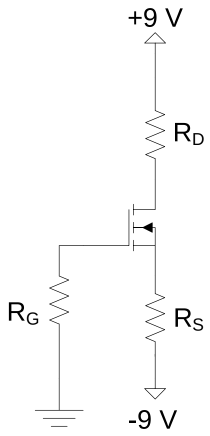
American University of Beirut
Department of Electrical and Computer Engineering

EECE 310 – Electronics | Fall 2007 – 2008

Homework 8

The MOSFET in the circuit has $V_t = 1.2$ V, $k'(W/L) = 1$ mA/V^2, and $V_A = 1/\lambda = 50$ V.



a) Find the values of R_S, R_D, and R_G so that $I_D = 1$ mA, the largest possible value of R_D is used while a maximum signal swing at the drain of ± 2.5 V is possible keeping the MOSFET in the saturation region, and the input resistance at the gate is 5 MΩ.

b) Find the values of g_m and r_o at the bias point.

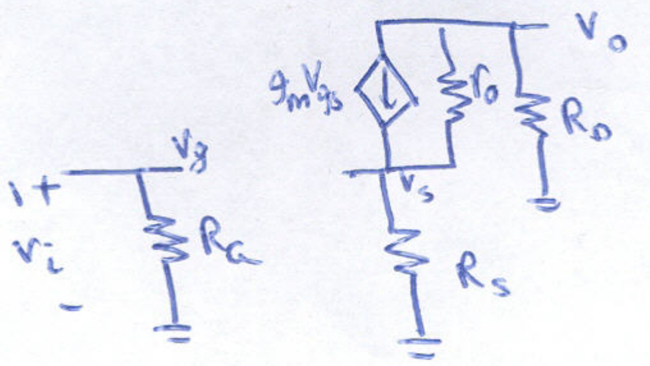
c) If the amplifier input (at the gate) is connected to a source with a 100 KΩ source resistance, and to a load (at the drain) with a resistance of 50 KΩ, find the voltage gain and the power gain from *signal* source to output.

d) To increase the voltage gain, a capacitor is used to bypass part of the resistor R_S. How much of R_S should be bypassed to obtain a voltage gain of –5 from signal source to load?

e) Verify your results using PSpice. Assume that the source and load are coupled to the MOSFET gate and drain, respectively, using capacitors. All capacitor values are 500μF, including the one used to partially bypass R_S. Use a sinusoidal source with a frequency of 1 KHz. Show the voltage gain, current gain, and maximum voltage swing at the drain.

Home Work 8:

a) Small signal model:



$$R_{in} = \frac{V_i}{I_i} = R_G$$

$$\Rightarrow R_G = 5M\Omega.$$

MOSFET in Saturation $\Rightarrow V_{DS} > V_{GS} - V_t$

$$\Rightarrow V_D > V_G - V_t$$

$$\Rightarrow V_D > 0 - 1.2V$$

$$\Rightarrow V_{D\,min} = -1.2V.$$

$$V_{D\,min} = V_D - \Delta V_{D\,max} = V_D - 2.5 \Rightarrow V_D = 1.3V.$$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{9 - 1.3}{1mA} = 7.7K\Omega.$$

$$V_{DS} = V_D - R_s I_s + 9. = 10.3 - R_s.$$

$$I_D = \frac{1}{2} K_n \frac{W}{L} (V_G - V_s - V_t)^2 (1 + \lambda V_{DS}) \Rightarrow 2 = (9 - R_s - 1.2)^2 \left(1 + \frac{10.3 - R_s}{50}\right)$$

$$\Rightarrow (7.8 - R_s)^2 (1.206 - 0.02 R_s) = 2 \quad (R_s \text{ in } K\Omega)$$

$\Rightarrow R_s = 60.26K\Omega$ rejected since $V_{GS} = -V_s = 9 - R_s = -51.26 < 1.2 = V_t$

OR $R_s = 9.2K\Omega$ rejected since $V_{GS} = -V_s = 9 - R_s = -0.2 < 1.2$

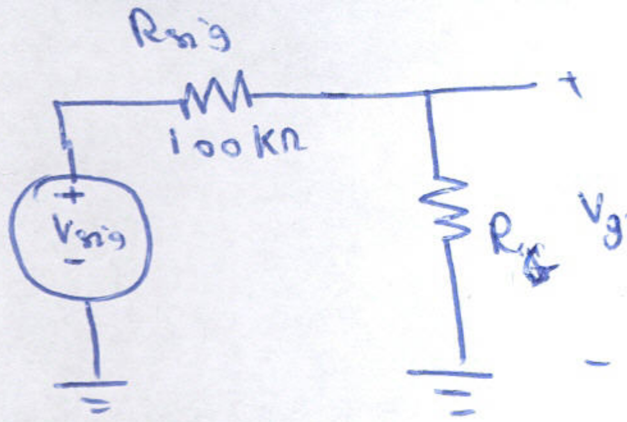
OR $R_s = 6.44K\Omega$ accepted $V_{GS} = -V_s = 9 - R_s = 2.56 > 1.2V$

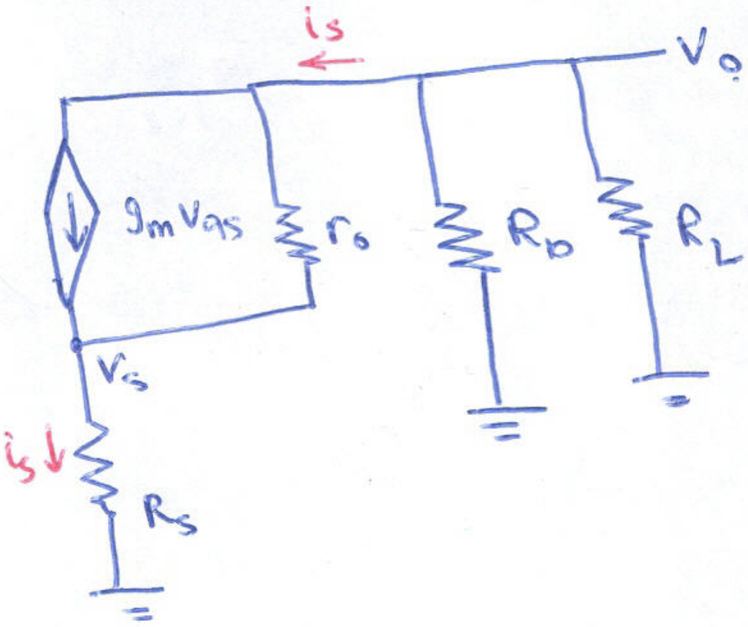
$\therefore R_G = 5M\Omega$; $R_D = 7.7K\Omega$; $R_s = 6.44K\Omega$.

b) $$g_m = \frac{2I_D}{V_{OV}} = \frac{2 \times 1 \times 10^{-3}}{V_G - V_S - V_t} = \frac{2mA}{9 - R_s - 1.2} = \frac{2mA}{1.36} = 1.47\,mA/V.$$

$$r_o = \frac{V_{DS} + 1/\lambda}{I_D} = \frac{1.3 + 2.56 + 50}{1 \times 10^{-3}} = 53.86K\Omega$$

c)





- $V_o = -i_s (R_D // R_L)$
- $V_S = i_s R_S = \frac{-V_o R_S}{R_D // R_L}$
- $i_s = g_m V_{gs} + \frac{V_o - V_s}{r_o}$

$$\therefore \frac{-V_o}{R_D // R_L} = g_m V_{gs} + \frac{V_o}{r_o} + \frac{V_o R_S}{r_o . R_D // R_L} = g_m V_g + g_m \frac{V_o R_S}{R_D // R_L} + \frac{V_o}{r_o} + \frac{V_o R_S}{r_o . R_D // R_L}$$

$$\Rightarrow V_o \left(\frac{1}{r_o} + \frac{1 + g_m R_S}{R_D // R_L} + \frac{R_S}{r_o \times R_D // R_L} \right) = -g_m V_g .$$

$$\Rightarrow \frac{V_o}{V_{gs}} = \frac{-g_m r_o \times R_D // R_L}{r_o + r_o g_m R_S + R_D // R_L + R_S} = -g_m . \frac{r_o (R_D // R_L)}{r_o (1 + g_m R_S) + R_D // R_L + R_S}$$

$$\frac{V_{gs}}{V_{sig}} = \frac{R_G}{R_G + R_{sig}}$$

$$A_v = \frac{V_o}{V_{sig}} = -\frac{R_G}{R_G + R_{sig}} . g_m \frac{r_o (R_D // R_L)}{r_o (1 + g_m R_S) + R_D // R_L + R_S}$$

Note : If we neglect $r_o \Rightarrow r_o \to \infty \Rightarrow A_v \to \frac{-R_G}{R_G + R_{sig}} . g_m . \frac{R_D // R_L}{1 + g_m R_S}.$

$$A_v = \frac{-5M}{(5 + 0.1)M} . 1.47 \times 10^{-3} . \frac{(53.86K)(7.7K // 50K)}{53.86K(1 + 1.47 \times 6.44) + (7.7K // 50K) + 6.44K} = -0.897 V/V.$$

input current $i_1 = \frac{V_{sig}}{5.1M}$

output current $i_o = \frac{V_o}{50K}$

$$\frac{i_o}{i_1} = \frac{V_o}{V_{sig}} \times \frac{5.1M}{50k.} = A_v \times \frac{5.1M}{50k.}$$

$$A_p = A_i A_v = A_v^2 \times \frac{5.1M}{50K} = 82.07 W/W$$

OR $$A_p = \frac{P_o}{P_i} = \frac{\frac{V_o}{\sqrt{2}}\frac{i_o}{\sqrt{2}}}{\frac{V_i}{\sqrt{2}}\frac{i_i}{\sqrt{2}}} = \frac{\frac{V_o^2}{2\times 50K}}{\frac{V_i^2}{2\times 5.1M}} = \frac{V_o^2}{V_i^2} \times \frac{5.1M}{50K} = A_v^2 \times \frac{5.1M}{50K} = 82.07 W/W$$

d) Part of R_s by passed will be short circuited.

$$A_v = -5 \Rightarrow \frac{-R_G}{R_G + R_{sig}} \cdot g_m \frac{r_o (R_D \| R_L)}{r_o(1+g_m R_s) + R_D \| R_L + R_s} = -5$$

$$\Rightarrow \frac{-5}{5.1} \times \frac{1.47\times10^{-3} \times 53.86K \times (7.7K \| 50k)}{53.86K(1+1.47\times10^{-3} R_s) + (7.7K \| 50k) + R_s} = -5$$

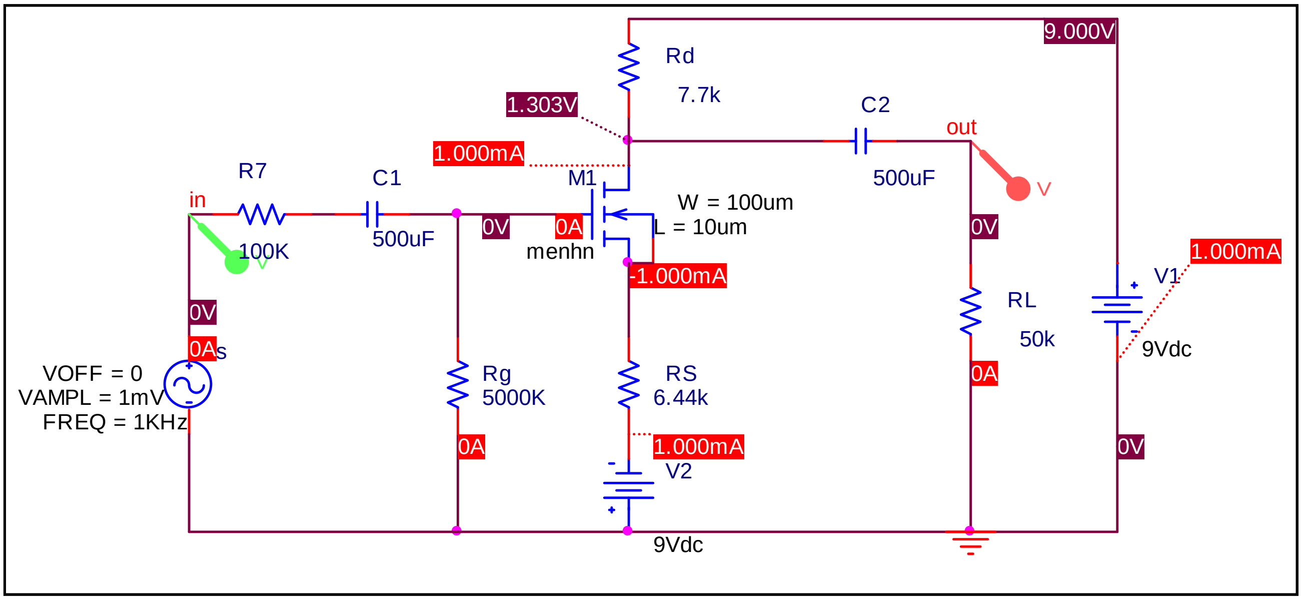
$$\Rightarrow 53.86k + 53.86 \times 1.47 R_s + (7.7K \| 50k) + R_s = \frac{1.47\times10^{-3}}{5.1} \times 53.86K \times (7.7K \| 50k)$$

$$\Rightarrow 80.1742 R_s = 103.585k - 53.8k - (7.7K \| 50k) = 43.053k$$

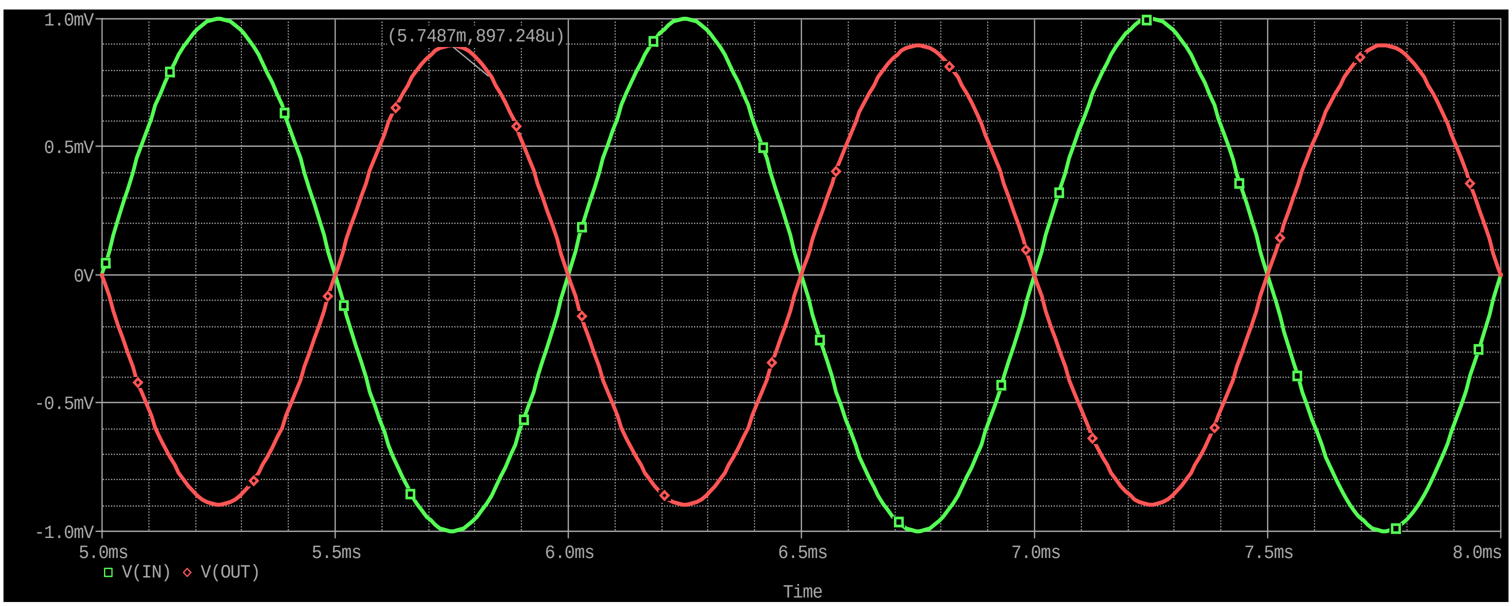
$$\Rightarrow R_s = 537 \Omega$$

Part of R_s by passed $= 6.44k - 537 = 5.903 K\Omega$.

e) For unbypassed Rs

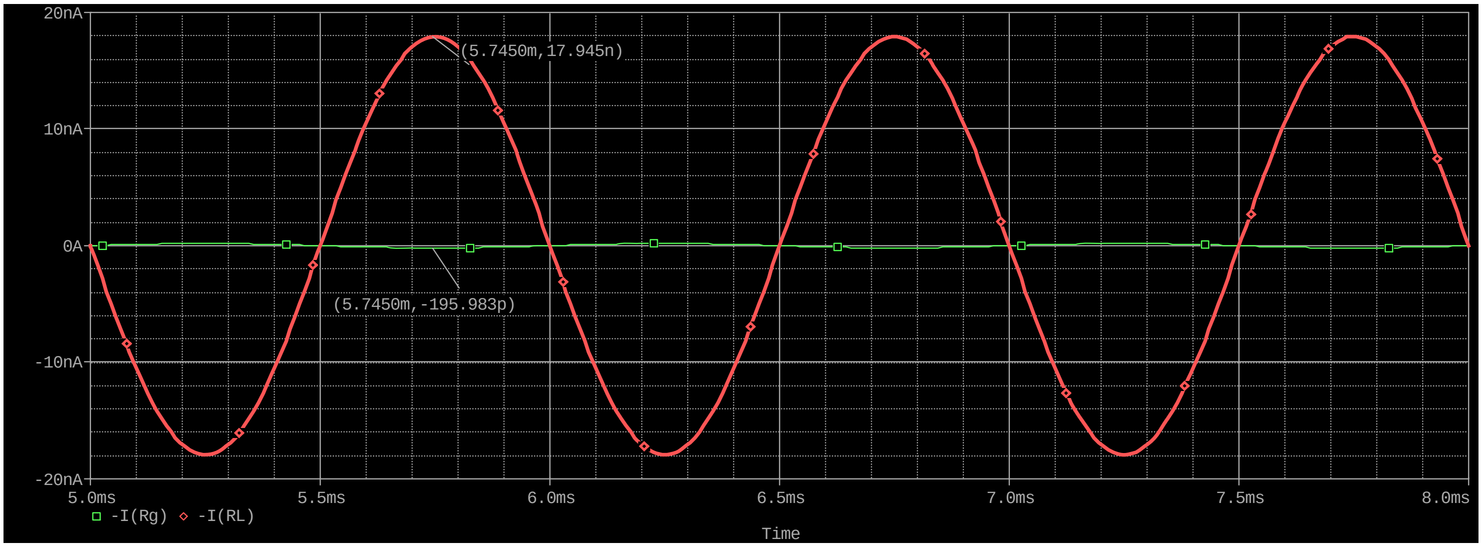


Vo: red, Vi in green.



Av=Vo/Vi= -0.897.248/1= -0.897.248

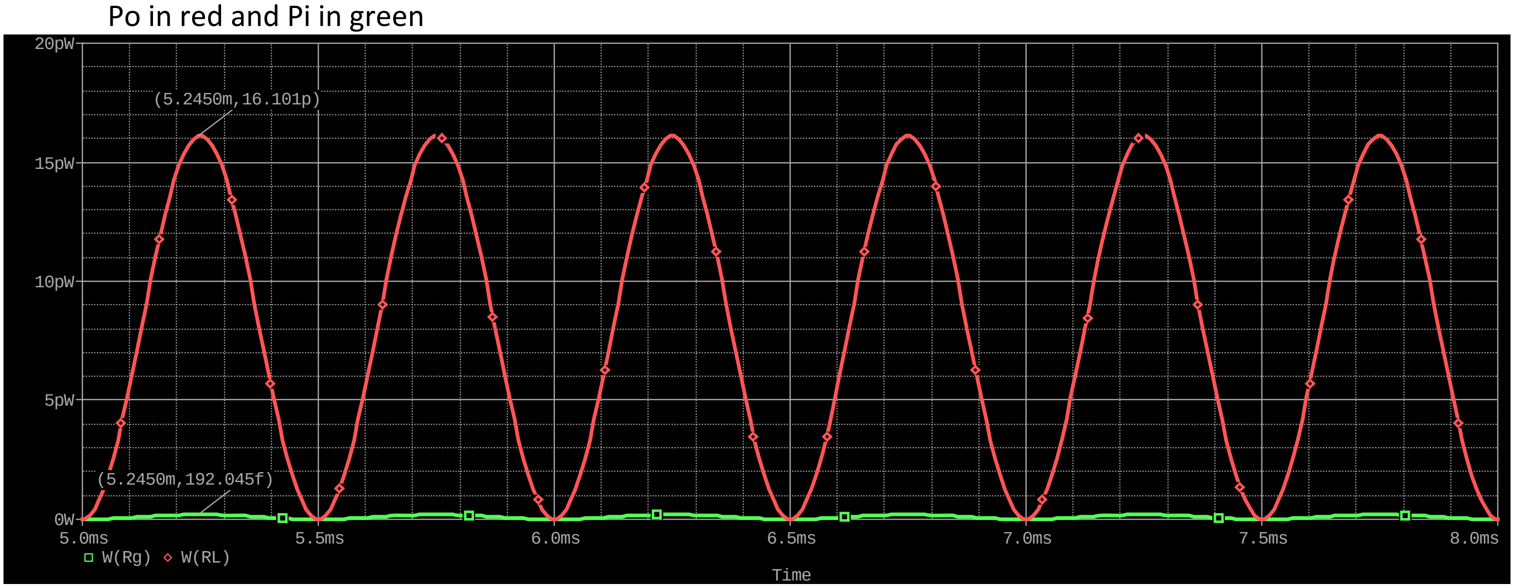
Io in red and Ii in green



Ai=Io/Ii = -17.945n/195.983p =91.564 A/A

1 pt

Po in red and Pi in green

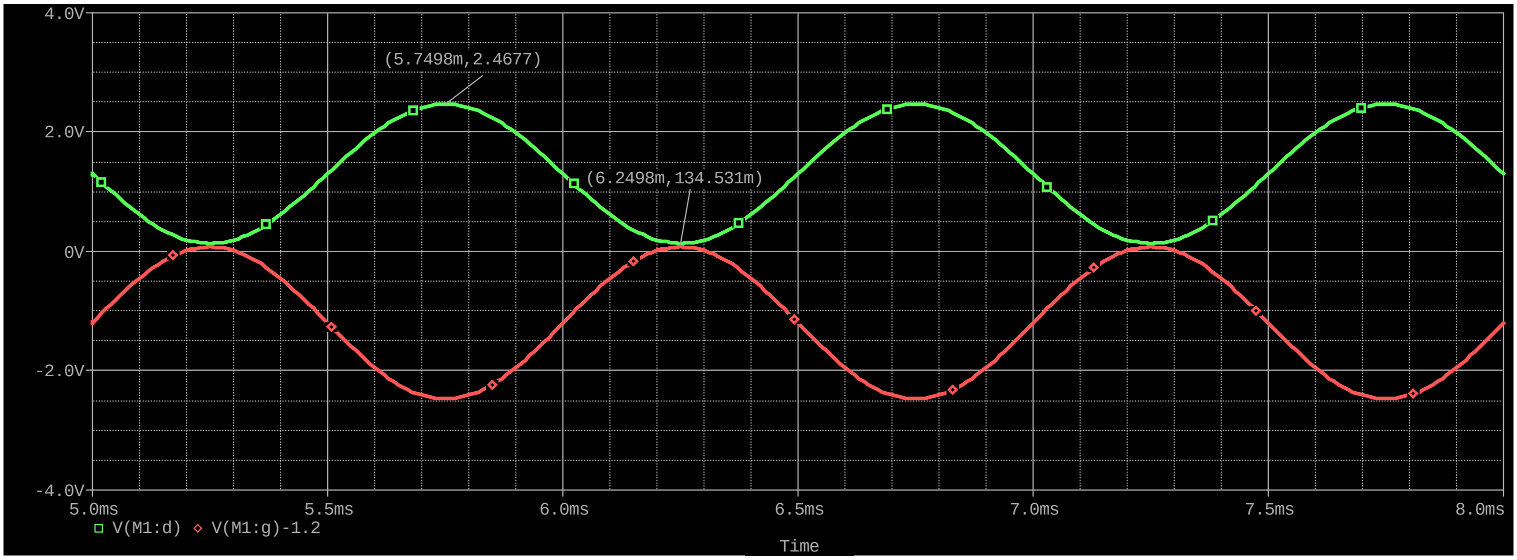


Ap=Po/Pi = 16.1p/192f =83.85 W/W

To find the maximum swing at the drain we can change Vs until V_D=V_G- V_t

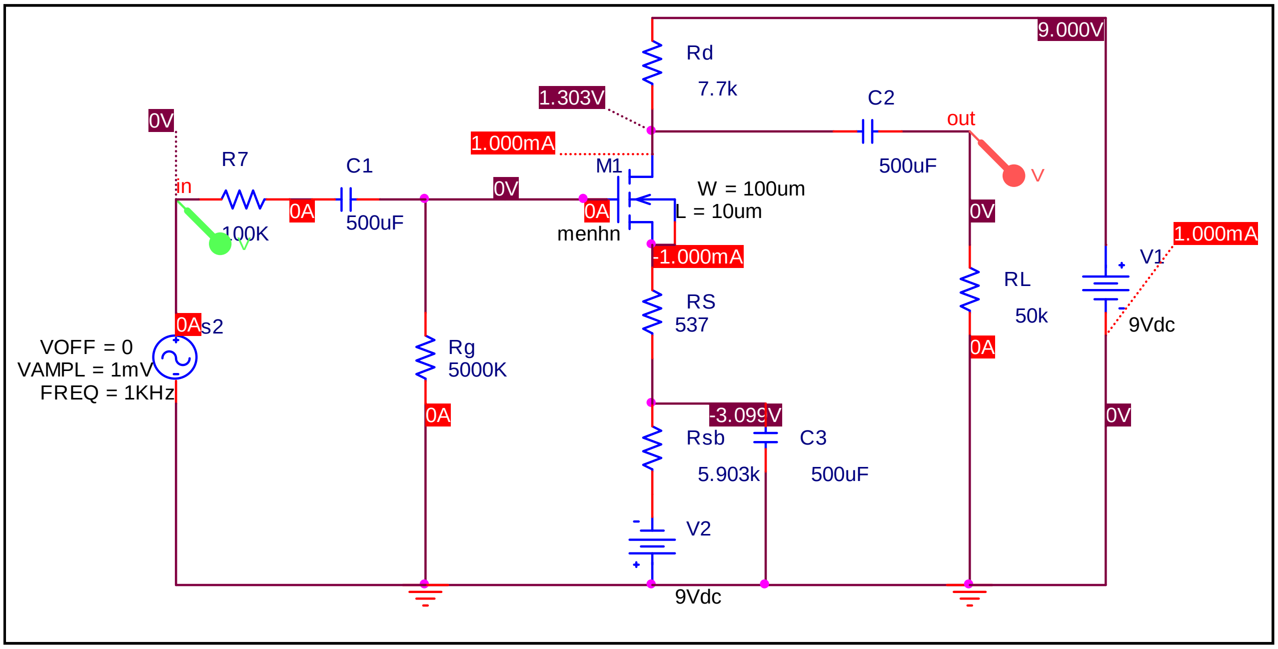
Note: The maximum swing here is less than ±2.5V since when we designed the circuit and calculated the value of R_D, we neglected the swing at the gate (swing at drain /Gain).
V_D-2.5 > V_G + ~~(2.5/Av)~~ - V_t
However Av turned out to be less than 1 and the swing of 2.5 requires Vg to change by more than 2.5V which can no longer be neglected. That is why the maximum swing at the drain here is less than 2.5V.

Trace of V_G- V_t and V_D

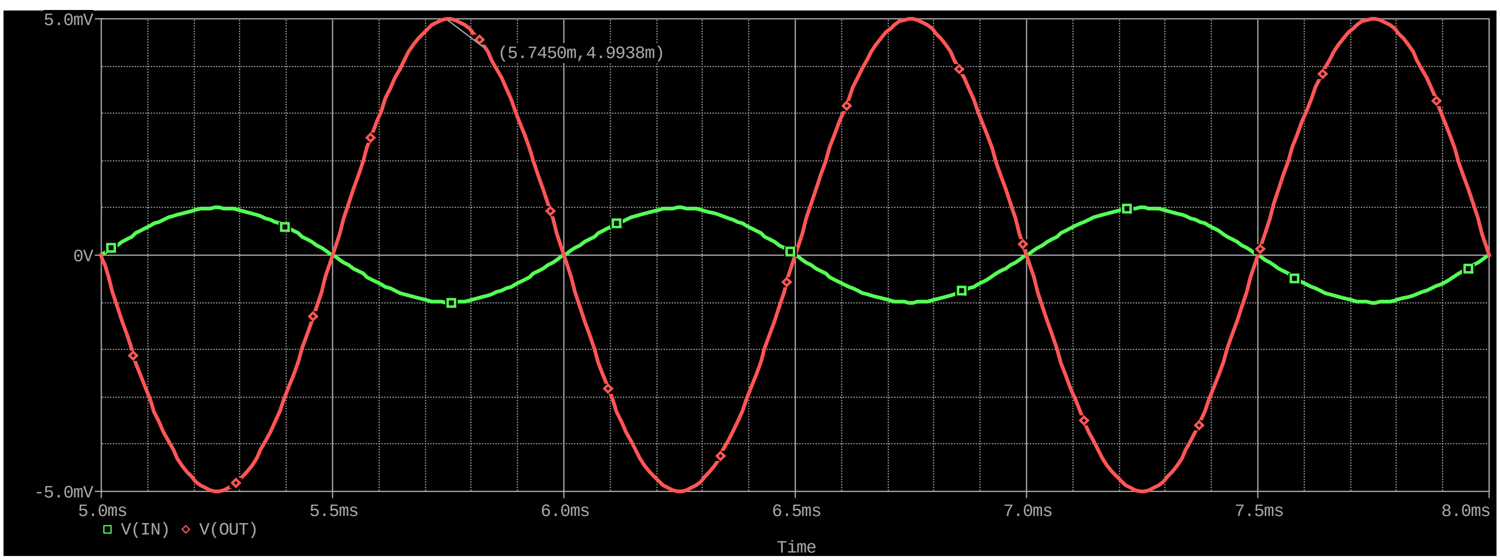


We find that for Vs=1.3V (amplitude) V_D starts to become equal to V_G- V_t for some values. So for larger values of Vs we will have distortion. So the maximum swing will be ±1.17V

e) For bypassed Rs

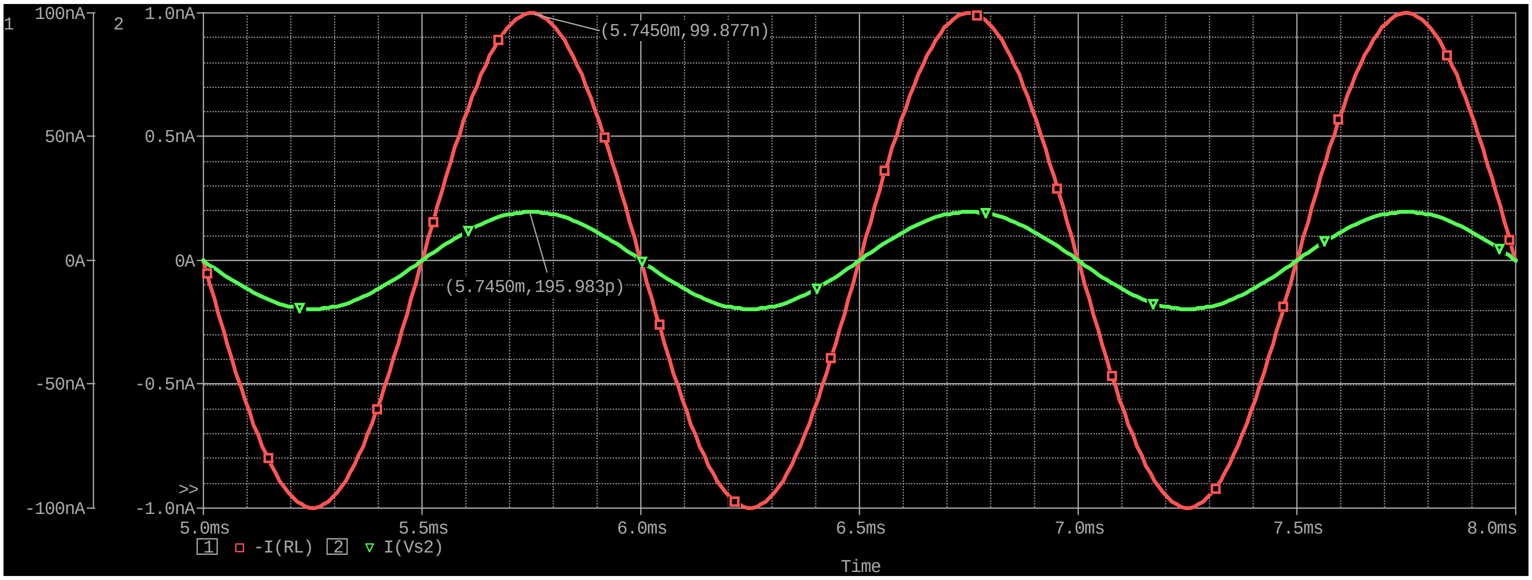


Vo: red, Vi in green.



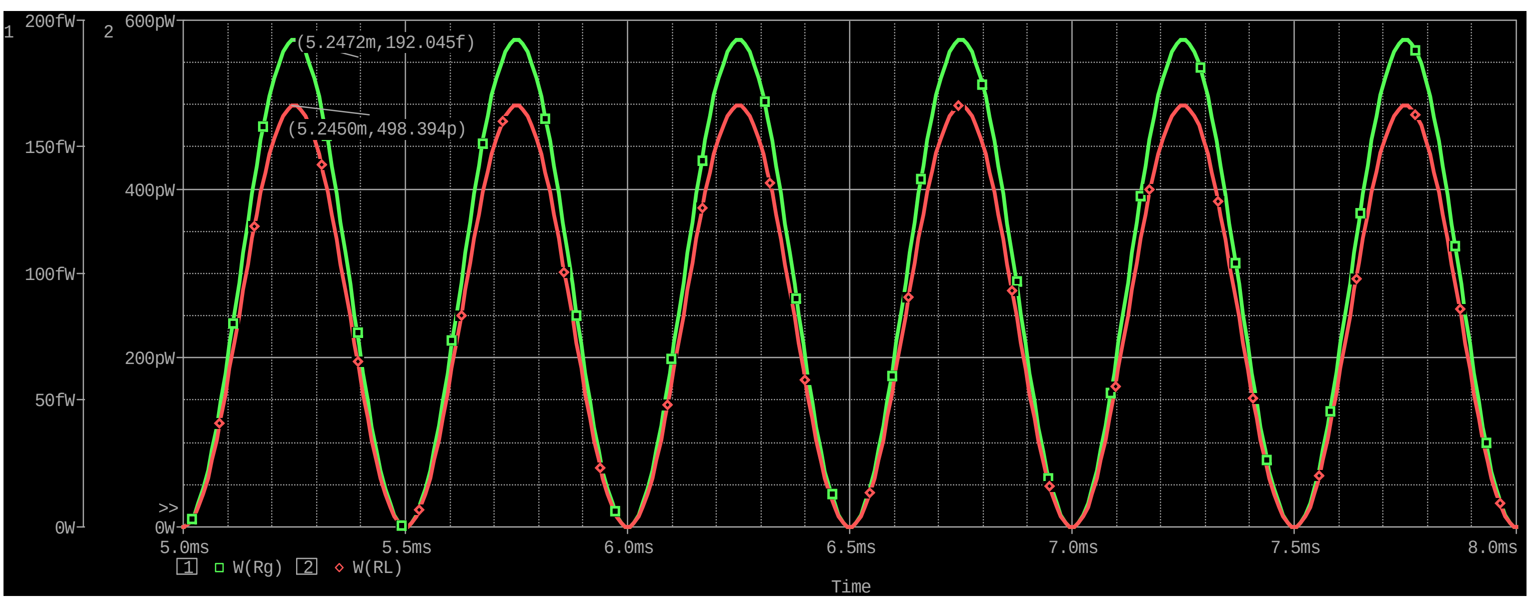
Av=Vo/Vi= -4.993/1= -4.993 V/V

Io in red and Ii in green



Ai=Io/Ii = 99.877n/195.983p =510 A/A

Po in red and Pi in green

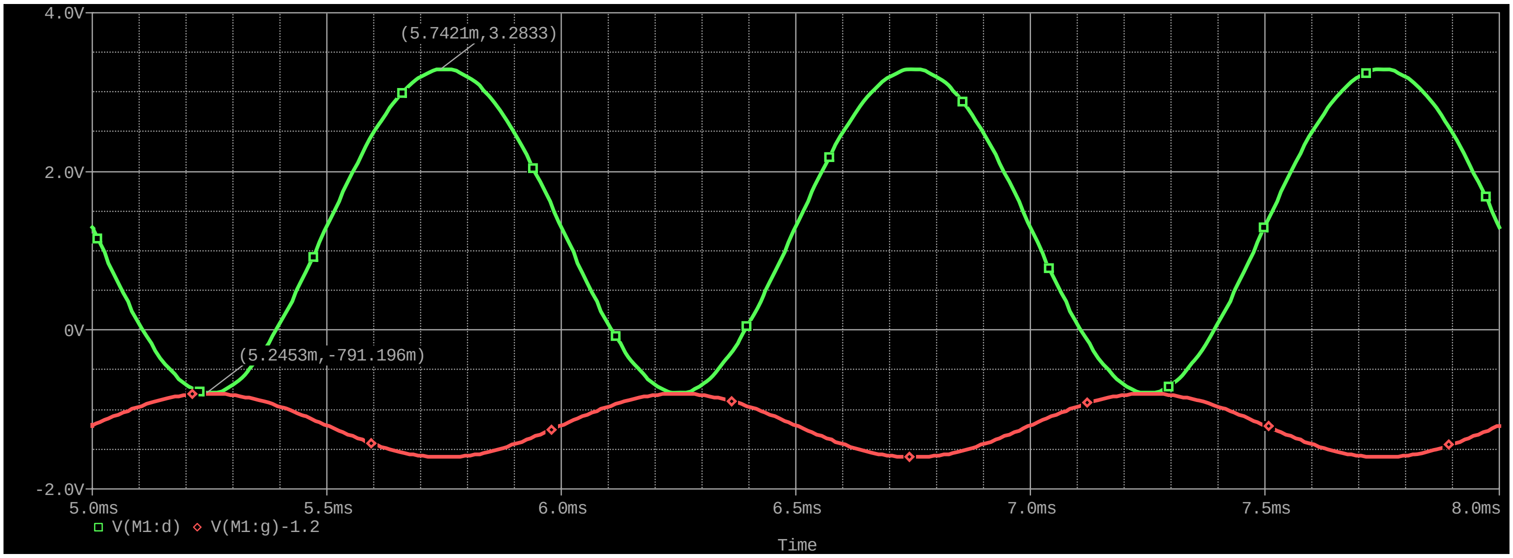


Ap=Po/Pi = 498.4p/192f =2595 W/W

To find the maximum swing at the drain we can change Vs until $V_D = V_G - V_t$

Note: The maximum swing here is slightly less than ±2.5V since now the gain is -5 and the swing at the gate can be neglected

Trace of $V_G - V_t$ and V_D



We find that for Vs=0.41V (amplitude) V_D starts to become equal to $V_G - V_t$ for some values. So for larger values of Vs we will have distortion. So the maximum swing will be ±2.04V