ECEN 474/704: Lab 01

Introduction to Cadence and MOS Device Characterization

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I. DISCUSSION OF THE LAB AND RESULTS

The purpose of this lab was to show how certain parameters affect the performance of a transistor, both for nMOS and pMOS transistors. First the lab teaches how to attain the required measurements to see the effects of the changes. The parameters we are interested in are shown below in **Table 1.** Additionally, the conditions it was measured in are recorded in **Table 2**. We are concerned with the effects of : μCox, Vth, θ, λ, f_T, A_i. Personally, I am most intrigued by the effects on the f_T parameter.

When the **width** is adjusted we find that although μC_{ox} is dependent on all parameters set, it seems to be more dependent upon the W. This makes sense because there is more surface area for the transistor to attain a higher oxide capacitance. Additionally, with a bigger width, there are more paths for the electrons to travel, meaning a higher mobility of electrons. For the V_{th} not much changes as it's more based on the effectiveness of the gate to channel to allow current through. So influencing the width doesn't affect it much since the gate covers the entire width of the channel anyways, despite its size. The thermal resistance **θ** however is greatly affected by the geometry of the transistor. With an increased surface area, there is a lot more for the transistor to heat up and it's easier to dissipate the energy. Width also seems to have a positive relationship with f_t**.** This makes sense since, as mentioned before, increasing the width of the transistor allows for more current to flow and have a higher mobility. With a higher mobility, its easier to oscillate from on and off faster and faster. This could be shown as to increase the transconductance of the transistor (gm) which is inversely proportional to the gain A_i. Therefore, this explains the dip in the intrinsic gain of the transistor.

The number of **fingers** is really important mainly for the V_{th} since the gate now has a "firmer grasp" upon the channel in which it's created. With a higher control over the channel it can allow for higher mobility which is seen in μC_{ox} and f_T**.** Since this doesn't necessarily change the physical amount of flow electrons through the channel, the thermal (**θ**) and channel modulation (**λ**) characters remain relatively unchanged.

Changing the **length** of the transistor has a massive effect on the intrinsic gain A_i and the channel length modulation **λ.** For the channel modulation this makes sense since the modulation has a longer channel to cover over. However I must say that I was surprised by its significant effect on intrinsic gain. In fact I would say that it has the highest effect upon intrinsic gain. However the effect is completely valid since a longer length gives a higher output resistance through the transistor, attaining a bigger gain. Trade off comes with it, usually decreasing the transconductance and dramatically lowering f_T. Length does seem to be the most powerful influencer of the transistor's characteristics, where we can trade off higher speeds for greater gains.

Overall when a transistor is a **pfetx** the same trends mentioned above apply similarly, but across the board, performs less optimally than its **nfetx** counterparts. The only advantage it seems to have is a lower threshold voltage to activate. At first glance a high benefit could be a lower oxidised capacitance, but I believe that simply the mobility **μ** was lowered since it conducts less effectively, and the C_{ox} stayed the same.

II. SUMMARY OF RESULTS

Table 1

Transistor Characteristics

Parameter	**μC_{ox}**	**V_{th}**	**θ**	**λ**	**f_T**	**A_i**
Condition 1	167.4µ	460.4 mV	0.920	0.3562	49.54 GHz	19.82 | 24.01
Condition 2	217.2µ	460.1 mV	1.295	0.6067	46.31 GHz	17.08 | 29.74
Condition 3	181.2µ	442.3 mV	0.9365	0.4043	52.54 GHz	18.53 | 33.47
Condition 4	214.3µ	447.0 mV	0.9942	0.1608	25.49 GHz	49.48 | 121.23
Condition 5	47.37µ	432.2 mV	1.386	0.6516	8.809 GHz	17.02 | 27.55
Condition 6	56.49µ	414.3 mV	1.474	0.5982	9.646 GHz	16.25 | 26.31
Condition 7	47.37µ	432.2 mV	1.386	0.5566	10.88 GHz	17.01 | 27.52
Condition 8	47.53µ	421.6 mV	1.267	0.2012	4.317 GHz	44.29 | 56.05

Note: For the Ai, the values are {approximated} | {simulation}, i wanted to see how off the error was of the approximation since i could.

Table 2

Transistor set properties

Condition #	W/L	fingers	nfetx/pfetx
1	0.5µ/0.18µ	1	nfetx
2	5µ/0.18µ	1	nfetx
3	5µ/0.18µ	10	nfetx
4	5µ/0.27µ	1	nfetx
5	0.5µ/0.18µ	1	pfetx
6	5µ/0.18µ	1	pfetx
7	5µ/0.18µ	10	pfetx
8	5µ/0.27µ	1	pfetx

Table 3

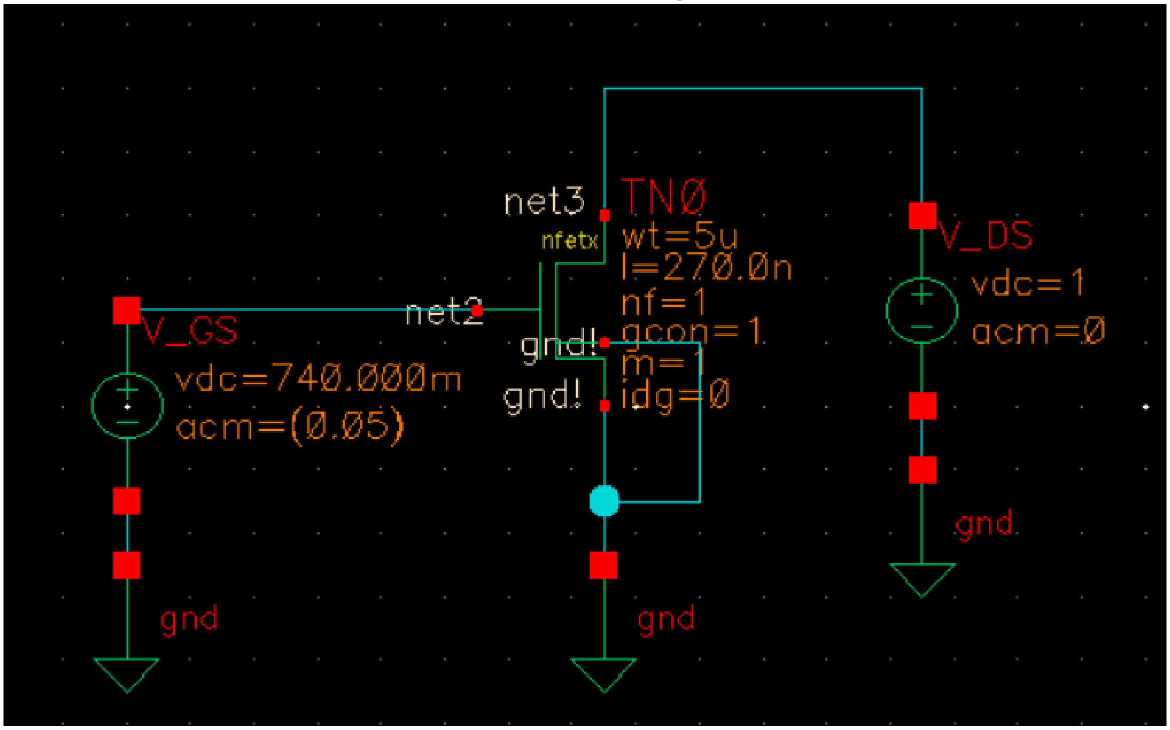
Set conditions to find Ai, along with table 2 conditions

Condition #	Vgs	ID	Veff
1.1	684.45 mV	14.801 uA	224.05
2	460.00 mV	9.301 uA	0
3	442.3 mV	10.47 uA	0
4	447.0 mV	6.873 uA	0
5	432.2 mV	0.3038 uA	
6	414.3 mV	3.42 uA	
7	432.2 mV	3.038 uA	
8	421.6 mV	2.069 uA	

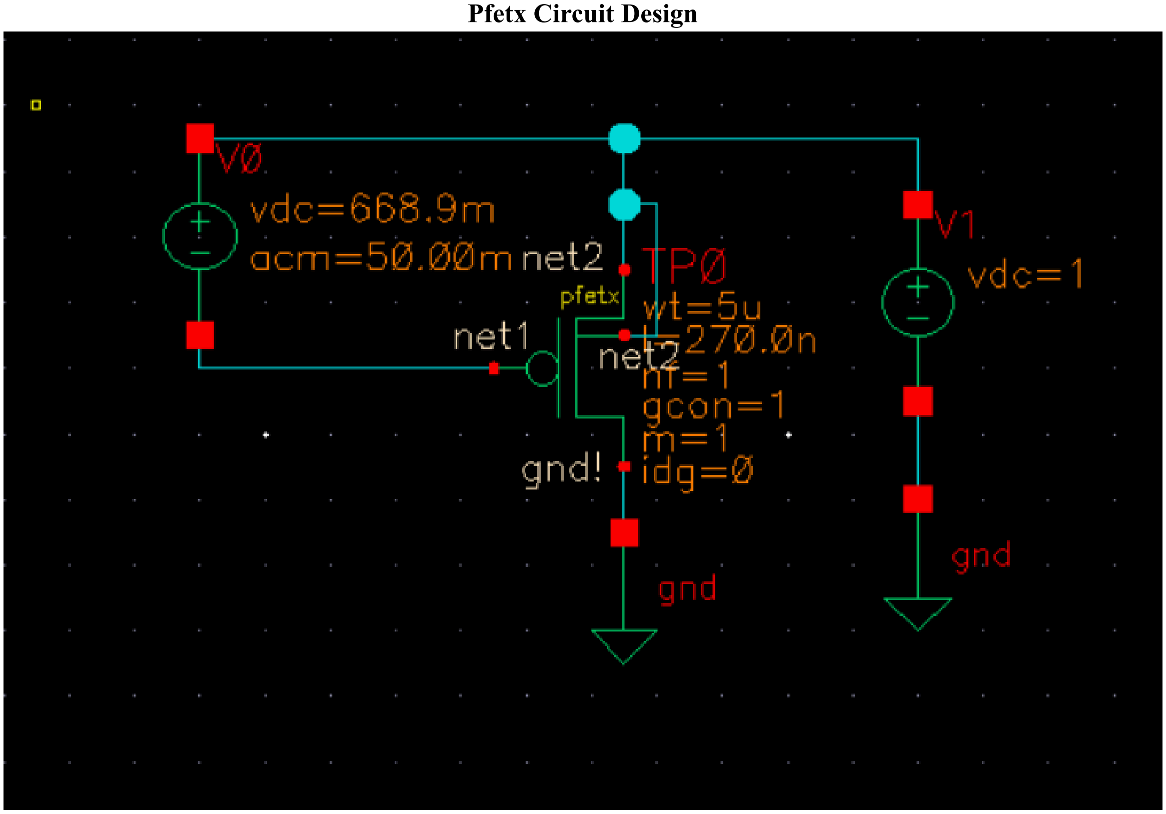
Note: These values are determined at the most mobile point found in the DC simulation. Therefore Vgs = Vt+ 1/4theta, and the current source will be set to the respective value found in previous simulations.

III. SUB-CIRCUIT AND TEST BENCH SCHEMATICS

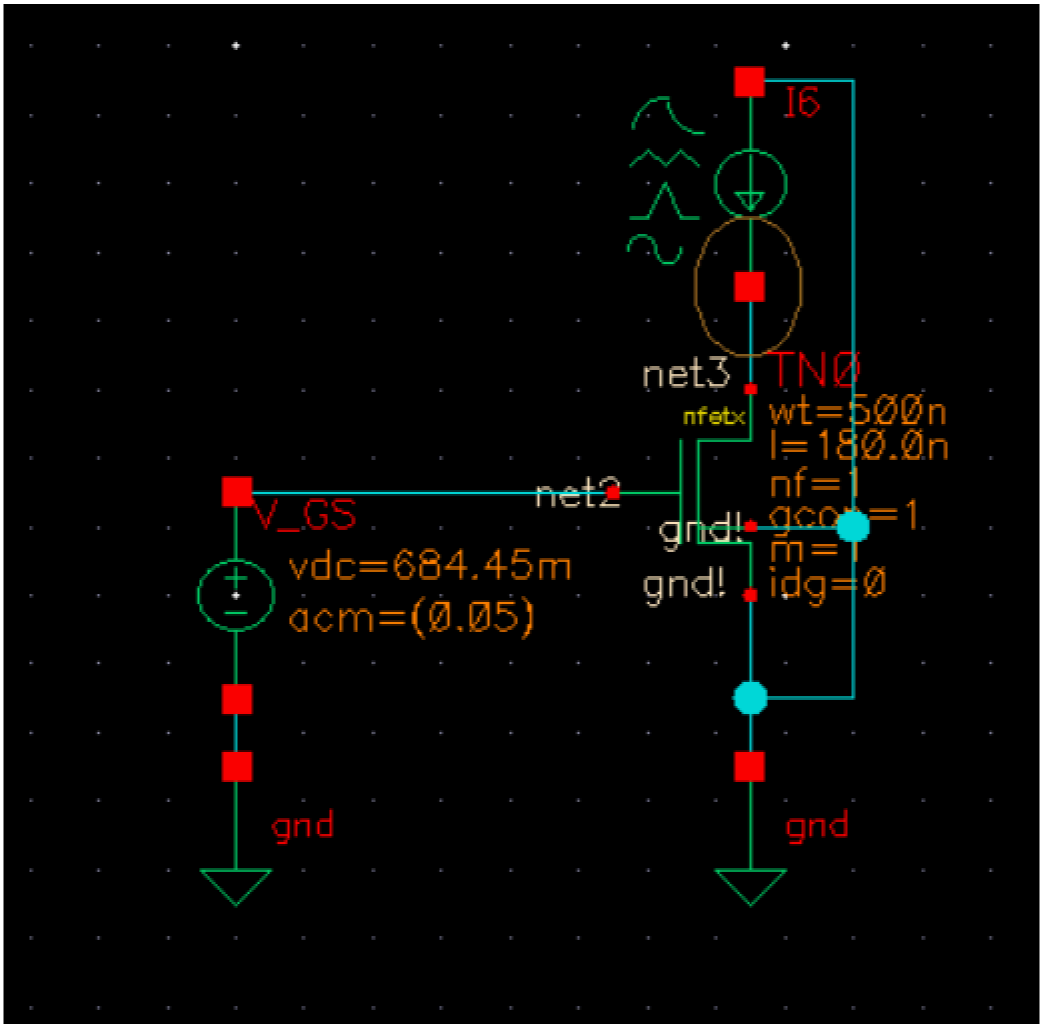
Nfetx Circuit Design



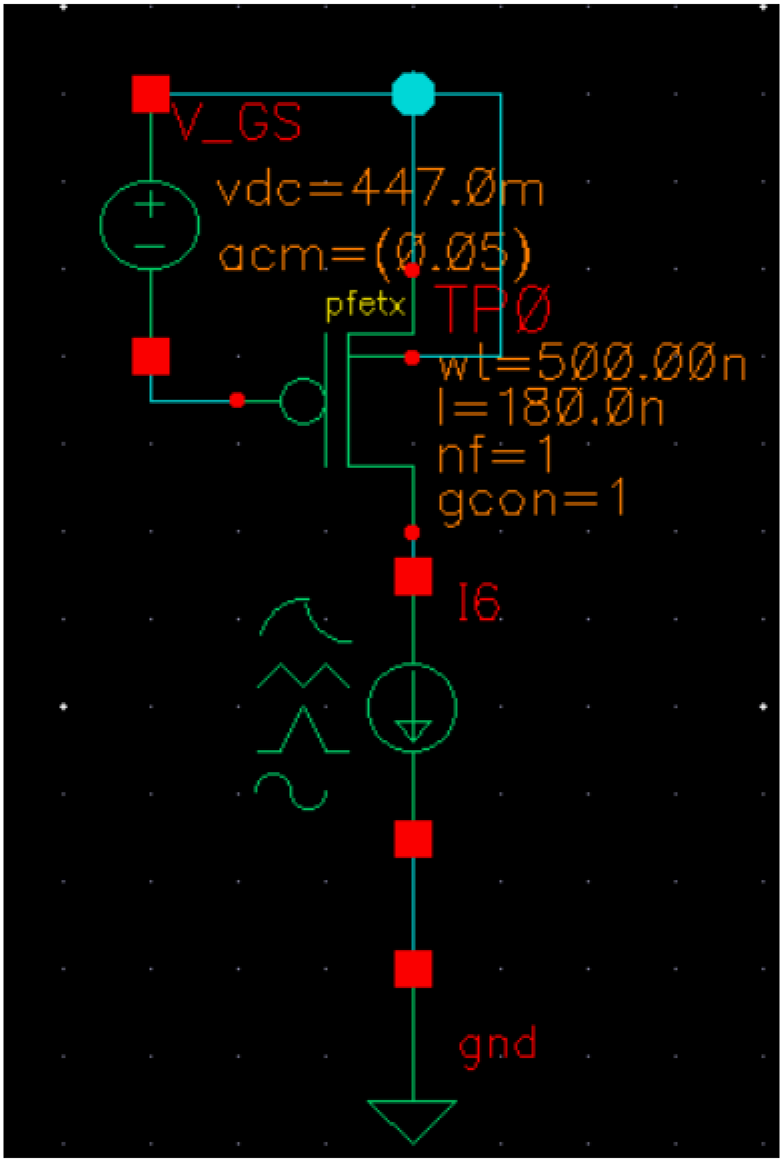
Pfetx Circuit Design



Nmos Circuit to find Ai



Pmos Circuit to find Ai



IV. SIMULATION RESULTS

Equations used in lab

V_{GS} sweep simulation:

I_D_1 = i("/TN0/D" ?result "dc")
D1_1 = deriv(I_D_1)
D2_1 = deriv(D1_1)
Max_slope_1 = cross(D2_1 ymax(D2_1)) //Gives the V_{GS} coordinates I will use later
TL = tangent(D1_1 ?x Max_slope_1 ?y value(D1_1 Max_slope_1) ?slope value(D2_1 Max_slope_1))
V_t_1 = cross(TL 0)
uCox = ((value(D2_1 Max_slope_1) * L) / W)
HzL_pt = cross(D2_1 0) //gives the point for the horizontal line to exist at
HzL = tangent(D1_1 ?x HzL_pt ?y value(D1_1 HzL_pt) ?slope value(D2_1 HzL_pt))
thetaEq = cross(TL value(HzL 1) 1 "either" nil nil 0.01) // gives **val** to be use in the theta equation.
Theta_1 = ((1 / (thetaEq - V_t_1)) * 0.5)
W = (whatever the condition is)
L = (whatever the condition is)

ID_for_Ai = value(I_D_1 (V_t_1 + ((1 / 4) * theta_1))) **// For when we need Ai**
VGS_for_AI **= (V_t_1 + ((1 / 4) * theta_1))**

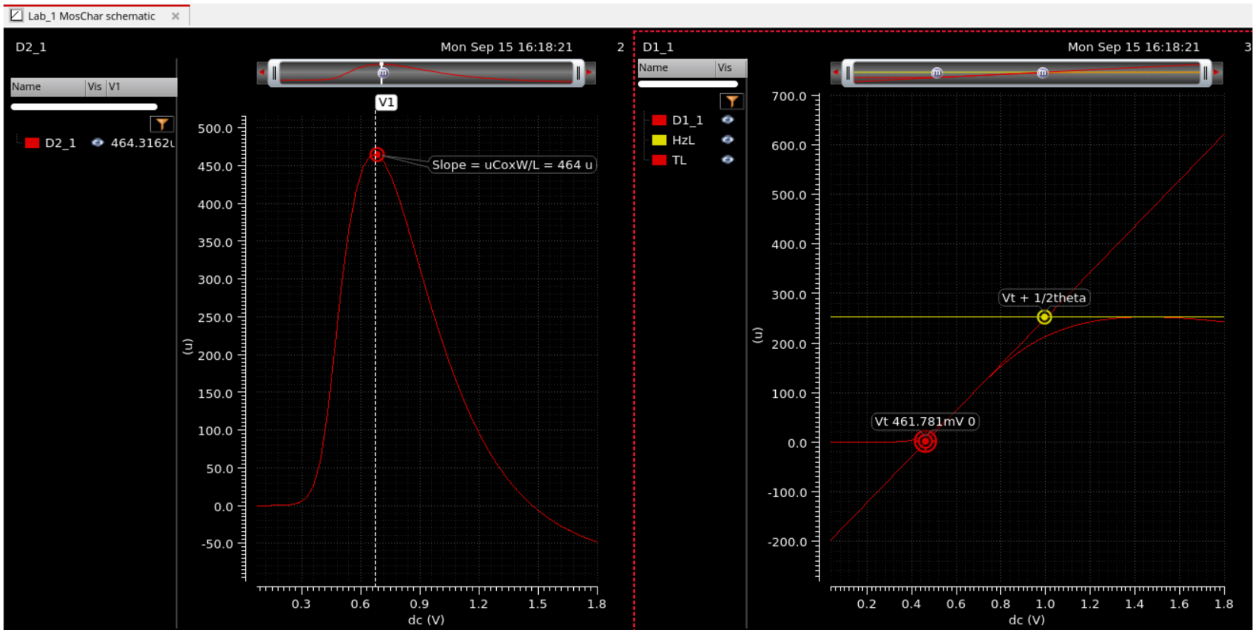
V_{DS} / AC sweep simulation:
Input = IF("/V_GS/PLUS")
Output = IF("/TN0/D")
Gain = mag((output / input))
Ft = cross(gain 1)
Plot2 = (deriv(i("/TN0/D" ?result "dc")) / i("/TN0/D" ?result "dc"))   //Plot used to find **lambda**
lambda = (value(plot2 1) / (1 - value(plot2 1)))
Theta = (whatever we found in previous step)
Ai = (2 / (lambda * (1 / (4 * theta))))

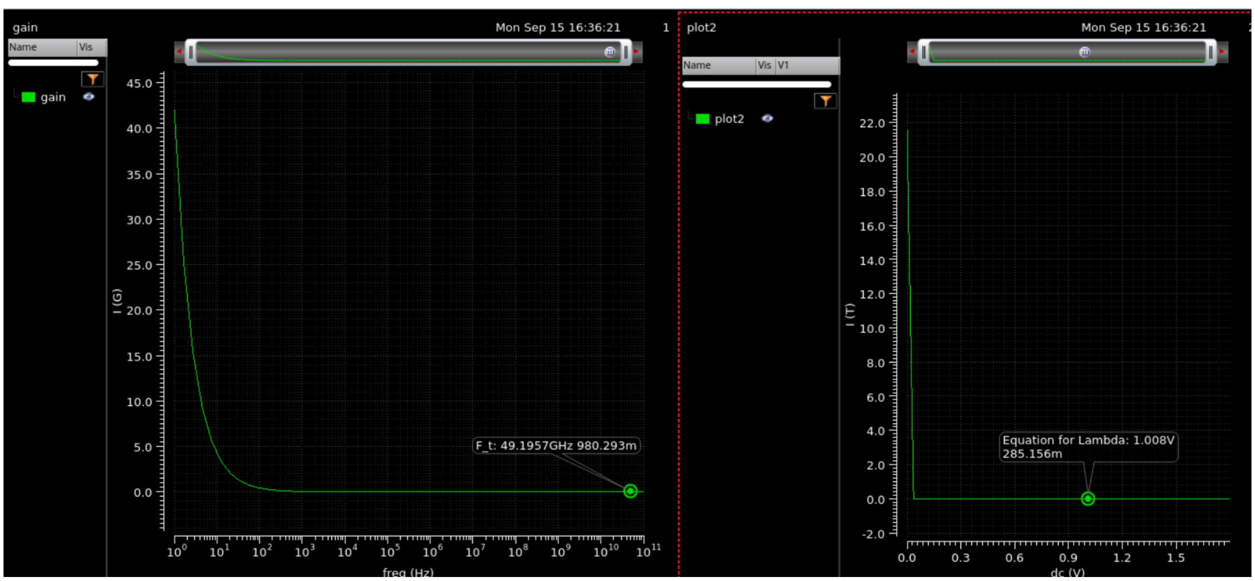
Ai circuit calculation
V_gs = mag(v("/net2" ?result "ac"))
ID = (whatever value we set it too)
V_out = 1V since thats what we force it to be with the set ID
ac_V_out = mag(v("/net3" ?result "ac"))
R_ds = 1V / ID
Gm = (ac_V_out / (r_ds * V_gs))
Ai = (gm * r_ds)

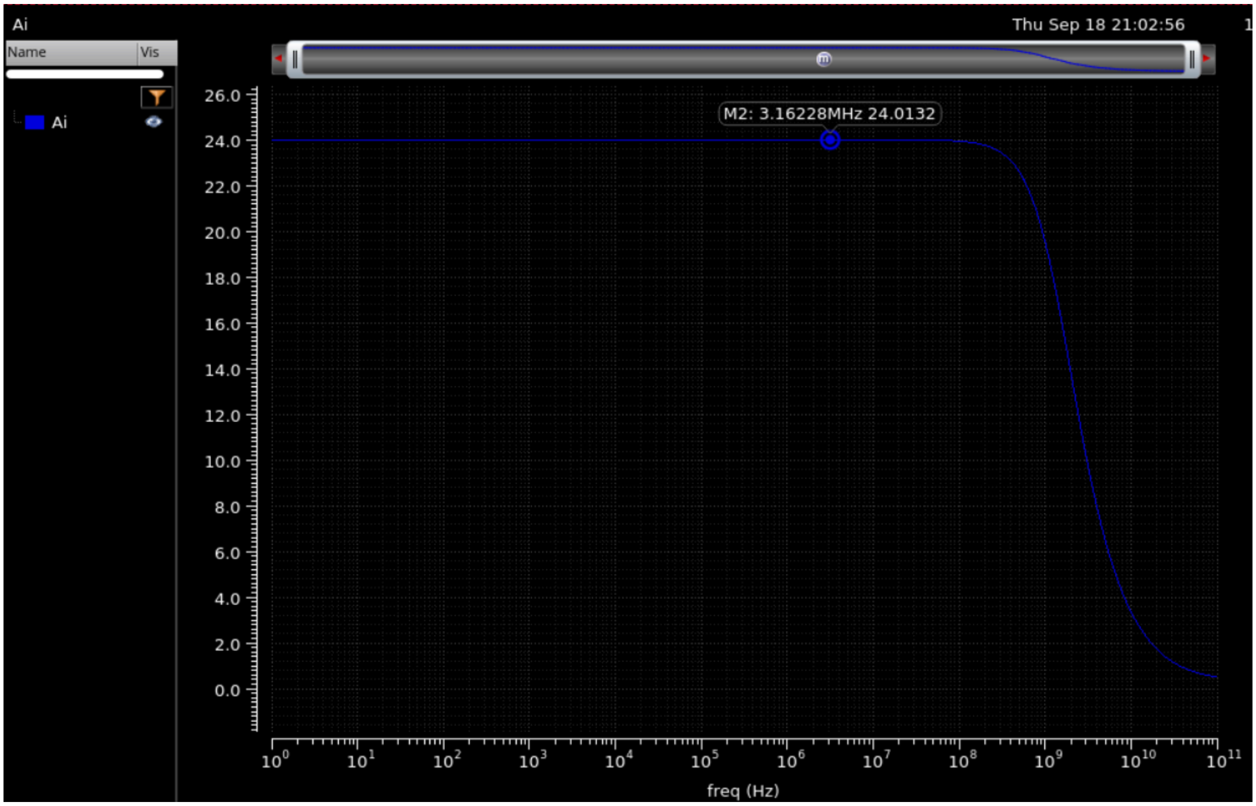
Screenshots

Note:the values submitted are calculated by the computer and might not match exactly what is shown in graphs. Additionally, the values shown in the graph could be equations to SOLVE its respective variables.

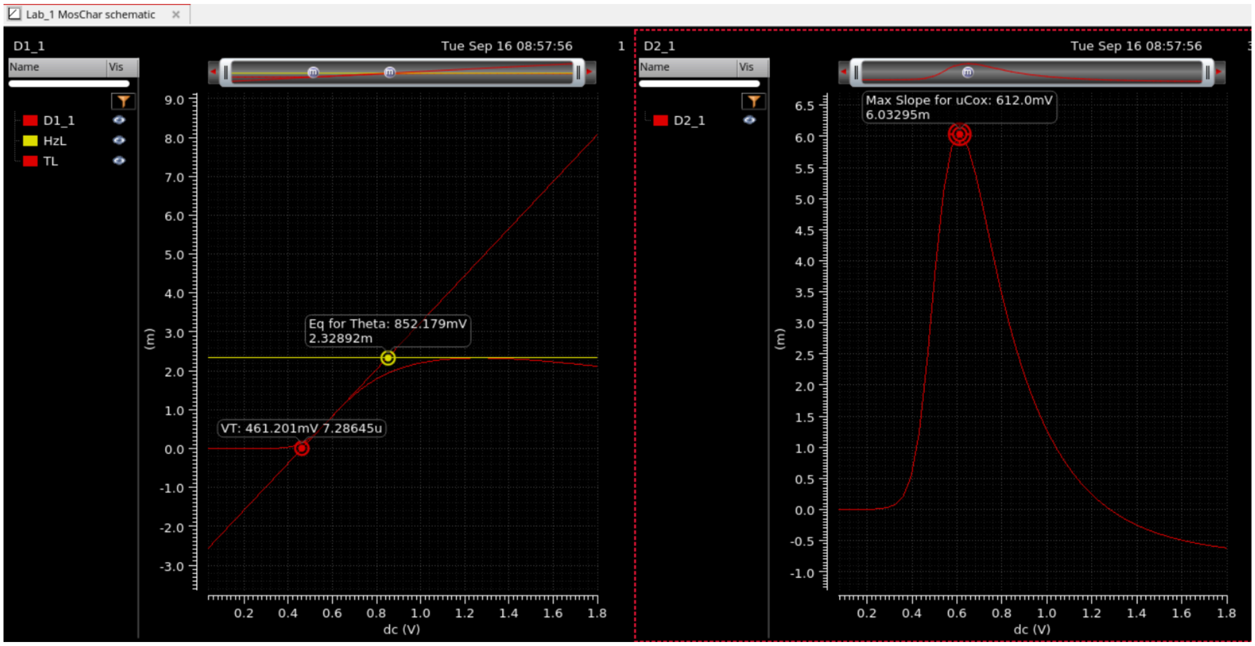
Condition 1



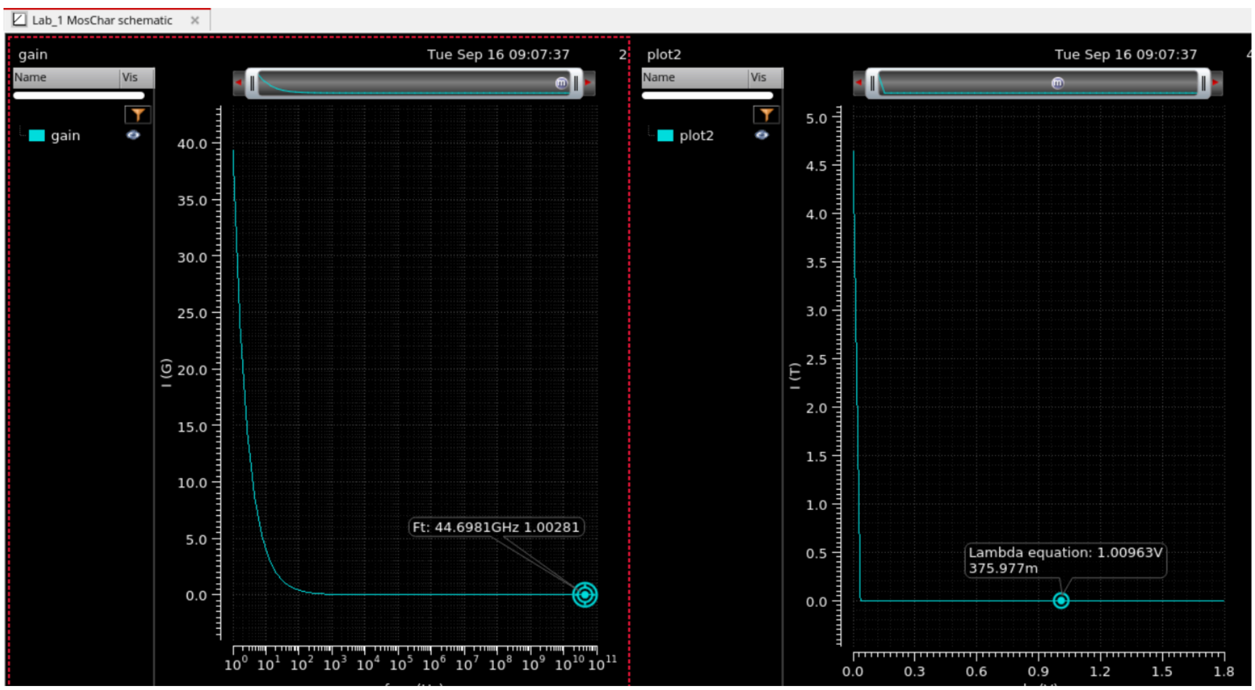



Ai
Thu Sep 18 21:02:56
Name
Vis
Ai
M2: 3.16228MHz 24.0132
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11}
freq (Hz)

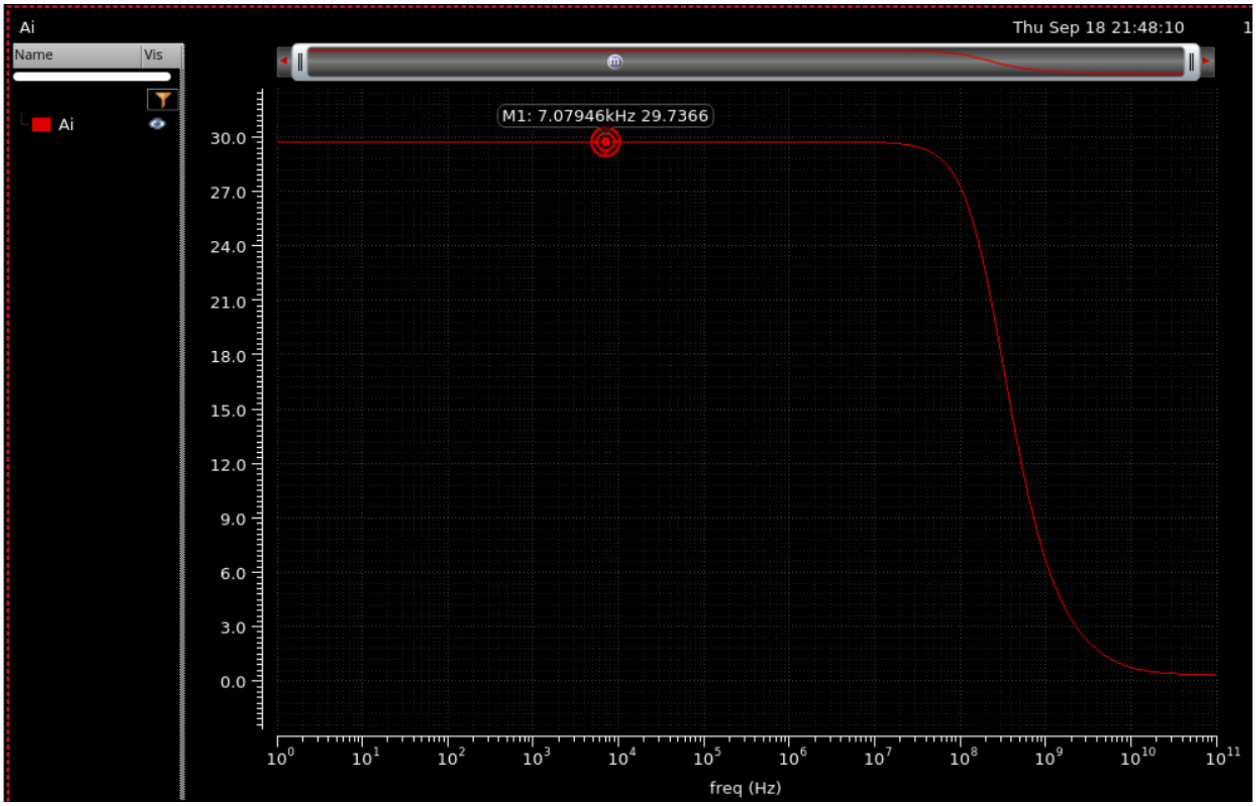
Condition 2



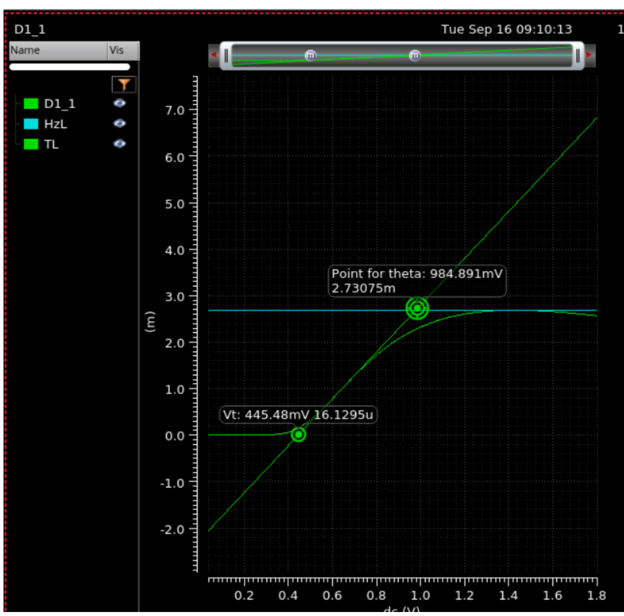
Lab_1 MosChar schematic
D1_1
Tue Sep 16 08:57:56
D1_1
HzL
TL
Eq for Theta: 852.179mV
2.32892m
VT: 461.201mV 7.28645u
(m)
dc (V)
D2_1
Tue Sep 16 08:57:56
D2_1
Max Slope for uCox: 612.0mV
6.03295m
(m)
dc (V)

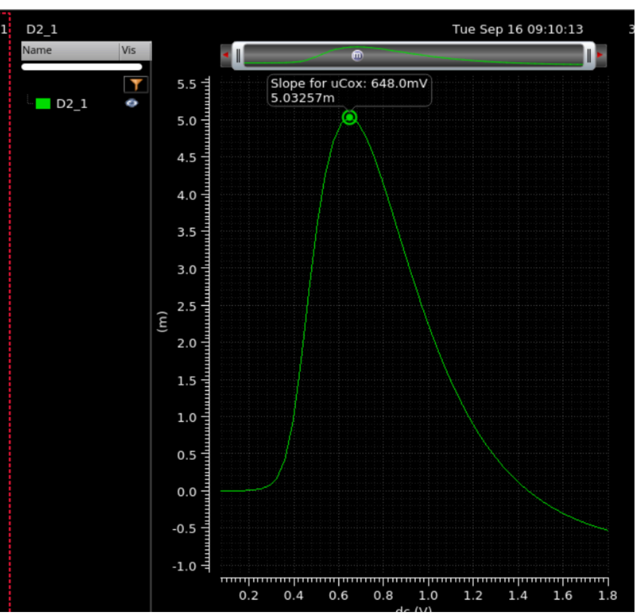


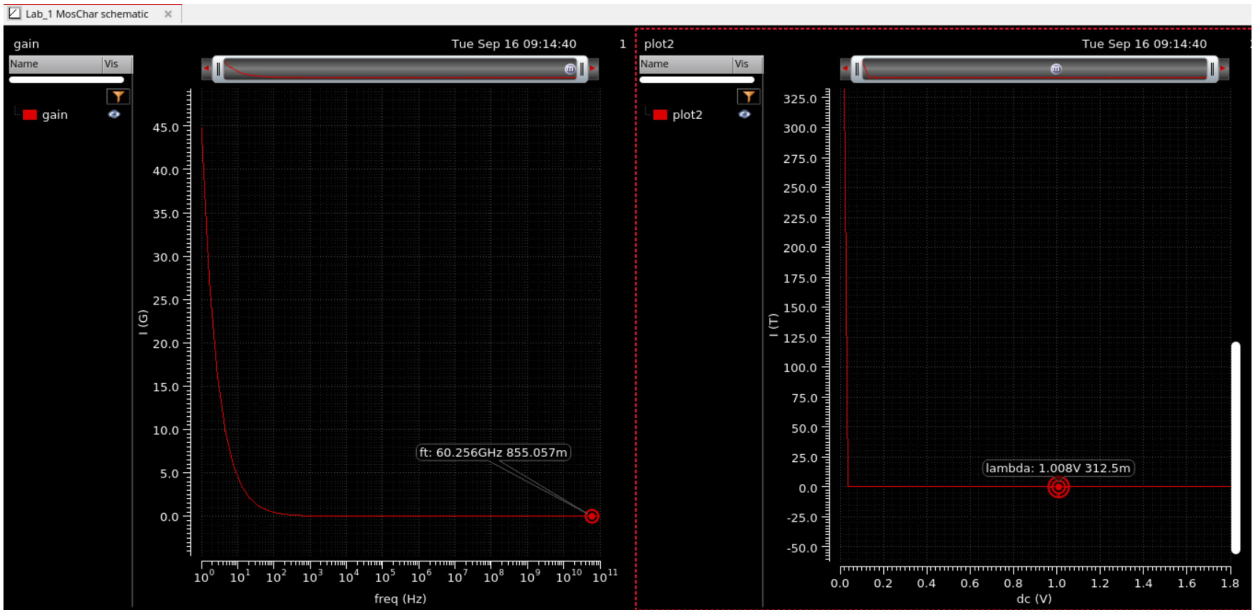
Lab_1 MosChar schematic
gain
Tue Sep 16 09:07:37
gain
Ft: 44.6981GHz 1.00281
I (G)
plot2
Tue Sep 16 09:07:37
plot2
Lambda equation: 1.00963V
375.977m
I (T)


Ai
Thu Sep 18 21:48:10
Name
Vis
Ai
M1: 7.07946kHz 29.7366
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
freq (Hz)

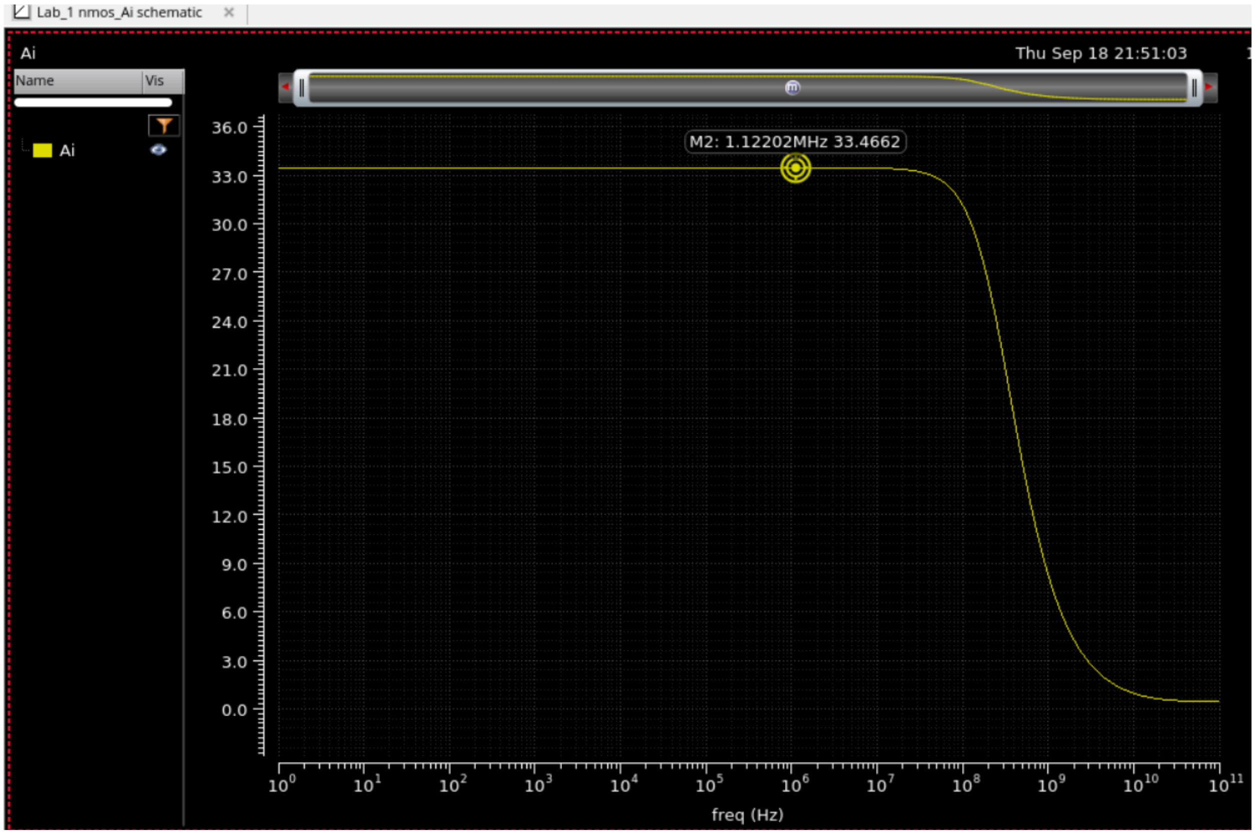
Condition 3


D1_1
Tue Sep 16 09:10:13
Name
Vis
D1_1
HzL
TL
Point for theta: 984.891mV
2.73075m
Vt: 445.48mV 16.1295u
(m)


D2_1
Tue Sep 16 09:10:13
Name
Vis
D2_1
Slope for uCox: 648.0mV
5.03257m
(m)

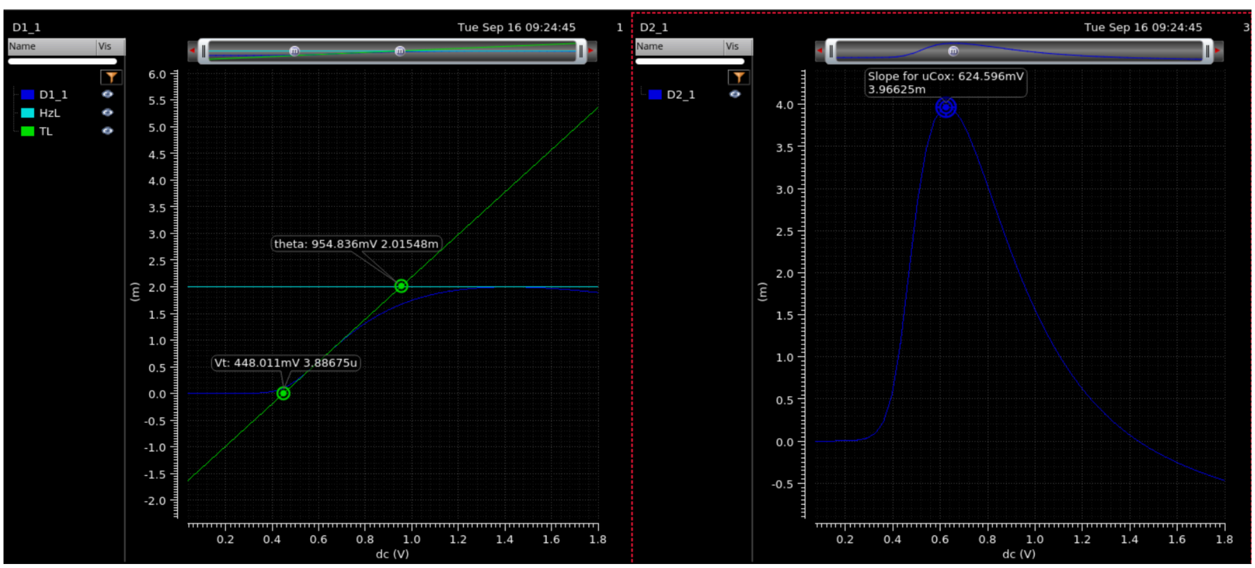


Lab_1 MosChar schematic
gain
Tue Sep 16 09:14:40
Name
Vis
gain
I (G)
freq (Hz)
ft: 60.256GHz 855.057m
plot2
Tue Sep 16 09:14:40
Name
Vis
plot2
I (T)
dc (V)
lambda: 1.008V 312.5m

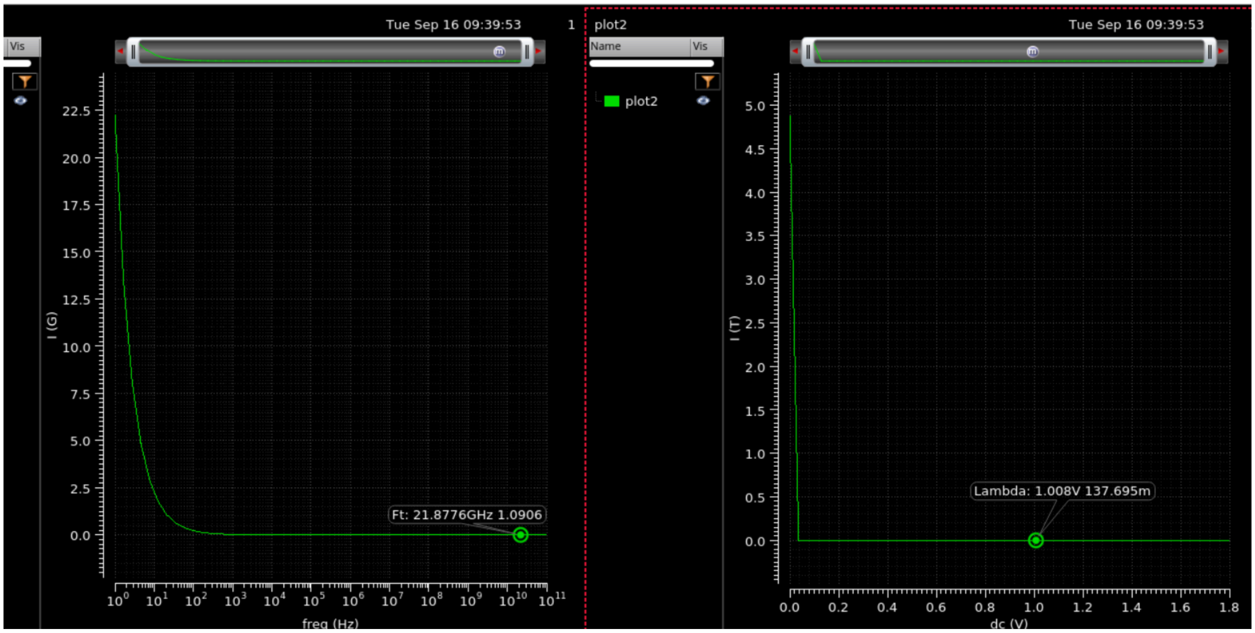


Lab_1 nmos_Ai schematic
Ai
Thu Sep 18 21:51:03
Name
Vis
Ai
M2: 1.12202MHz 33.4662
36.0
33.0
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11}
freq (Hz)

Condition 4

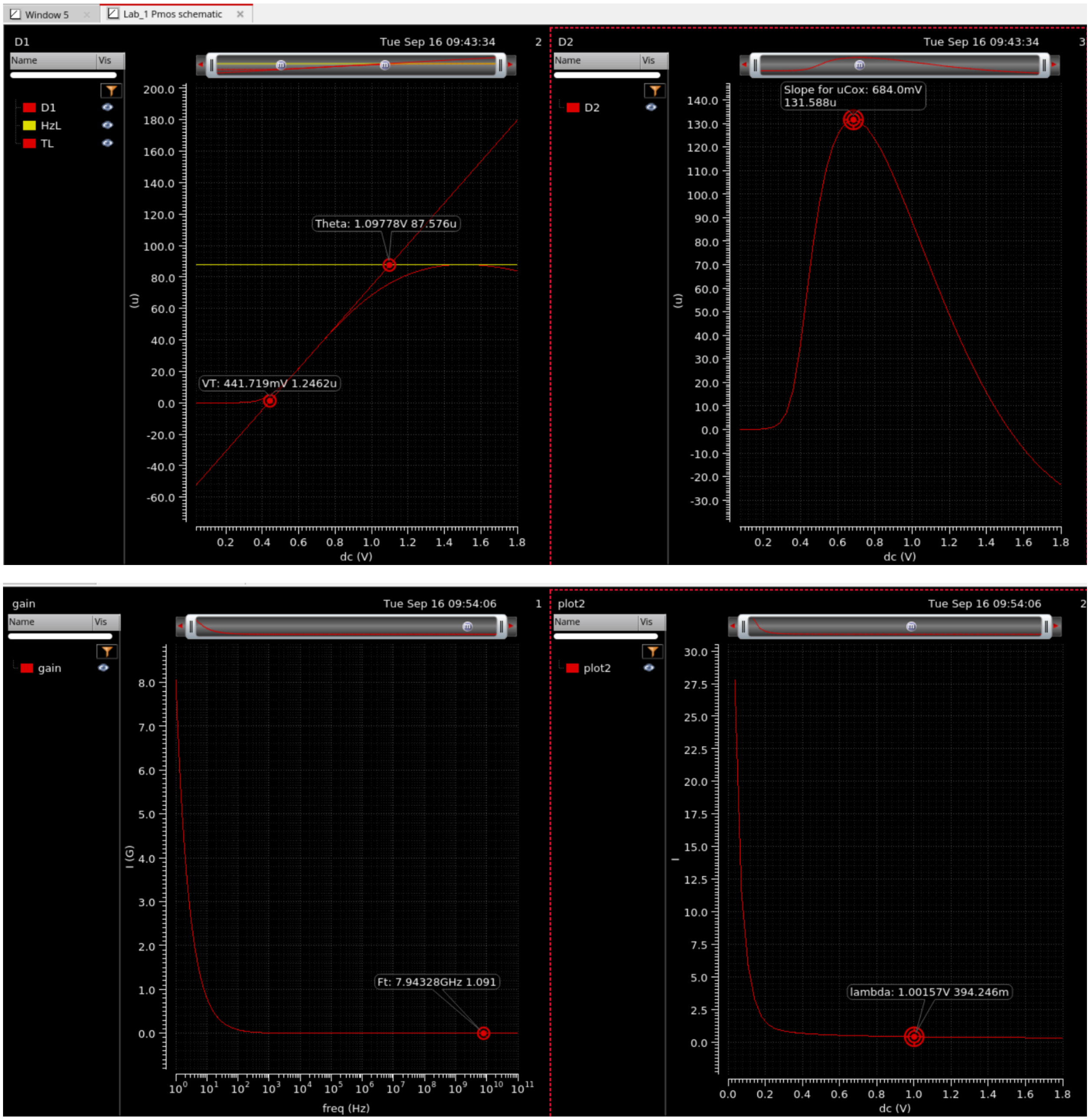


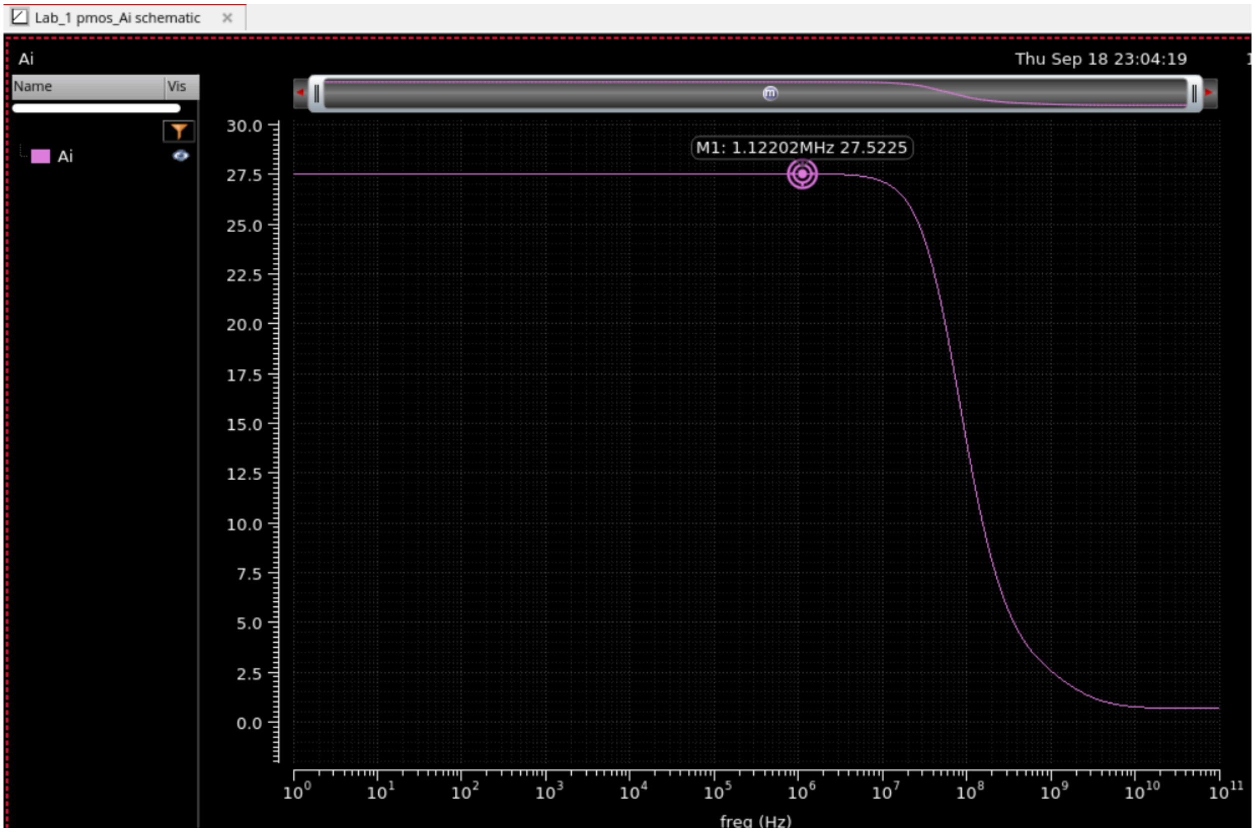
D1_1
Tue Sep 16 09:24:45
Name
Vis
D1_1
HzL
TL
theta: 954.836mV 2.01548m
Vt: 448.011mV 3.88675u
(m)
dc (V)
D2_1
Tue Sep 16 09:24:45
Name
Vis
D2_1
Slope for uCox: 624.596mV
3.96625m
(m)
dc (V)



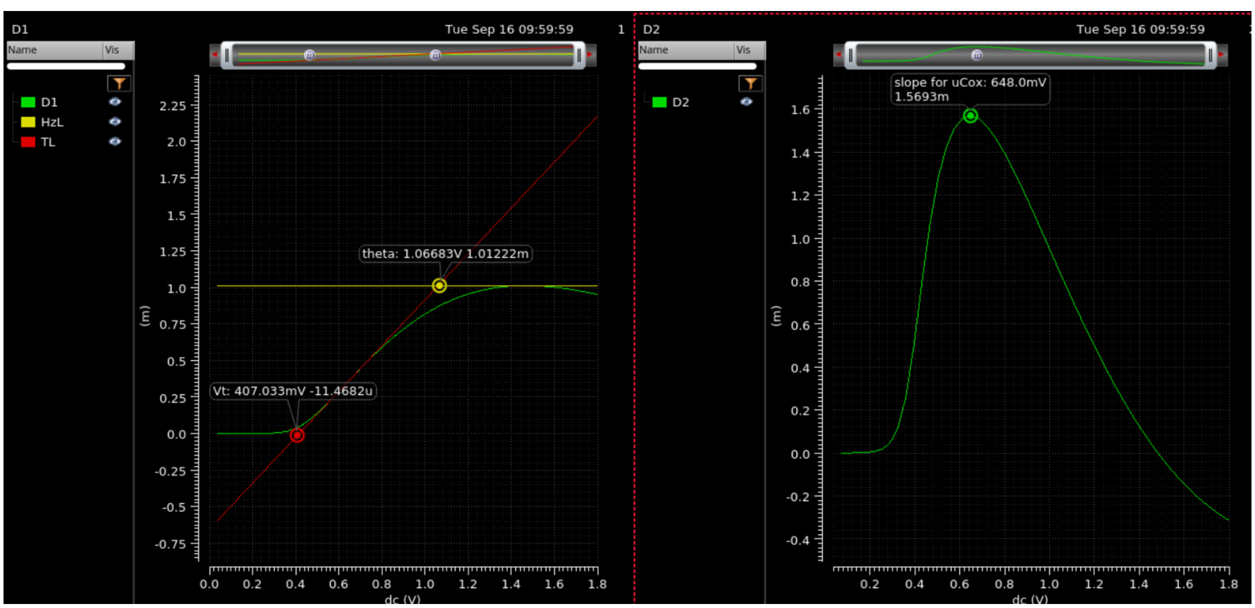
Tue Sep 16 09:39:53
Vis
I (G)
Ft: 21.8776GHz 1.0906
freq (Hz)
plot2
Name
Vis
plot2
Tue Sep 16 09:39:53
I (T)
Lambda: 1.008V 137.695m
dc (V)

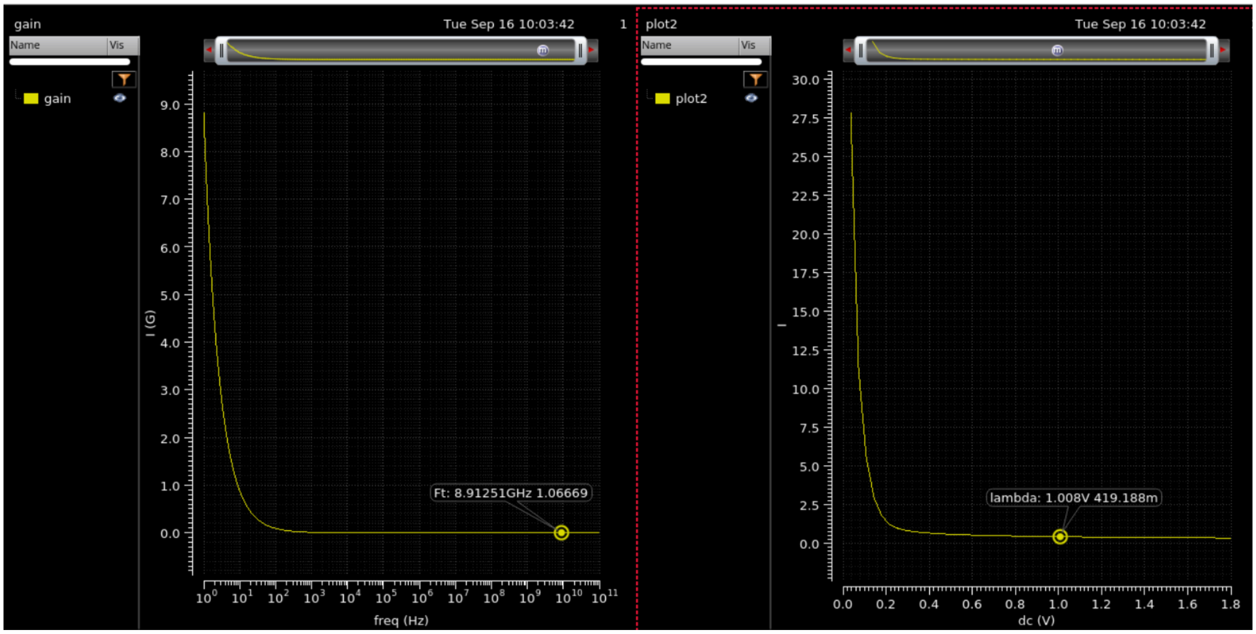
Condition 5


Window 5
Lab_1 Pmos schematic
D1
Tue Sep 16 09:43:34
Name
Vis
D1
HzL
TL
Theta: 1.09778V 87.576u
VT: 441.719mV 1.2462u
(u)
dc (V)
D2
Tue Sep 16 09:43:34
D2
Slope for uCox: 684.0mV
131.588u
(u)
dc (V)
gain
Tue Sep 16 09:54:06
gain
Ft: 7.94328GHz 1.091
I (G)
freq (Hz)
plot2
Tue Sep 16 09:54:06
plot2
lambda: 1.00157V 394.246m
dc (V)

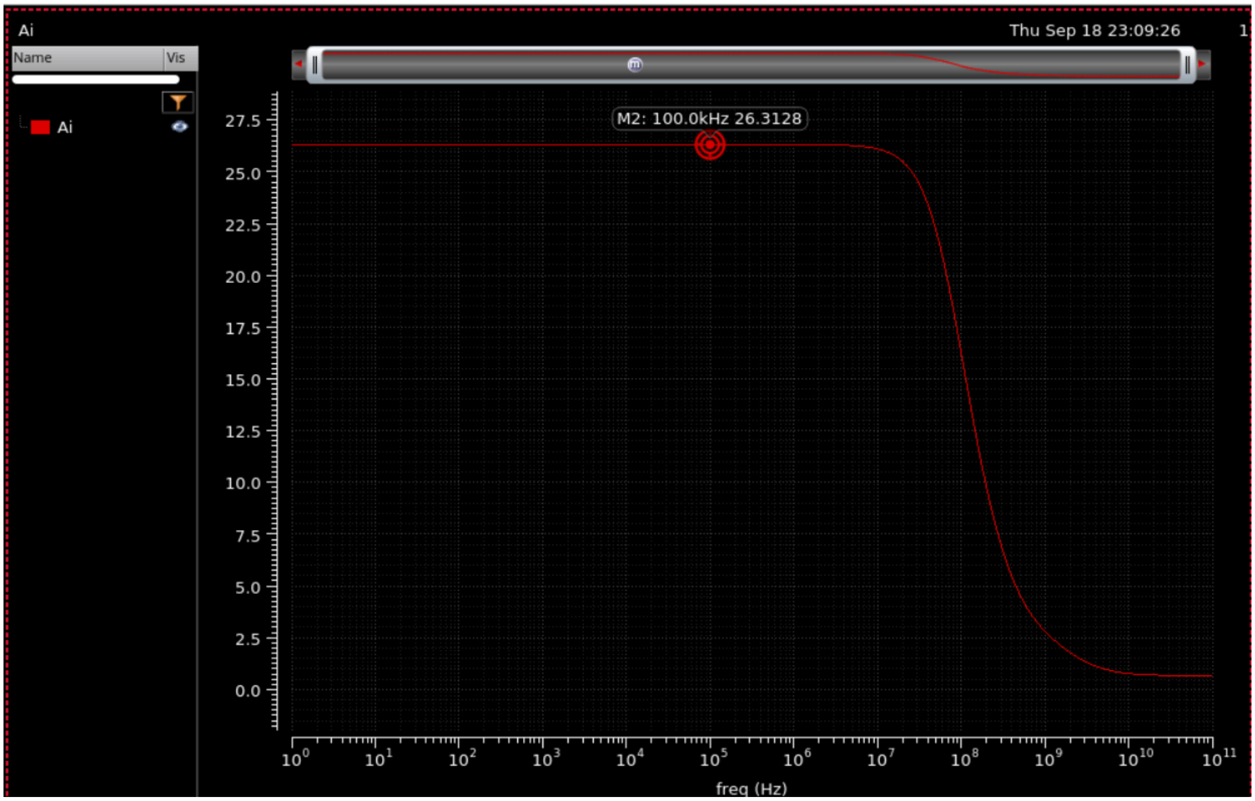

Lab_1 pmos_Ai schematic
Ai
Thu Sep 18 23:04:19
Name
Vis
Ai
M1: 1.12202MHz 27.5225
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
freq (Hz)

Condition 6

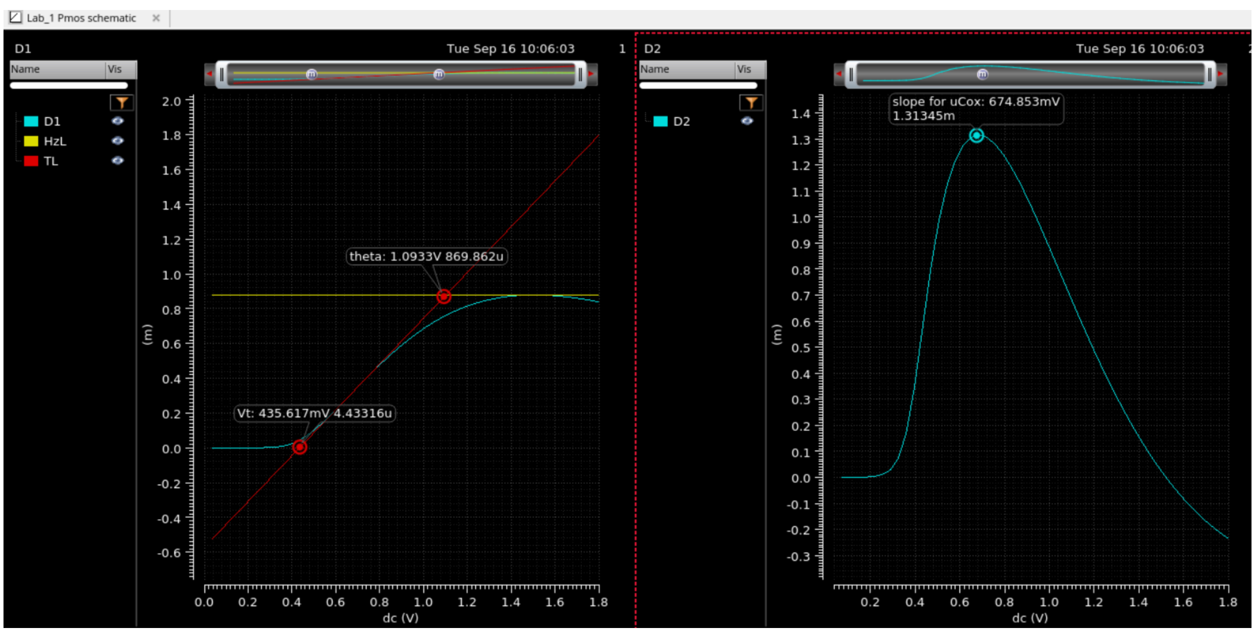

D1
Tue Sep 16 09:59:59
Name
Vis
D1
HzL
TL
theta: 1.06683V 1.01222m
Vt: 407.033mV -11.4682u
(m)
dc (V)
D2
Tue Sep 16 09:59:59
D2
slope for uCox: 648.0mV
1.5693m
(m)
dc (V)

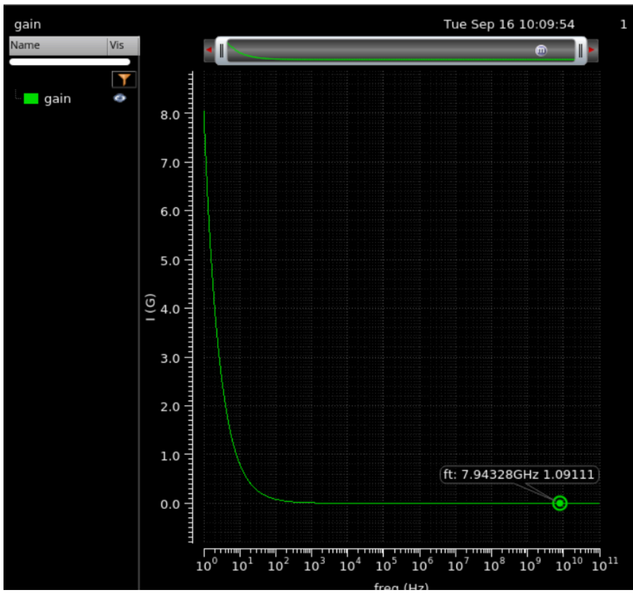


gain
Tue Sep 16 10:03:42
1
Name
Vis
gain
I (G)
Ft: 8.91251GHz 1.06669
freq (Hz)
plot2
Tue Sep 16 10:03:42
Name
Vis
plot2
I
lambda: 1.008V 419.188m
dc (V)

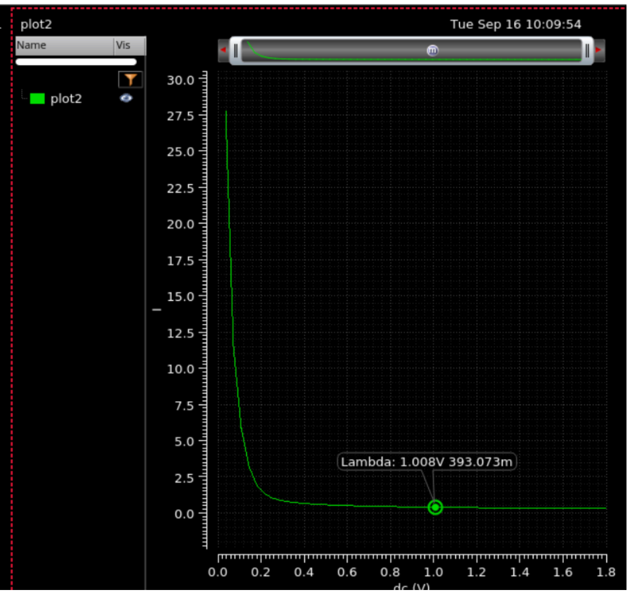

Ai
Thu Sep 18 23:09:26
Name
Vis
Ai
M2: 100.0kHz 26.3128
freq (Hz)

Condition 7

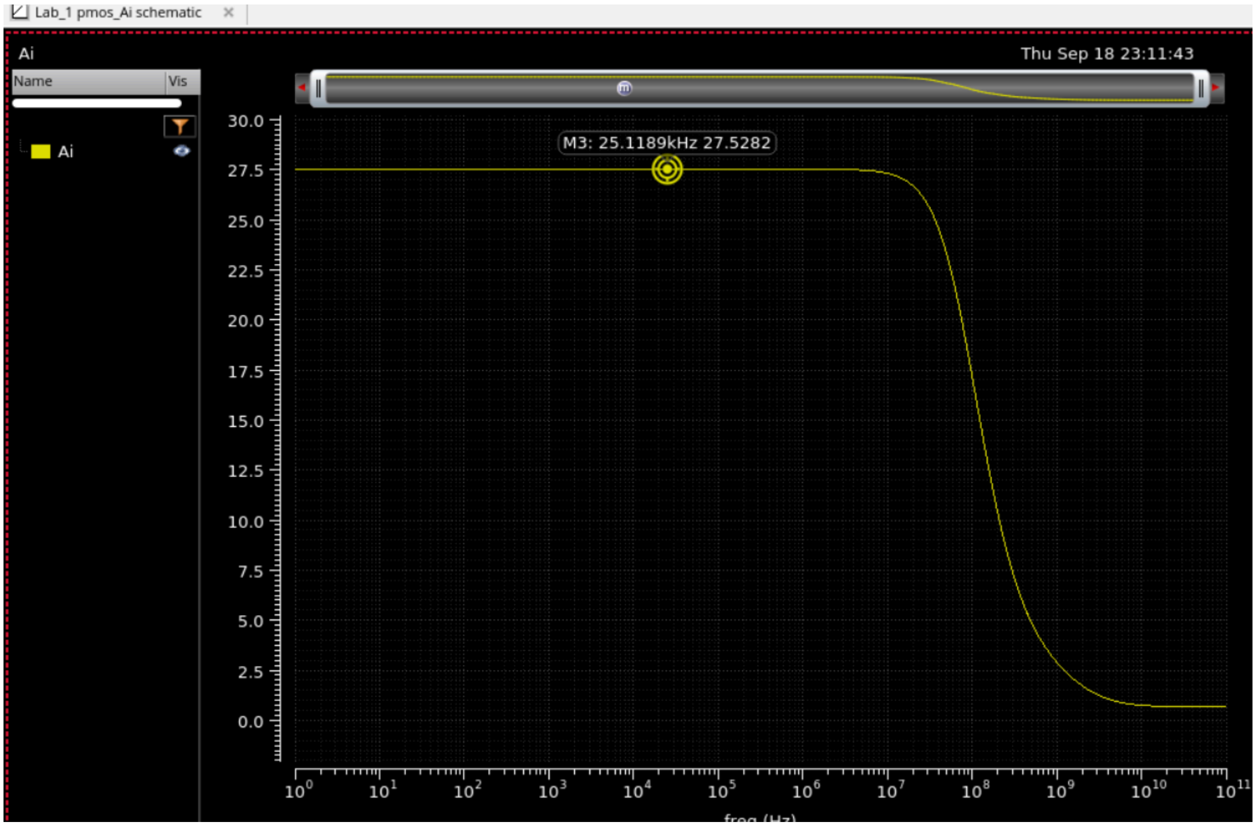

Lab_1 Pmos schematic
D1
Tue Sep 16 10:06:03
D1
HzL
TL
theta: 1.0933V 869.862u
Vt: 435.617mV 4.43316u
(m)
dc (V)
D2
Tue Sep 16 10:06:03
D2
slope for uCox: 674.853mV
1.31345m
(m)
dc (V)



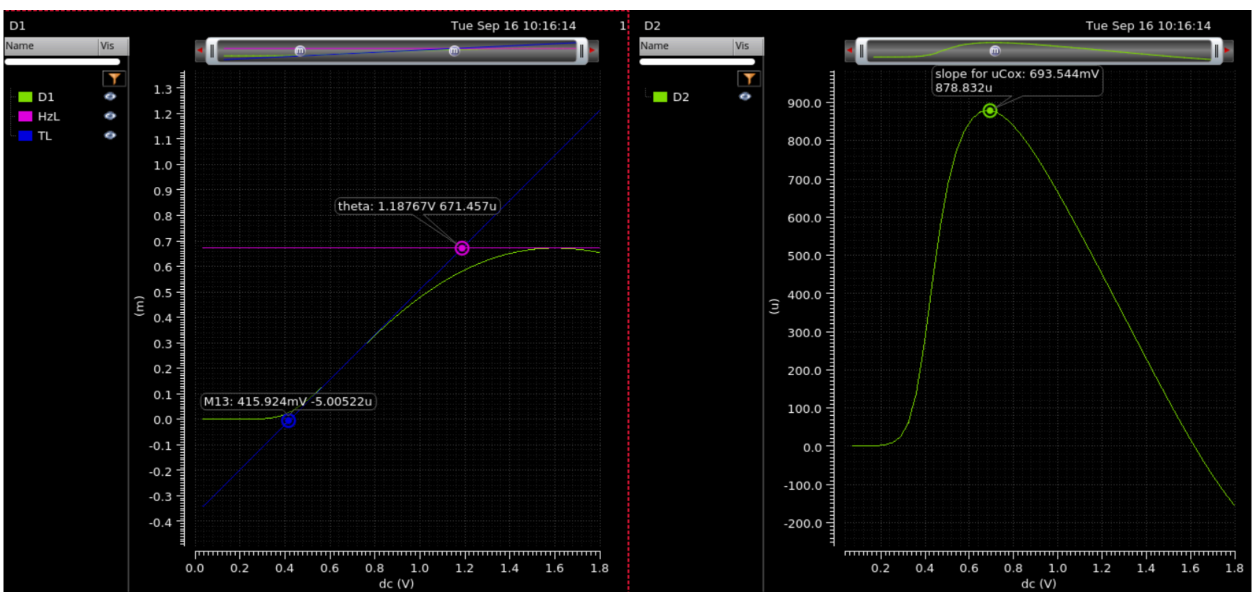
gain
Tue Sep 16 10:09:54
1
Name
Vis
gain
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
I (G)
ft: 7.94328GHz 1.09111
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11}
freq (Hz)

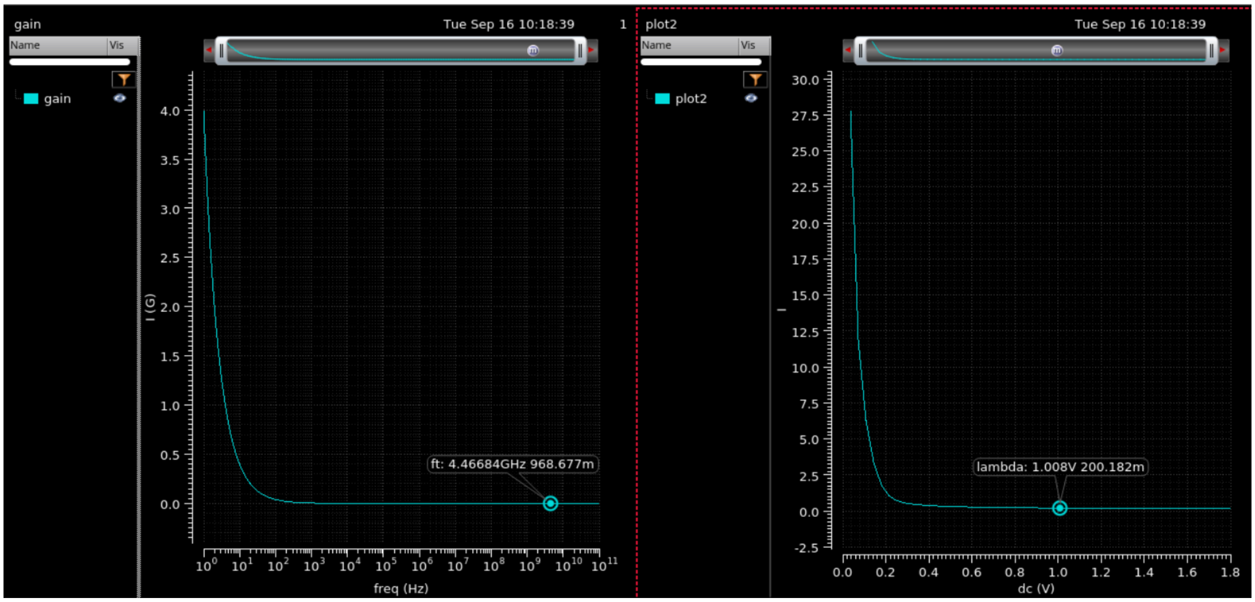


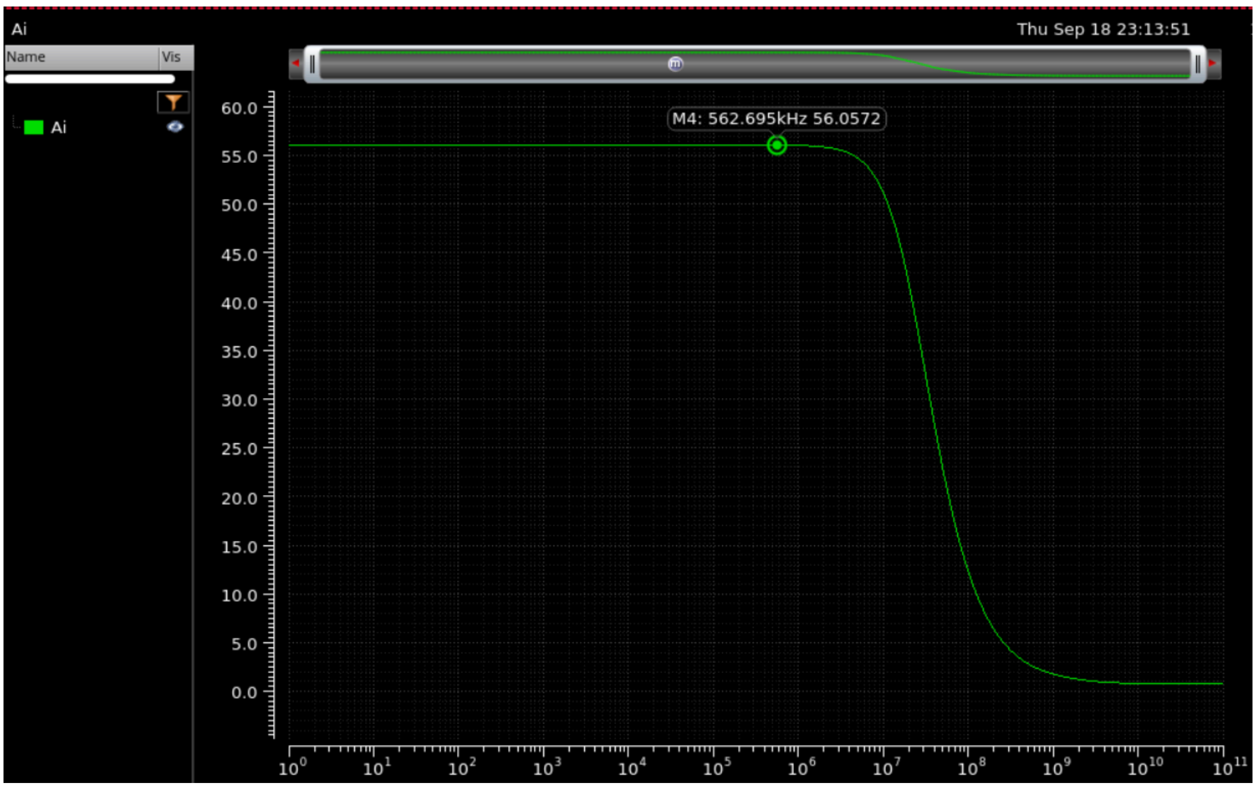
plot2
Tue Sep 16 10:09:54
Name
Vis
plot2
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
I
Lambda: 1.008V 393.073m
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
dc (V)


Lab_1 pmos_Ai schematic
Ai
Thu Sep 18 23:11:43
Name
Vis
Ai
M3: 25.1189kHz 27.5282
freq (Hz)

Condition 8


D1
Tue Sep 16 10:16:14
Name
Vis
D1
HzL
TL
theta: 1.18767V 671.457u
M13: 415.924mV -5.00522u
(m)
dc (V)
D2
Tue Sep 16 10:16:14
D2
slope for uCox: 693.544mV
878.832u
(u)
dc (V)


gain
Tue Sep 16 10:18:39
Name
Vis
gain
I (G)
ft: 4.46684GHz 968.677m
freq (Hz)
plot2
Tue Sep 16 10:18:39
Name
Vis
plot2
lambda: 1.008V 200.182m
dc (V)


Ai
Thu Sep 18 23:13:51
Name
Vis
Ai
M4: 562.695kHz 56.0572