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(kΩ)	15kΩ
2	C1 (nF)	1nF

Circuit as on LT SPICE

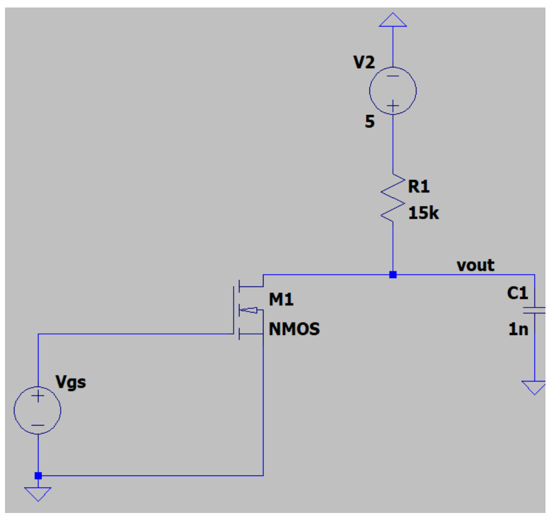

Figure 1: Circuit for question 1

Graphs

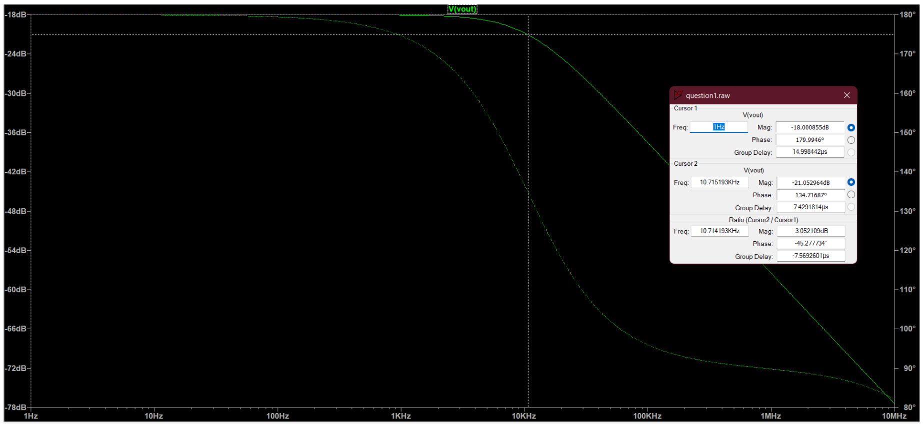

Figure 2: Frequency Response

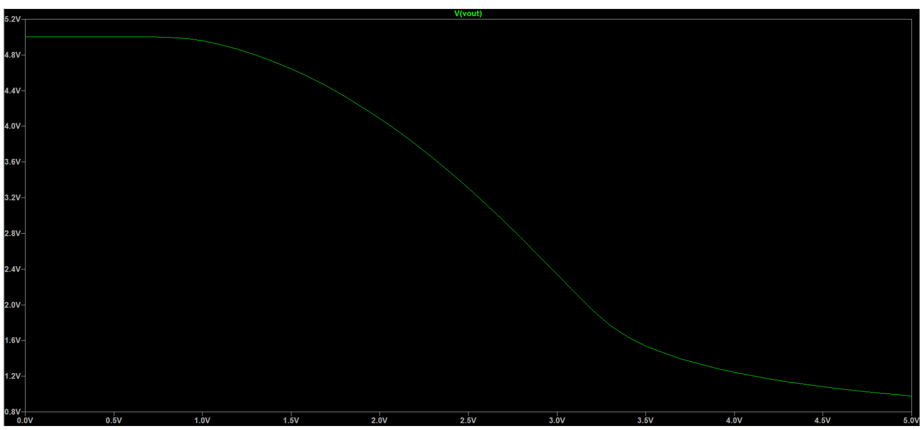

Figure 3: Voltage transfer characteristics

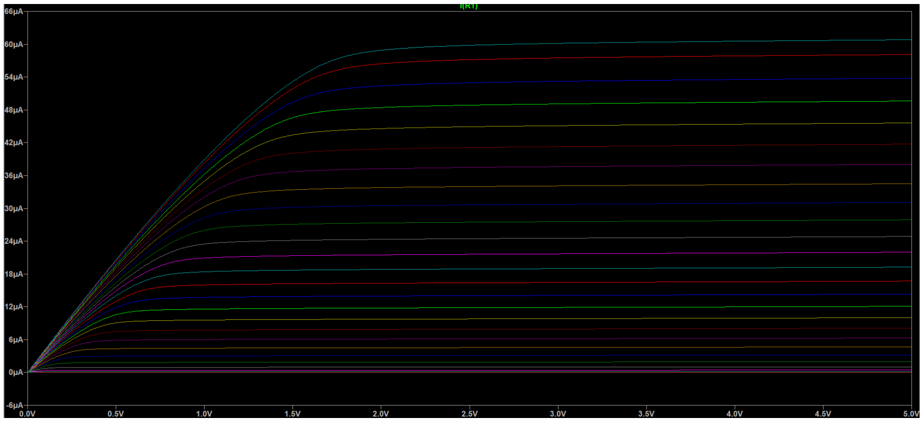

Figure 4: Graph of i_{DS} vs V_{DS}

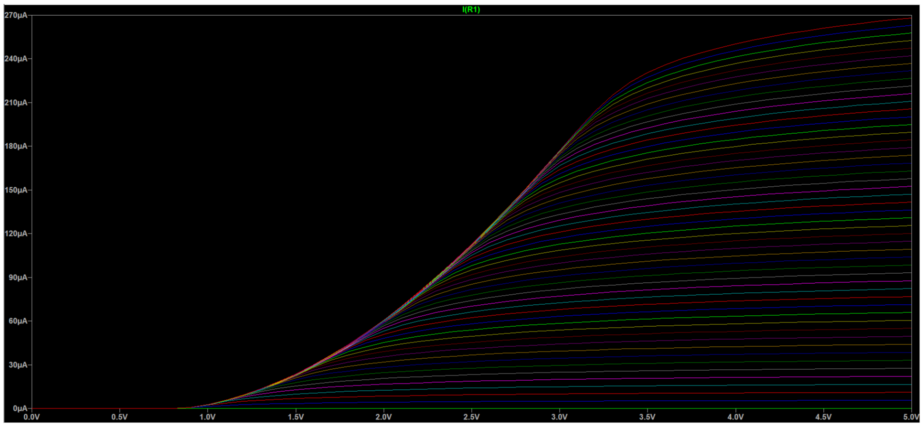

Figure 5: Graph of i_{DS} vs V_{GS}

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

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 $V_{GS} = V_{TH} + V_{OV} = 0.8696061$V. With this value of V_{GS}, the simulation yields the following values:

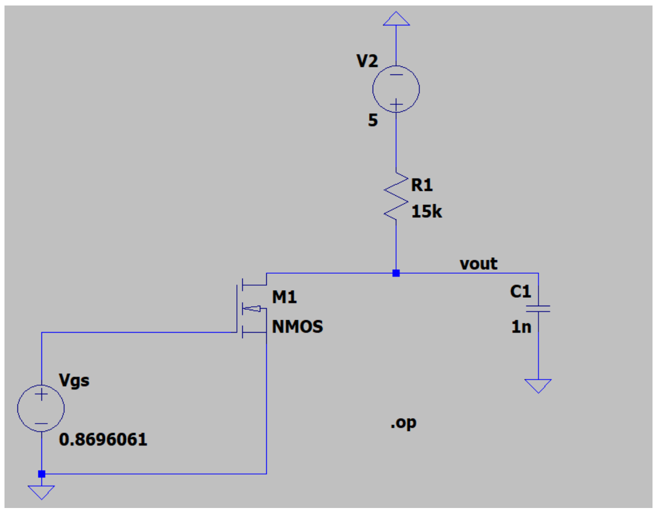

Figure 6: DC operating point circuit

--- 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

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

The value of the output resistance r_0 corresponding to the early effect/channel length modulation is given by:

$$r_0 = \left(\frac{\partial i_D}{\partial V_{DS}} \right)^{-1} \Bigg|_{V_{GS}=\text{constant}}$$

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 $V_{DS} = 5\text{V}$.

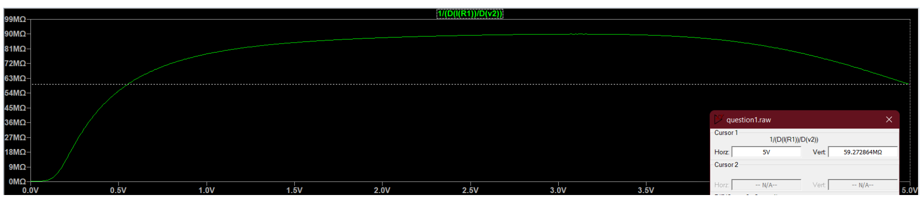

Figure 8: Output resistance for small signal calculations

The value of r_0 we get from this graph is $r_0 = 59.272865\text{M}\Omega$. Collectively, we get the small signal model as below:

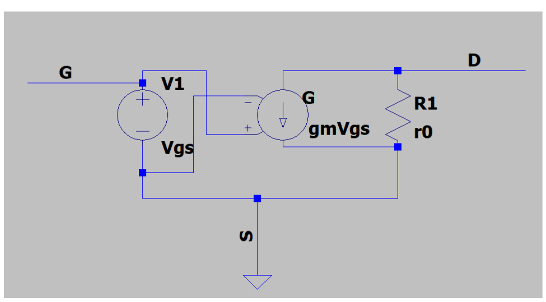

Figure 9: Small signal model

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(kΩ)	30kΩ
2	R_2(kΩ)	17kΩ
3	R_3(kΩ)	30kΩ
4	R_4(kΩ)	50kΩ
5	k	18 V/V

Circuit as on LT SPICE

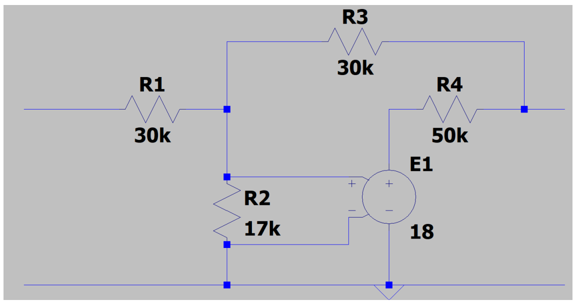

Figure 10: Original 2 port network simulated on LT SPICE

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

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

H parameters

$$H = \begin{bmatrix} 40.851062k\Omega & 361.70211m\mathrm{V/V} \\ -4.268085\mathrm{A/A} & -88.936169\mho \end{bmatrix}$$

Calculations

Z parameters

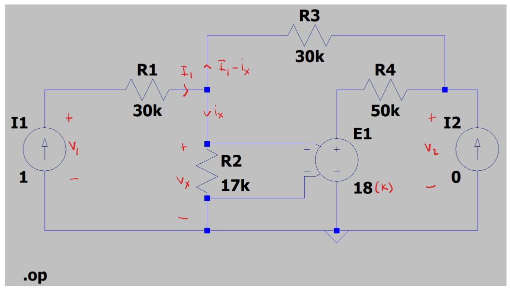

Figure 11: Z parameter circuit 1 (for z_{11} and z_{21})

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

$$
\begin{gathered}
-(I_1 - i_x)(R_3 + R_4) - kV_x + V_x = 0 \\
(i_x - I_1)(R_3 + R_4) = V_x(k-1) \\
(i_x - I_1)(R_3 + R_4) = i_x R_2(k-1) \\
i_x(R_3 + R_4 - R_2(k-1)) = I_1(R_3 + R_4) \\
\implies i_x = I_1 \frac{(R_3 + R_4)}{R_3 + R_4 - R_2(k-1)} \\
V_1 = I_1 R_1 + V_x \\
V_1 = I_1 R_1 + i_x R_2 \\
V_1 = I_1 \left[R_1 + \frac{R_2(R_3 + R_4)}{R_3 + R_4 - R_2(k-1)} \right] \\
\implies \frac{V_1}{I_1} = \boxed{z_{11} = R_1 + \frac{R_2(R_3 + R_4)}{R_3 + R_4 - R_2(k-1)}} \\
\text{Also :} \\
V_2 = (I_1 - i_x)R_4 + kV_x \\
V_2 = (I_1 - i_x)R_4 + k i_x R_2 \\
V_2 = i_x(kR_2 - R_4) + I_1 R_4 \\
V_2 = I_1 \left[R_4 + \frac{(kR_2 - R_4)(R_3 + R_4)}{R_3 + R_4 + R_2(k-1)} \right] \\
\implies \frac{V_2}{I_1} = \boxed{z_{21} = R_4 + \frac{(kR_2 - R_4)(R_3 + R_4)}{R_3 + R_4 - R_2(k-1)}}
\end{gathered}
$$

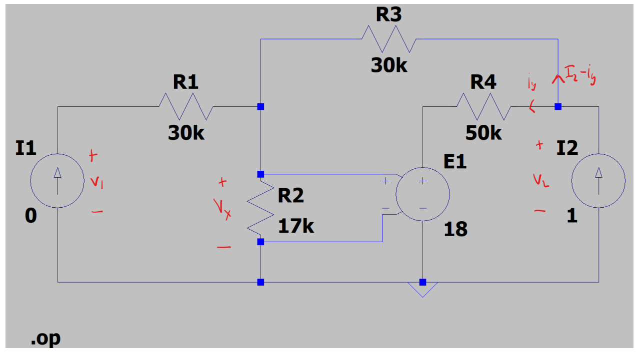

Figure 12: Z parameter circuit 2 (for z_{12} and z_{22})

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

$$
\begin{gathered}
-R_3(I_2 - i_y) - V_x + kV_x + i_y R_4 = 0 \\
i_y R_4 - R_3(I_2 - i_y) = (1-k)V_x \\
i_y R_4 - R_3(I_2 - i_y) = (1-k)(I_2 - i_y)R_2 \\
i_y R_4 = (I_2 - i_y)[(1-k)R_2 + R_3] \\
(R_4 + R_3 + (1-k)R_2)i_y = I_2[(1-k)R_2 + R_3] \\
\implies i_y = I_2 \frac{(1-k)R_2 + R_3}{(1-k)R_2 + R_3 + R_4} \\
V_2 = i_y R_4 + kV_x \\
V_2 = i_y R_4 + k(I_2 - i_y)R_2 \\
V_2 = i_y[R_4 - kR_2] + KI_2R_2 \\
V_2 = I_2\left[\frac{(R_4 - kR_2)\{(1-k)R_2 + R_3\}}{(1-k)R_2 + R_3 + R_4} + kR_2\right] \\
\implies \frac{V_2}{I_2} = \boxed{z_{22} = \frac{(R_4 - kR_2)\{(1-k)R_2 + R_3\}}{(1-k)R_2 + R_3 + R_4} + kR_2} \\
\text{Also :} \\
V_1 = V_x = (I_2 - i_y)R_2 \\
V_1 = I_2R_2\left[1 - \frac{(1-k)R_2 + R_3}{(1-k)R_2 + R_3 + R_4}\right] \\
\implies \frac{V_1}{I_2} = \boxed{z_{12} = R_2\left[1 - \frac{(1-k)R_2 + R_3}{(1-k)R_2 + R_3 + R_4}\right]}
\end{gathered}
$$

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:

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

Simplifying the above matrix, we get the Y parameters:

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

H parameters

Similarly, we can calculate the H parameters as follows:

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

Simplifying the above matrix, we get the H parameters:

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

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:

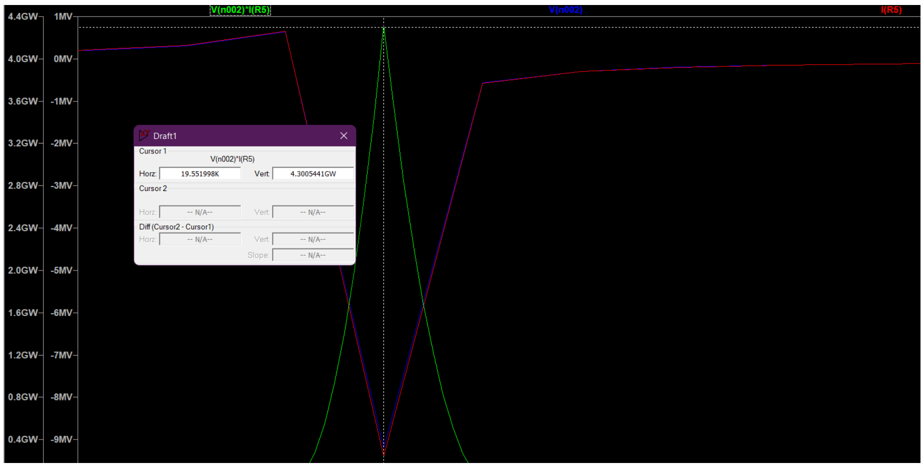

Figure 13: Load resistance value at port 2

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:

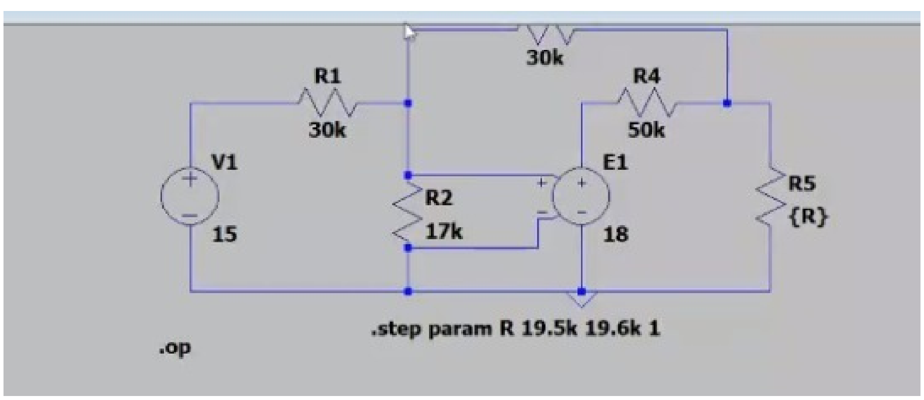

Figure 14: Load resistance value at port 2

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