I_0 + i_{out}(t)$$

(V_0,I_0) representing the biasing and ($v_{out}(t)$,$i_{out}(t)$) representing the AC component, the alternative signals can be rewritten as,

$$v_{out}(t) = V_{AC} + sin\,(\omega t)$$

$$i_{out}(t) = I_{AC} + sin\,(\omega t)$$

The dissipated power in the load P_{RL} is,

$$P_{RL} = \frac{V_{AC}^2}{2R_L}$$

The instant power p(t) dissipated in both transistors is,

$$p(t) = (V_{supply} - v_{out}(t)) \text{ x } i_{out}(t)$$

The average power P_A dissipated in the transistors is,

$$P_A = \frac{2V_{supply}V_{AC}}{\pi R_L} - \frac{V_{AC}^2}{2R_L}$$

If we take total power as P_{total} delivered by the supply , it will be the sum of the power dissipated in both the load and the transistors P_{RL}+P_A ,

$$P_{total} = \frac{2V_{supply}V_{AC}}{\pi R_L}$$

So, the efficiency can be taken from,

$$\text{Efficiency} = \frac{\pi}{4} \text{x} \frac{V_{AC}}{V_{supply}}$$

$$\text{Efficiency} = \frac{\pi}{4} \text{x} \frac{V_{out-peak}}{V_{CC}}$$

$$= \frac{\pi \text{ x } 9.92 \text{ V}}{4 \text{ x } 10 \text{ V}}$$

$$= 77.91\%$$

d) Observe the cross over distortion at the output, insert Y-T and X-Y mode output plots.

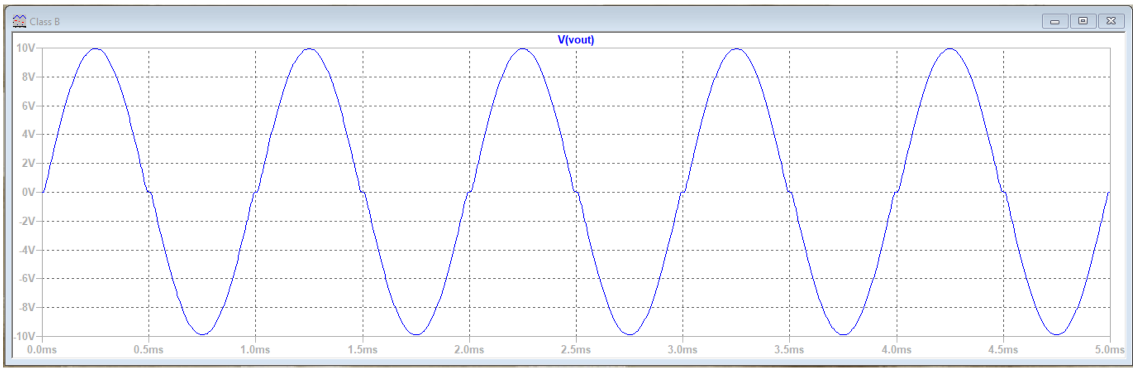


Figure 2.2: Y-T mode output

(V_{out}) vs time

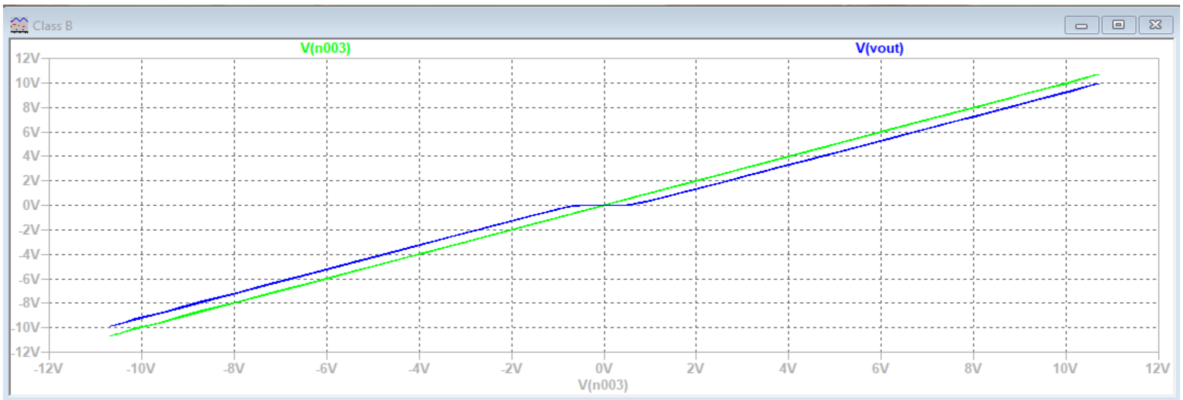


Figure 2.3: X-Y mode output

(V_{out}) vs V_{in}

e) Comment on your observations in (d).

We can observe a crossover distortion in the Y-T mode output where the output voltage is plotted against the time in part (d). When we plot the output voltage (V_{out}) against the input voltage (V_{in}), we can have a clear understanding of how this happen. From the X-Y mode output plot, we can see that only a part of the plot is linear.

In class B amplifier, the npn and pnp transistors are working in the cutoff region. So, when the input signal is lower than the +0.7 V threshold value, the npn transistor does not conduct the signal. This behavior creates an interval between -0.7 V and +0.7 V of 1.4 V where no signal can be conducted between the base and emitter branches. This creates the crossover distortion observed in the part (d).

Simulation 3: Class ‘**AB**’ Amplifier

a) Connect the offset complementary amplifier circuit as shown in figure 3. Paste your circuit diagram.

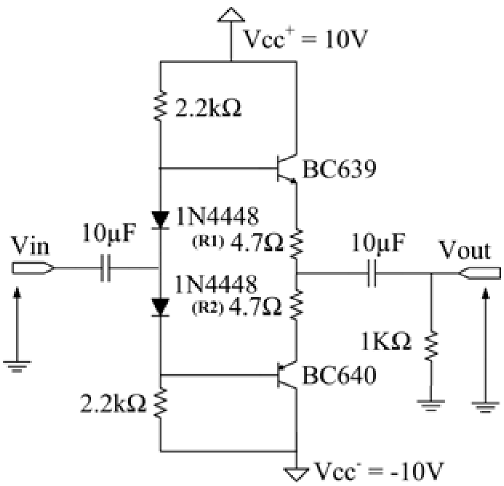


Figure 3

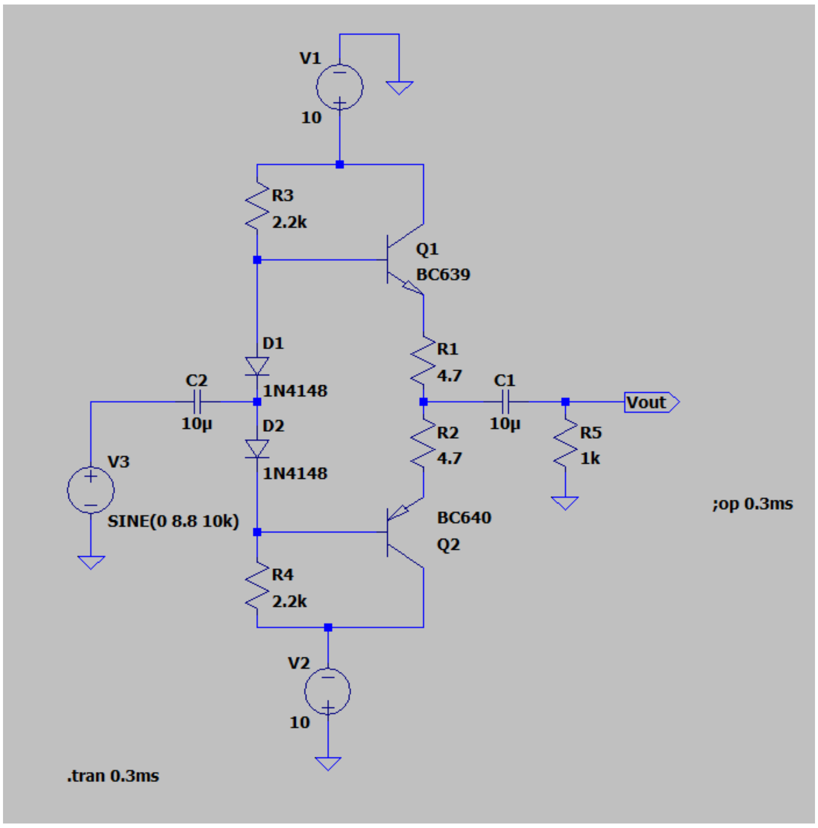


Figure 3.1: Circuit Diagram

b) Using the signal block, adjust the 10 kHz input signal to the maximum output possible without clipping. Adjust R_1 and R_2 to remove the cross over distortion occurring at the output. Measure and note down the maximum voltages.

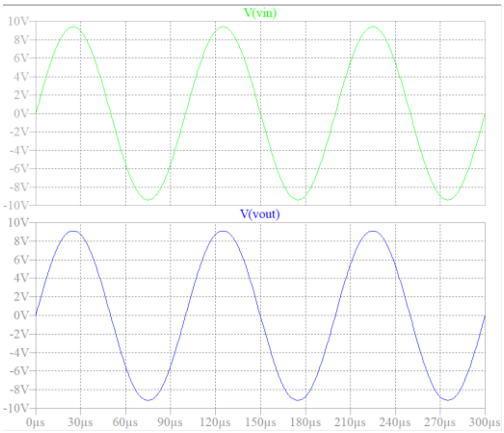


Figure 3.2: 9.4V input

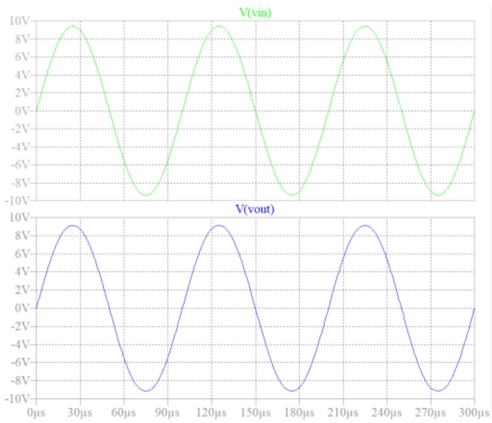


Figure 3.3: 9.5V input

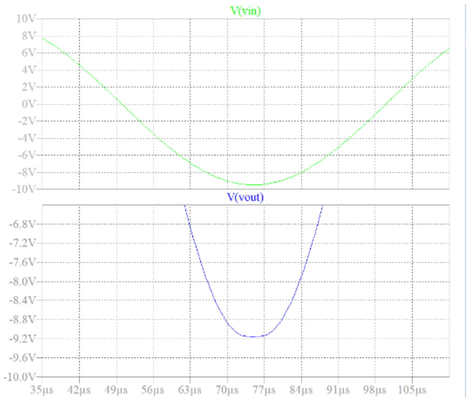


Figure 3.4: voltage clipping at 9.5V

When changing the R1 and R2, cross over distortion was not occurring at the output. Clipping is started at 9.5V but distortions are started at 8.9V.

V_I (max) = 9.4V $\qquad$ V_O (max) = 9.076V

c) Calculate the efficiency of the amplifier at this input signal level.

$$Efficiency(\eta) = \frac{\pi}{4} \times \frac{V_{AC}}{V_{supply}} \times 100\%$$

$$Efficiency(\eta) = \frac{\pi}{4} \times \frac{9.076\ V}{10\ V} \times 100\%$$

$$Efficiency(\eta) = 71.28\ \%$$

d) Reduce the output to about 60% of the maximum output voltage. Measure and note down the following voltages.

$New\ Output\ Voltage = 9.076\ \times 0.6 = 5.44$ V
$New\ Input\ Voltage = 5.54$ V

V_I = 5.54V $\qquad$ V_O= 5.44V

e) Calculate the efficiency of the amplifier at this input signal level.

$$Efficiency(\eta) = \frac{\pi}{4} \times \frac{5.44\ V}{10\ V} \times 100\%$$

$$Efficiency(\eta) = 42.43\%$$

f) Remove the input signal. Using operating point analysis, measure and note down the DC voltages V_{B1}, V_{B2} and V_E

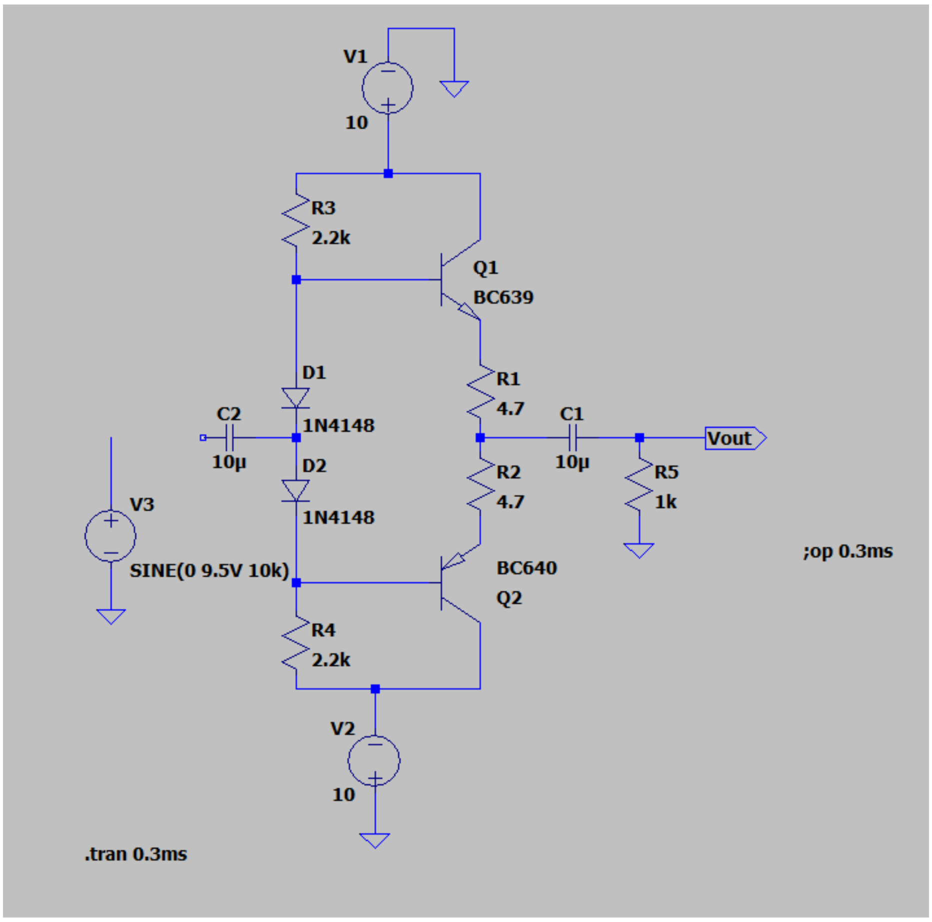


Figure 3.5: Removing the input signal

V_{B1} = 651.181 mV V_{B2} = -652.569 mV

V_{E1} = 16.163 mV V_{E2} = -17.9813 mV

```
       --- Operating Point ---

V(n002):        0.651181       voltage
V(n004):        -0.00069372    voltage
V(n007):        -0.652569      voltage
V(n001):        10             voltage
V(n008):        -10            voltage
V(n005):        -0.000909041   voltage
V(n006):        -0.0179814     voltage
V(n003):        0.0161633      voltage
V(vout):        -9.09041e-018  voltage
V(vin):         0              voltage
Ic(Q2):         -0.0036088     device_current
Ib(Q2):         -2.36061e-005  device_current
Ie(Q2):         0.00363241     device_current
Ic(Q1):         0.00360817     device_current
Ib(Q1):         2.42367e-005   device_current
Ie(Q1):         -0.00363241    device_current
I(C2):          -6.9372e-021   device_current
I(C1):          9.09041e-021   device_current
I(D2):          0.00422523     device_current
I(D1):          0.00422523     device_current
I(R5):          -9.09041e-021  device_current
I(R1):          0.00363241     device_current
I(R2):          0.00363241     device_current
I(R4):          0.00424883     device_current
I(R3):          0.00424946     device_current
I(V1):          -0.00785764    device_current
I(V3):          -6.9372e-021   device_current
I(V2):          -0.00785764    device_current
```

Figure 3.6: Operating point simulation window