– EHB 335E – ANALOG ELECTRONICS – 11219 –

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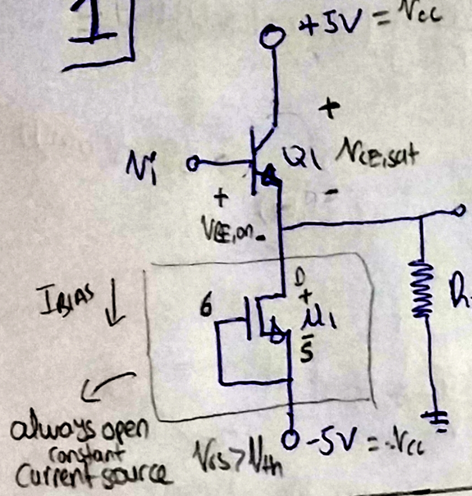
EHB-335E / HMW#4

1)



$V_{BE,on} = 0.7V$

$V_{CE,sat} = 0.2V$

$V_{th} = -1.8V$

$k_n = \frac{1}{2}\mu_n C_{ox} = \frac{12 mA}{V^2}$

$V_A = \infty$, $\lambda = 0$ } no transistor output impedance

a) $V_{CC} - V_{CE,sat} = V_{o,max}$ (At the edge of saturation)

$-V_{CC} + V_{OV1} = V_{o,min_1}$ (At the edge of triode) $V_{DS} = V_{OV}$

OR

$-I_{BIAS}R_L = V_{o,min_2}$ (Q_1 off)

$$\Rightarrow \boxed{V_{o,max} = 5V - 0.2V = 4.8V};$$

$$I_{BIAS} = k_n(\overset{0}{V_{GS}} - V_{th})^2 = \left(12\frac{mA}{V^2}\right)\cdot(1.8V)^2 = 12\cdot(1.8)^2\ mA = 38.88\ mA$$

→ For V_{min}

- $V_{o,min_1} = -V_{CC} + V_{OV} = -V_{CC} + (\overset{0}{V_{GS}} - V_{th}) = -5V + 1.8V = -3.2V$
- $V_{o,min_2} = -I_{BIAS} \cdot R_L$

i) For $R_L = \infty$ (open-circuit)

$$\boxed{V_{o,min} = -3.2V}$$

ii) For $R_L = 400\Omega = 0.4k\Omega \Rightarrow V_{o,min_2} = -(38.88)(0.4) = -15.552V$

$$\boxed{V_{o,min} = -3.2V}$$

b) Since M_1 is a constant current source, the maximum current that can flow through the load resistance is equal to the bias current, it is achieved if Q_1 is in cut off.

Then,

$$I_{BIAS} = \frac{V_{out}}{R_L} = \frac{|V_e \sin\omega t|}{R_{L,min}} \Rightarrow R_{L,min} = \frac{|V_e|}{I_{BIAS}} = \frac{2V}{38.88mA} = 51.44\ \Omega.$$

c) What is power efficiency?

Given stage is an example of class-A output-stage.

$$P_{avg,L} = \frac{1}{T}\int_0^T (V_{out}).\frac{V_{out}}{R_L} = \frac{V_p^2}{TR_L}\int_0^T \sin^2 wt\, dt = \frac{V_p^2}{TR_L}\int_0^T \left(\frac{1}{2} - \cos(2wt)\right)dt$$

$(V_{out} = V_p \sin wt)$

$$P_{avg,L} = \frac{V_p^2}{T.R_L}.\frac{T}{2} - \cancel{\frac{V_p^2}{T.R_L}\int_0^T \cos(2wt)\,dt}^{\,0} = \frac{V_p^2}{2R_L} = \frac{(2)^2}{2(51.44)} = 38.88\,mW$$

$$P_{avg,V+} = \frac{1}{T}\int_0^T (I_{BIAS} + i_{RL})V_{cc} = I_{BIAS}V_{cc} + \frac{V_{cc}}{TR_L}\int_0^T V_{out}\,dt$$

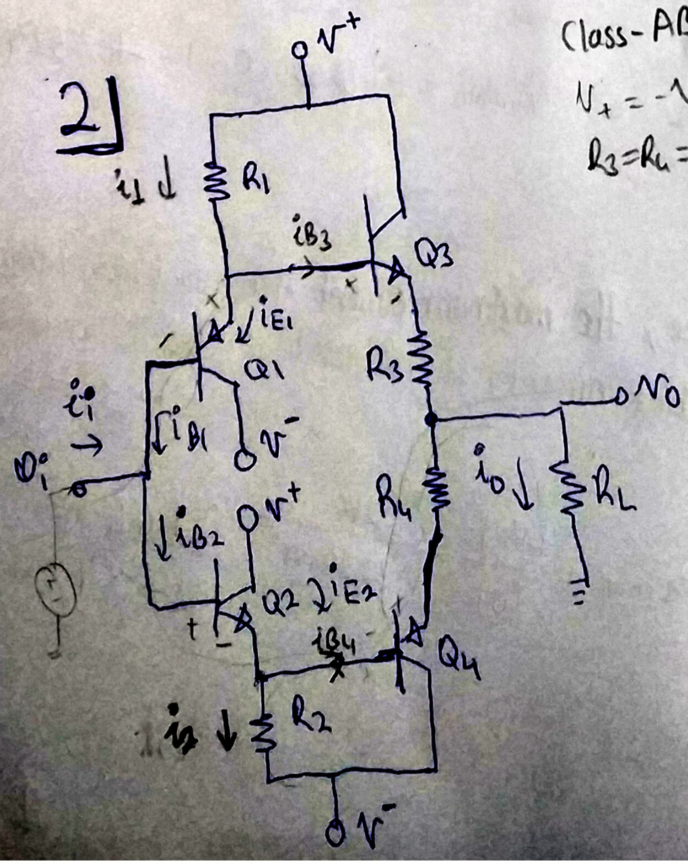
$$P_{avg,V^+} = I_{BIAS}V_{cc} + \frac{V_{cc}}{T.R_L}\int_0^T V_p \sin wt\,dt = I_{BIAS}V_{cc} + \cancel{\frac{V_{cc}.V_p}{T.R_L}\int_0^T \sin wt\,dt}^{\,0}$$

$$P_{avg,V^+} = I_{BIAS}V_{cc}\ ; \quad P_{avg,V^-} = I_{BIAS}V_{cc} = (38.88)(5)$$

$$\eta = \frac{P_{avg,L}}{P_{avg,V^+} + P_{avg,V^-}} = \frac{P_{avg,L}}{2P_{avg,V^-}} = \frac{38.88\,mW}{2(38.88)(5)\,mW} = \frac{1}{10} = 10\%$$

$\Rightarrow$ Since this is a class-A output stage, 10% power conversion efficiency is not surprising.

2] Class-AB (Assume all transistors are matched)



$V_+ = -V_- = 12V$; $\beta = 40$; $V_{BE} = 0.7$; $R_1 = R_2 = 250\Omega$

$R_3 = R_4 = 0\,\Omega$; $R_L = 8\Omega$.

a) for $v_i = 0V$

$$v_i + \cancel{v_{EB1}} - \cancel{V_{BE3}} - V_o = 0$$

$$v_i = V_o = 0 \Rightarrow i_o = \frac{v_o}{R_L} = 0$$

$$i_1 = \frac{V^+ - V_{BE1}}{R_1} = \frac{12-0.7}{250} = 45.2\,mA$$

$$i_2 = \frac{-V_{EB2} - (V^-)}{R_2} = \frac{12-0.7}{250} = 45.2\,mA$$

$$i_{E3} = i_o = 0 \Rightarrow$$

$\Rightarrow i_{E3} = i_o = 0A \Rightarrow i_{B3} = 0 \Rightarrow i_1 = i_{E_1} = 45.2mA$

$i_{B1} = i_{E_1} / (\beta+1) = \frac{45.2}{41} = 1.1mA$

and since $i_{E3} = i_o + i_{E4} \Rightarrow i_{E4} = 0 \Rightarrow i_{B4} = 0 =$

$i_{B4} = 0 \Rightarrow i_2 = i_{E_2} = 45.2mA \Rightarrow i_{B_2} = \frac{45.2mA}{41} = 1.1mA$

$\Rightarrow \boxed{i_{E_1} = 45.2mA}$; $\boxed{i_{E_2} = 45.2mA}$; $\boxed{i_{B_1} = 1.1mA}$; $\boxed{i_{B_2} = 1.1mA}$

b) for $V_i = 5V$

we know that $V_i + \cancel{V_{eb1}} - \cancel{V_{eb3}} - V_o = 0 \Rightarrow V_i = V_o = 5V$

Assume

$i_{E_3} = i_o = \frac{V_o}{R_L} = \frac{5V}{8\Omega} = 0.625A \Rightarrow i_{B_3} = \frac{i_{E3}}{\beta+1} = \frac{0.625}{41} = 15.24mA$

$i_1 = i_{E_1} + i_{B3} \Rightarrow i_{E_1} = i_1 - i_{B3} = \frac{V^+ - (V_i + V_{eb_1})}{R_1} - i_{b3}$

$i_{E_1} = \frac{12 - 5.7}{250} - 15.24 = 9.96mA$

$i_{B_1} = \frac{9.96}{41} = 0.243mA$

$i_{E_3} = i_o \Rightarrow i_{E4} = 0 \Rightarrow i_{B4} = 0$

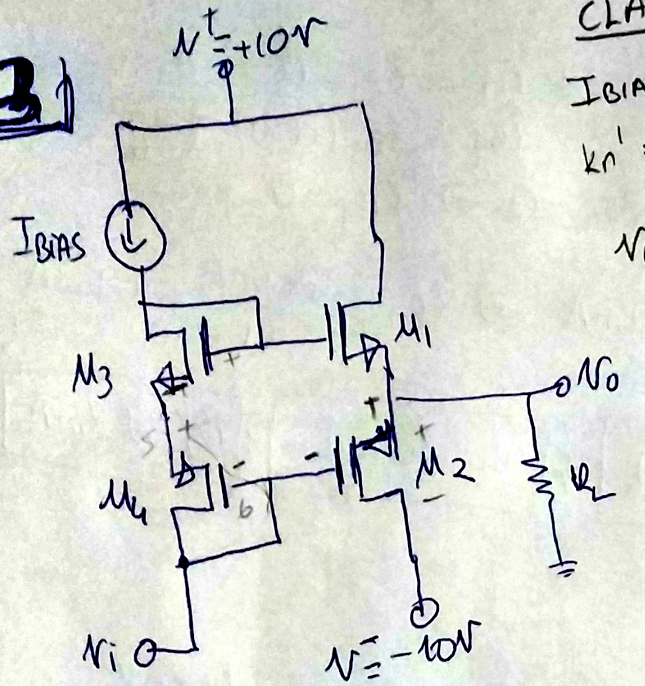
$i_{E_2} = i_2 = \frac{(V_i - V_{BE_2}) - V^-}{R_2} = 65.2mA$

$i_{B_2} = \frac{i_{E2}}{\beta+1} = \frac{65.2}{41} = 1.6mA \Rightarrow i_{IN} = i_{B_2} - i_{B_1} = 1.3474mA$

$\boxed{i_{IN} = 1.347mA}$; $\boxed{i_o = 0.625A}$; $\boxed{i_{E_1} = 9.96mA}$; $\boxed{i_{E_2} = 65.2mA}$; $\boxed{i_{B_2} = 1.6mA}$ $\boxed{i_{B_1} = 0.243mA}$

c) Current Gain is calculated $A_i = \frac{i_{out}}{i_{in}} = \frac{i_o}{i_{IN}} = \frac{0.625A}{1.347mA} = 463.994$

3)



CLASS AB

$I_{BIAS} = 0.2mA$, $R_L = 1k\Omega$, $V_{th,n} = 0.8V$

$k_n' = 100\mu A/V^2$, $V_{th,p} = -0.8V$, $k_p' = 40\mu A/V^2$

$V_{GS,3} = V_{SG,4}$; $V_{GS,1} = V_{SG,2}$; $\lambda = 0$

a) $V_i = -1.5V$; $V_o = 0V$ $i_{D_1} = i_{D_2} = 0.5mA$

$$V_i + V_{SG,4} + V_{GS,3} - V_{GS,1} = V_o$$

$$V_i + 2V_{GS,3} - V_{GS,1} = 0V$$

-1.5

$$\boxed{2V_{GS,3} - V_{GS,1} = 1.5V}$$

$$V_i + V_{SG,2} = V_o \Rightarrow V_{SG,2} = -V_i$$

$$V_{SG,2} = 1.5V$$

$$2V_{GS,3} = 3V$$

$$\boxed{V_{GS,3} = 1.5V}$$

For M_1 and M_2 $i_{D_1} = i_{D_2} = 0.5mA$

$$5\times10^{-3} = (0.5)(10^{-4}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_1(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_1 = 20.4$$

$$5\times10^{-3} = (0.5)(4\times10^{-5}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_2(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_2 = 51.02$$

For M_3 and M_4 $I_{D_3} = I_{D_4} = I_{bias} = 0.2mA$

$$2\times10^{-3} = (0.5)(10^{-4}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_3(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_3 = 8.16$$

$$2\times10^{-3} = (0.5)(4\times10^{-5})\left(\tfrac{W}{L}\right)_4(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_4 = 20.4$$

b) **$V_{o,max}$**

$$V_{o,max_1} = V^+ - V_{ov_1} = V^+ - (V_{GS1} - V_{th,n}) = 10V - (0.7V) = 9.3V$$

$$V_{o,max_2} = V^+ - V_{Ibias} - V_{GS,1} = 10 - (0.2 + 1.5V) = 8.3V$$

then $V_{o,max} = 8.3V$

$V_{o,min}$

$$V_{o,min_1} = V_{in} + V_{SG_2} = (-1.5V) + (1.5V) = 0$$

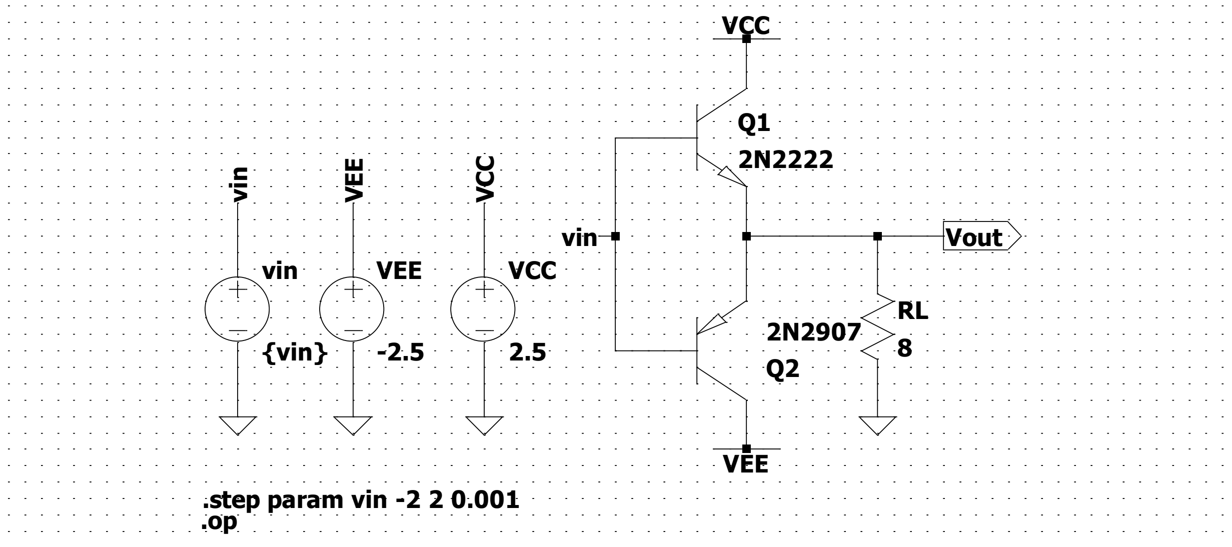
$$V_{o,min_2} = V^- + V_{SG_1} = V^- + (V_{SG} - |V_{th}|) = -10V + (1.5 - 0.8V) = -9.3V$$

then $V_{o,min} = 0V$

$$\boxed{0V \le V_o \le 8.3V}$$

4th QUESTION IS REALIZED USING LTSPICE

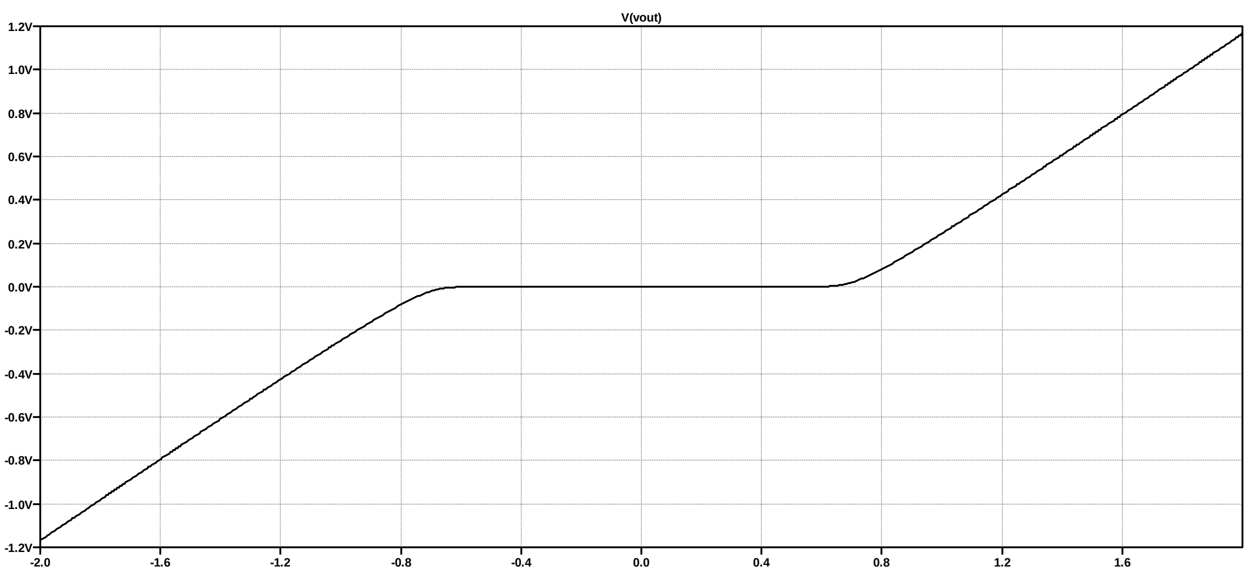
First of all, the circuit is drawn:



RL = 8 **Ω**

In order to see how the output of the circuit responds changes in input voltage, lets sweep some input voltage from -2V to 2V by using the command .step param vin -2 2 0.001 and .op

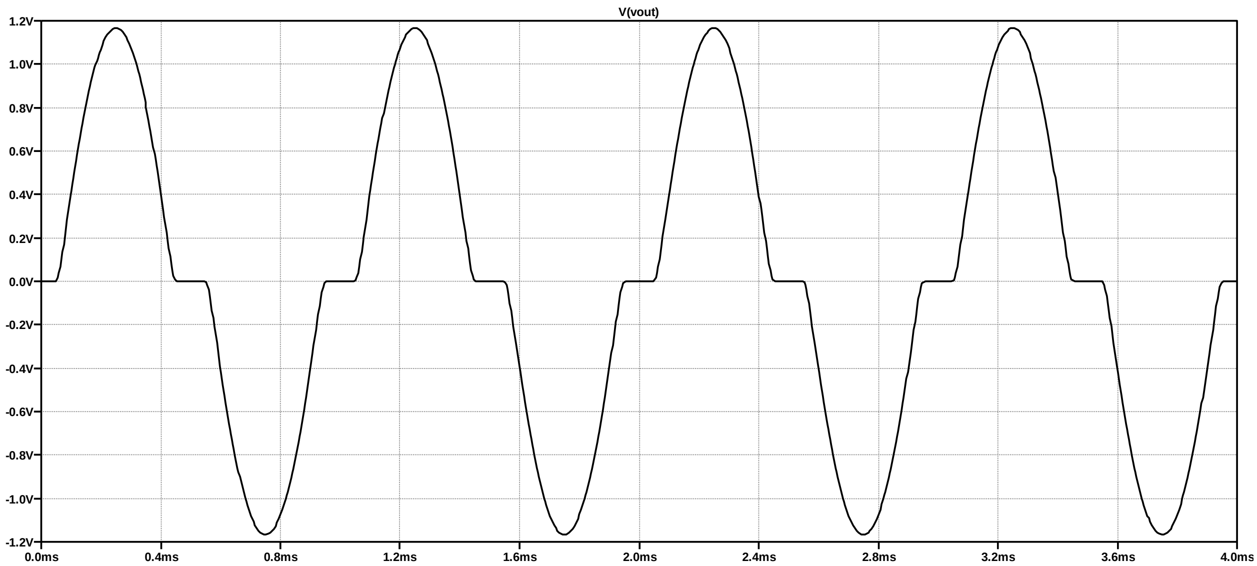
The graph is shown as:



As it can be seen from this graph, for some input voltage values the output voltage becomes zero and the characteristic is not linear. Not being linear will introduce some harmonics to the amplified signal and therefore the audio or the output signal will be distorted (will be in different shape form from the input voltage).

To see the crossover distortion(harmonics) let's do transient analysis for an input sinusoid with 2V peak amplitude and 1 kHz frequency.

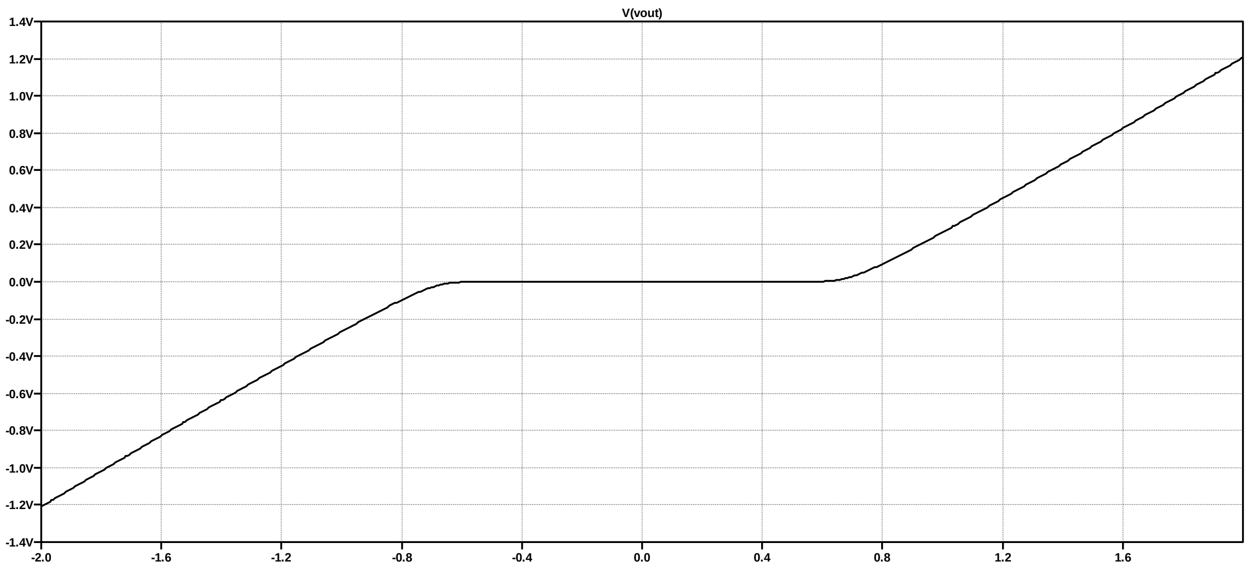
The plot is given as:



As it can be seen from this graph, the output signal is not sinusoid anymore which is not desirable and will introduce some higher frequencies into the signal.

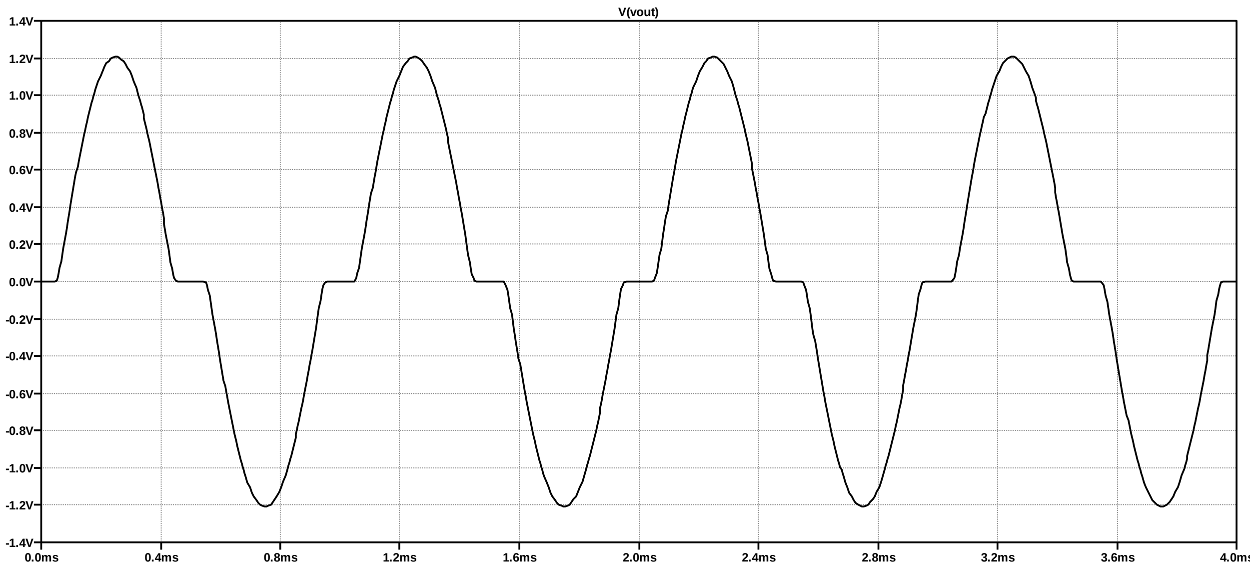
RL = 16 **Ω**

Now let's increase the load resistance a bit and see what happens. Let's begin with linearity



Nothing changes much. Let us also analyze the circuit by transient analysis

The transient analysis for the same input sinusoid (2V peak amplitude and 1 kHz frequency) as given:



Very little changes occur in the amplitude but negligible. On the other hand in shape-wise if we increase the load resistance to 16 **Ω**, No big changes occur.