

# Microelectronic Circuits Assignment 1

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## Question 1

Value of components (resistor/capacitor) present in the circuit:

Table 1: Calculated values for question 1

Sl. No.	Component Name	Value
1	R1(k $\Omega$ )	15k $\Omega$
2	C1 (nF)	1nF

Circuit as on LT SPICE

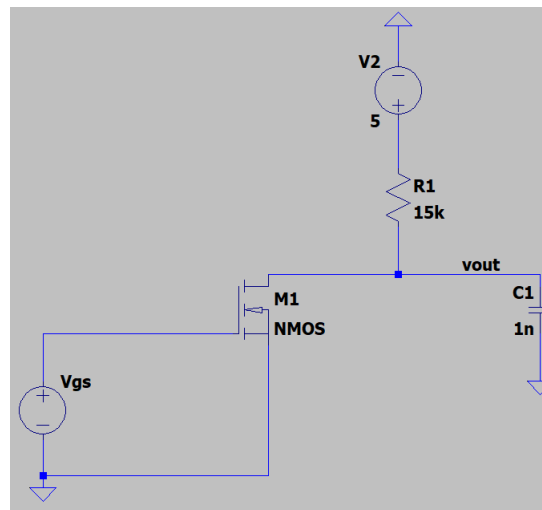


Figure 1: Circuit for question 1

## Graphs

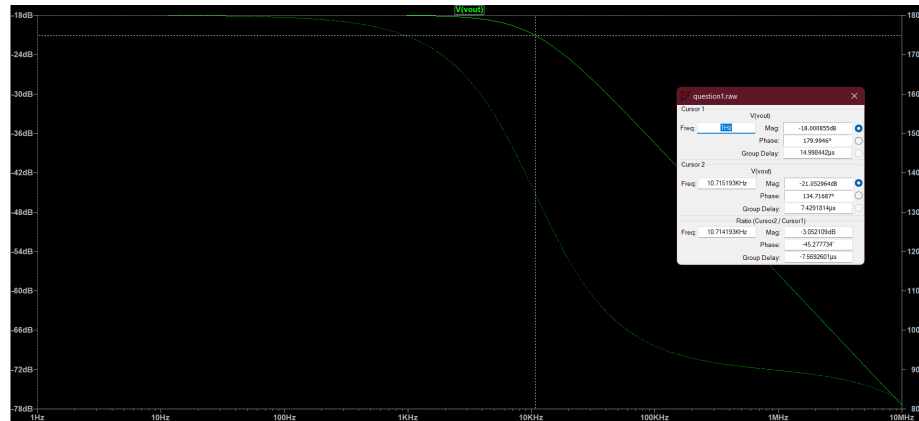


Figure 2: Frequency Response

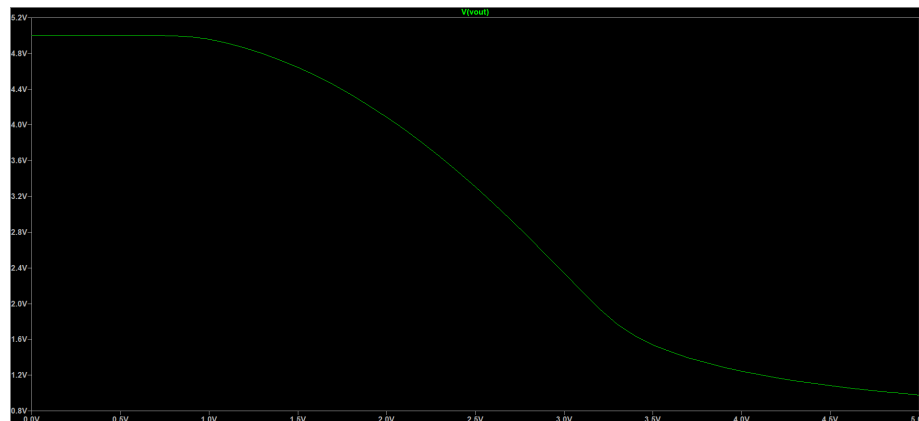


Figure 3: Voltage transfer characteristics

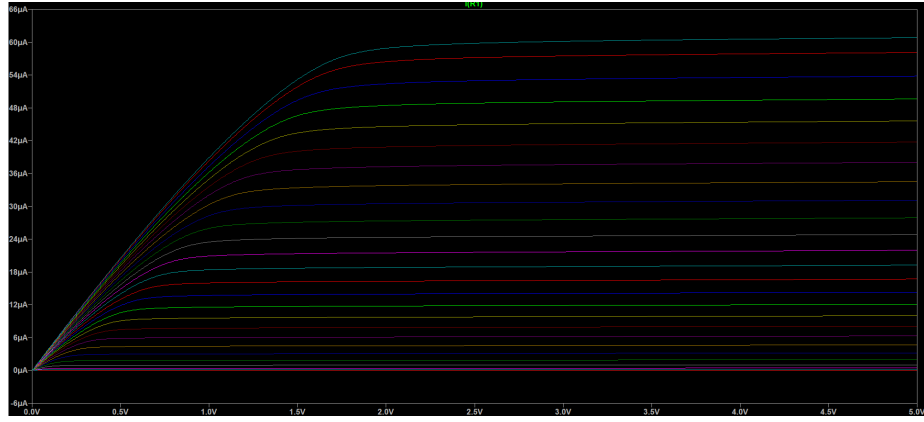


Figure 4: Graph of  $i_{DS}$  vs  $V_{DS}$

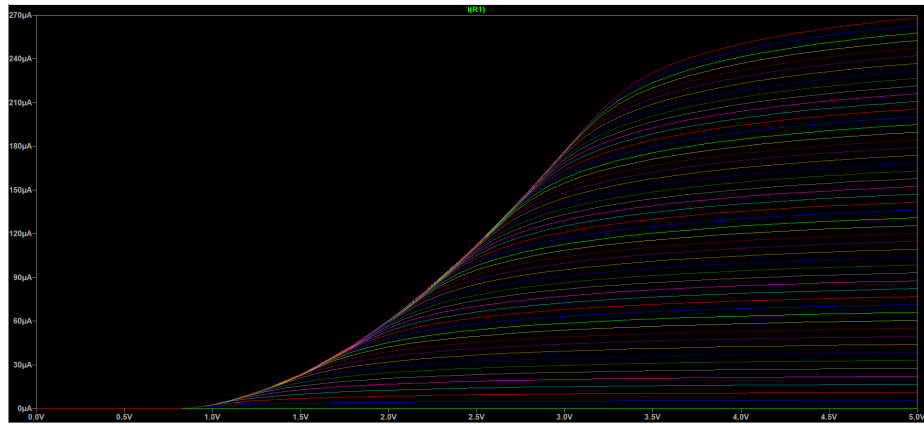


Figure 5: Graph of  $i_{DS}$  vs  $V_{GS}$

In figure 2, for an approximate 3dB change in frequency (as shown by both cursors), we see the phase shift by approximately  $45^\circ$ .

## Miscellaneous calculations

### DC operating point

Given the overdrive voltage of the MOSFET as 0.2V and the threshold voltage as 0.6696061V, to calculate the DC operating point, we must take  $V_{GS} = V_{TH} + V_{OV} = 0.8696061\text{V}$ . With this value of  $V_{GS}$ , the simulation yields the following values:

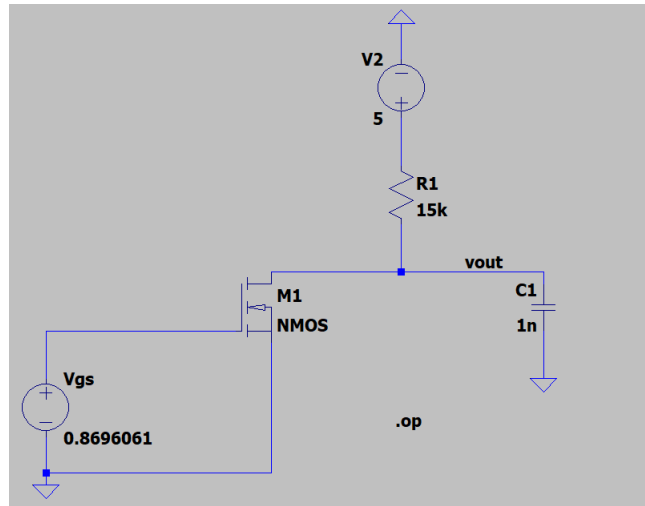


Figure 6: DC operating point circuit

--- Operating Point ---		
V(n002) :	0.869606	voltage
V(n001) :	5	voltage
V(vout) :	4.99329	voltage
Id(M1) :	4.47302e-007	device_current
Ig(M1) :	0	device_current
Ib(M1) :	-5.00329e-012	device_current
Is(M1) :	-4.47297e-007	device_current
I(C1) :	-4.99329e-021	device_current
I(R1) :	4.47302e-007	device_current
I(V2) :	-4.47302e-007	device_current
I(Vgs) :	0	device_current

Figure 7: DC operating point parameters

### Small signal calculations

Transconductance  $g_m$  is given by:

$$g_m = \frac{2I_D}{V_{OV}}$$

Using the values found above from the DC operating point calculations, we can calculate the transconductance to be

$$g_m = \frac{2 \times 4.47302 \times 10^{-7}}{0.2} = 4.47302 \times 10^{-6} \text{ A/V}$$

The value of the output resistance  $r_o$  corresponding to the early effect/channel length modulation is given by:

$$r_o = \left( \frac{\partial i_D}{\partial V_{DS}} \right)^{-1} \bigg|_{V_{GS}=\text{constant}}$$

This can be found out from the simulation by setting  $V_{GS} = V_{TH} + V_{OV}$  and finding the value of the inverse of the differential at  $V_{DS} = 5\text{V}$ .

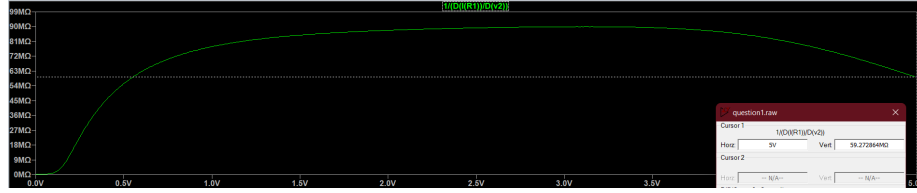


Figure 8: Output resistance for small signal calculations

The value of  $r_o$  we get from this graph is  $r_o = 59.272865\text{M}\Omega$ . Collectively, we get the small signal model as below:

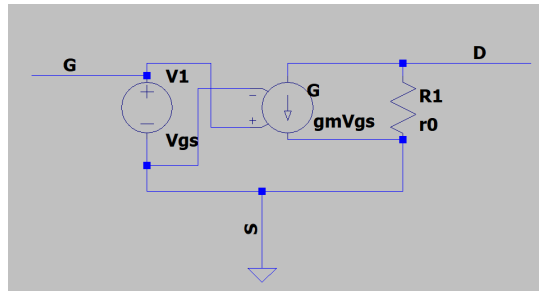


Figure 9: Small signal model

## Question 2

Value of components (resistors/gain) present in the circuit

Table 2: Calculated values for question 2

Sl. No.	Component Name	Value
1	$R_1(\text{k}\Omega)$	$30\text{k}\Omega$
2	$R_2(\text{k}\Omega)$	$17\text{k}\Omega$
3	$R_3(\text{k}\Omega)$	$30\text{k}\Omega$
4	$R_4(\text{k}\Omega)$	$50\text{k}\Omega$
5	k	18 V/V

Circuit as on LT SPICE

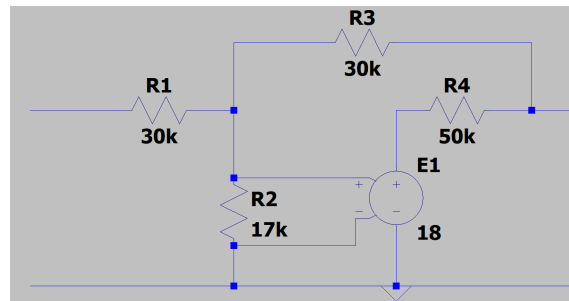


Figure 10: Original 2 port network simulated on LT SPICE

## **Z, Y and H Parameters**

### **Z parameters**

Z parameters as obtained from LT SPICE

$$Z = \begin{bmatrix} 23.492822k\Omega & -4.0669856k\Omega \\ -47.99043k\Omega & -11.24402k\Omega \end{bmatrix}$$

### **Y parameters**

Y parameters as obtained from LT SPICE

$$Y = \begin{bmatrix} 24.479166\mu\mathcal{U} & -8.8541665\mu\mathcal{U} \\ -104.47916\mu\mathcal{U} & -51.145835\mu\mathcal{U} \end{bmatrix}$$

### **H parameters**

$$H = \begin{bmatrix} 40.851062k\Omega & 361.70211mV/V \\ -4.268085A/A & -88.936169\mathcal{U} \end{bmatrix}$$



## Calculations

### Z parameters

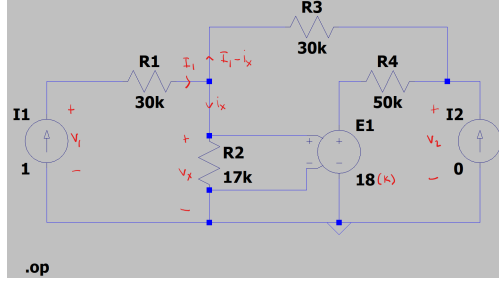


Figure 11: Z parameter circuit 1 (for  $z_{11}$  and  $z_{21}$ )

Assume the convention in the above circuit for the calculations that follow

$$\begin{aligned}
 -(I_1 - i_x)(R_3 + R_4) - kV_x + V_x &= 0 \\
 (i_x - I_1)(R_3 + R_4) &= V_x(k - 1) \\
 (i_x - I_1)(R_3 + R_4) &= i_x R_2(k - 1) \\
 i_x(R_3 + R_4 - R_2(k - 1)) &= I_1(R_3 + R_4) \\
 \implies i_x &= I_1 \frac{(R_3 + R_4)}{R_3 + R_4 - R_2(k - 1)} \\
 V_1 &= I_1 R_1 + V_x \\
 V_1 &= I_1 R_1 + i_x R_2 \\
 V_1 &= I_1 \left[ R_1 + \frac{R_2(R_3 + R_4)}{R_3 + R_4 - R_2(k - 1)} \right] \\
 \implies \frac{V_1}{I_1} &= z_{11} = R_1 + \frac{R_2(R_3 + R_4)}{R_3 + R_4 - R_2(k - 1)}
 \end{aligned}$$

Also :

$$\begin{aligned}
 V_2 &= (I_1 - i_x)R_4 + kV_x \\
 V_2 &= (I_1 - i_x)R_4 + k i_x R_2 \\
 V_2 &= i_x(kR_2 - R_4) + I_1 R_4 \\
 V_2 &= I_1 \left[ R_4 + \frac{(kR_2 - R_4)(R_3 + R_4)}{R_3 + R_4 - R_2(k - 1)} \right] \\
 \implies \frac{V_2}{I_1} &= z_{21} = R_4 + \frac{(kR_2 - R_4)(R_3 + R_4)}{R_3 + R_4 - R_2(k - 1)}
 \end{aligned}$$

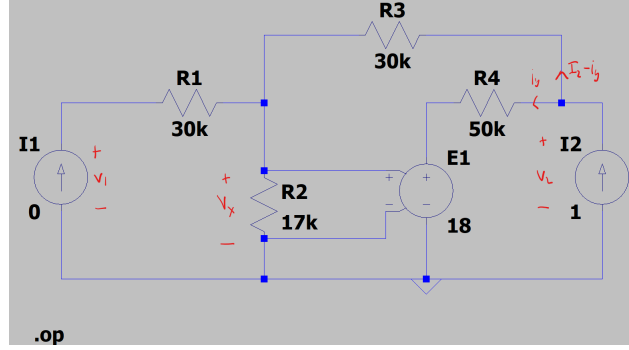


Figure 12: Z parameter circuit 2 (for  $z_{12}$  and  $z_{22}$ )

Assume the convention in the above circuit for the calculations that follow

$$\begin{aligned}
 -R_3(I_2 - i_y) - V_x + kV_x + i_y R_4 &= 0 \\
 i_y R_4 - R_3(I_2 - i_y) &= (1 - k)V_x \\
 i_y R_4 - R_3(I_2 - i_y) &= (1 - k)(I_2 - i_y)R_2 \\
 i_y R_4 &= (I_2 - i_y)[(1 - k)R_2 + R_3] \\
 (R_4 + R_3 + (1 - k)R_2)i_y &= I_2[(1 - k)R_2 + R_3] \\
 \implies i_y &= I_2 \frac{(1 - k)R_2 + R_3}{(1 - k)R_2 + R_3 + R_4} \\
 V_2 &= i_y R_4 + kV_x \\
 V_2 &= i_y R_4 + k(I_2 - i_y)R_2 \\
 V_2 &= i_y[R_4 - kR_2] + KI_2 R_2 \\
 V_2 &= I_2 \left[ \frac{(R_4 - kR_2)\{(1 - k)R_2 + R_3\}}{(1 - k)R_2 + R_3 + R_4} + kR_2 \right] \\
 \implies \frac{V_2}{I_2} &= \boxed{z_{22} = \frac{(R_4 - kR_2)\{(1 - k)R_2 + R_3\}}{(1 - k)R_2 + R_3 + R_4} + kR_2}
 \end{aligned}$$

Also :

$$\begin{aligned}
 V_1 &= V_x = (I_2 - i_y)R_2 \\
 V_1 &= I_2 R_2 \left[ 1 - \frac{(1 - k)R_2 + R_3}{(1 - k)R_2 + R_3 + R_4} \right] \\
 \implies \frac{V_1}{I_2} &= \boxed{z_{12} = R_2 \left[ 1 - \frac{(1 - k)R_2 + R_3}{(1 - k)R_2 + R_3 + R_4} \right]}
 \end{aligned}$$

Using the corresponding values taken from table 2 into the above equations, we get the matrix for the Z parameters:

$$Z = \begin{bmatrix} 23.49282297k\Omega & -4.066985646k\Omega \\ -47.99043062k\Omega & -11.244041914k\Omega \end{bmatrix}$$

Which is in accordance with the values obtained from the simulation.

### Y parameters

From the above matrix for Z parameters, we can calculate the Y parameters as follows:

$$\begin{aligned} \Delta Z &= z_{11}z_{22} - z_{12}z_{21} \\ \Rightarrow \Delta Z &= [(23.49282297 \times -11.244041914) - \\ &\quad (-47.99043062 \times -4.066985646)] \times 10^3 \\ \Delta Z &= -459.326 \times 10^6 \\ Y &= \begin{bmatrix} \frac{z_{22}}{\Delta Z} & -\frac{z_{12}}{\Delta Z} \\ -\frac{z_{21}}{\Delta Z} & \frac{z_{11}}{\Delta Z} \end{bmatrix} \end{aligned}$$

Simplifying the above matrix, we get the Y parameters:

$$Y = \begin{bmatrix} 2.448 \times 10^{-5} \mu\mathcal{U} & -8.8541 \times 10^{-6} \mu\mathcal{U} \\ -1.104480 \times 10^{-4} \mu\mathcal{U} & -5.11 \times 10^{-5} \mu\mathcal{U} \end{bmatrix}$$

### H parameters

Similarly, we can calculate the H parameters as follows:

$$H = \begin{bmatrix} \frac{\Delta Z}{z_{22}} & -\frac{z_{12}}{z_{22}} \\ -\frac{z_{21}}{z_{22}} & \frac{1}{z_{22}} \end{bmatrix}$$

Simplifying the above matrix, we get the H parameters:

$$H = \begin{bmatrix} 40.8507k\Omega & -0.3617V/V \\ -4.2681A/A & -88.9363\mathcal{U} \end{bmatrix}$$

## Load resistance value at port 2

Varying the output resistance at the terminals of port 2 and by calculating the voltage and current across the resistance, we can calculate the maximum power dissipated across the resistance. This can be seen in the following figure:

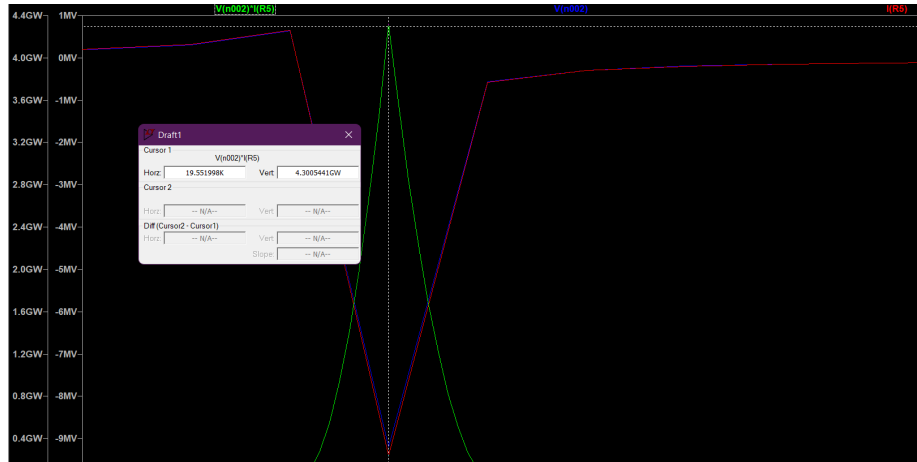


Figure 13: Load resistance value at port 2

According to the simulation results shown above, the value for the resistance at which maximum power transfer occurs is  $19.551998K\Omega$  and the maximum power transferred is  $4.3005441GW$ . The circuit used to determine the above graph is shown below:

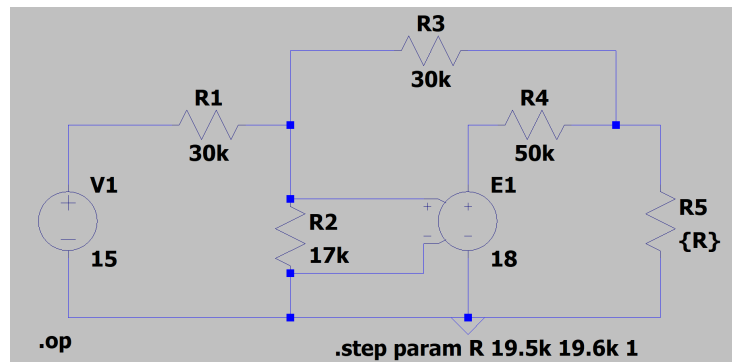


Figure 14: Load resistance value at port 2

The values through which the resistance is varied, is deduced through trial and error to get a clear graph.