Designing an Operational Amplifier

Vellios George Serafeim

AEM: 9471

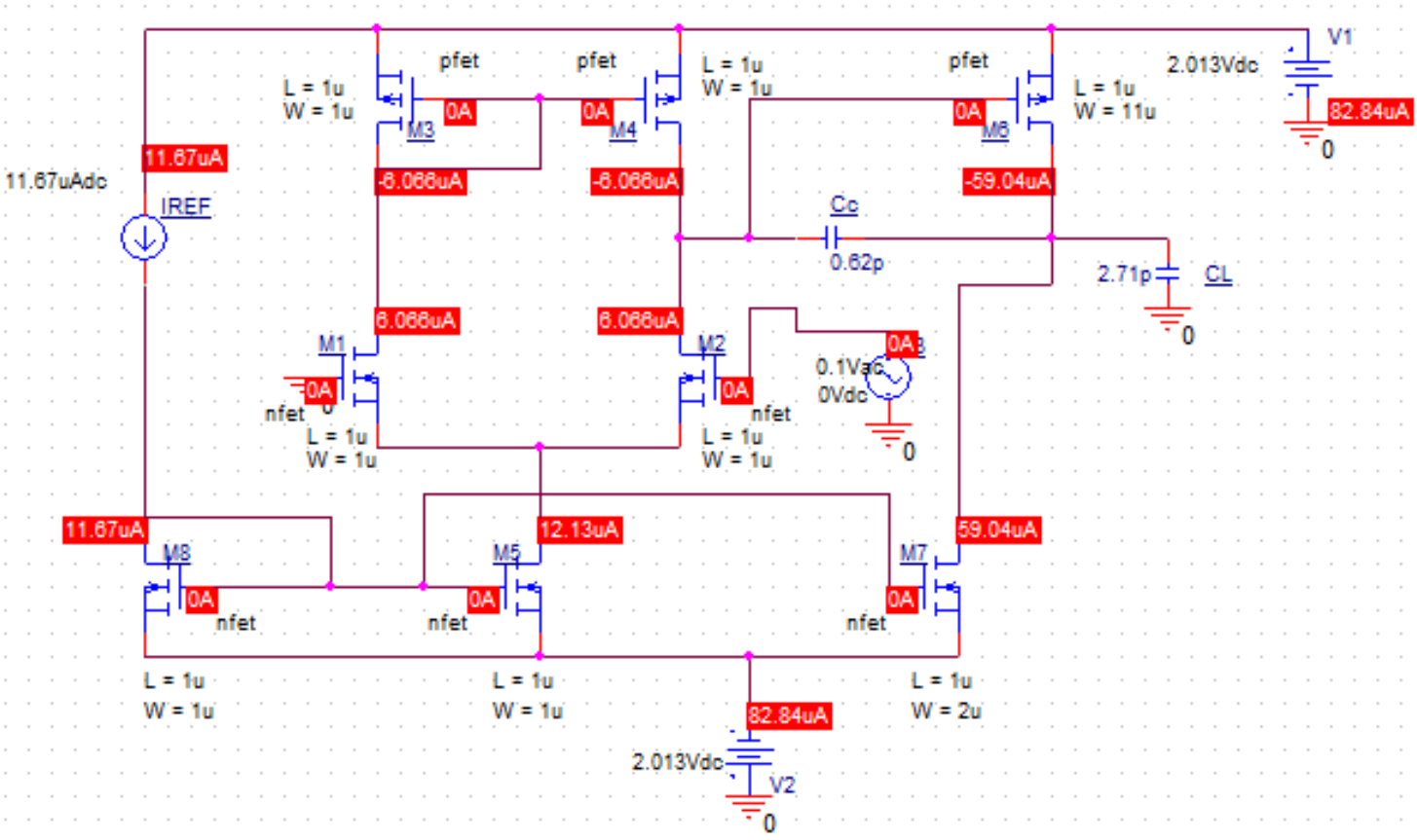
A design algorithm was designed for a first estimate of the op amp parameters. The operand is an n - MOS input and the variation of Vto is chosen to be +- 0.15 V. The L of the transistors was chosen to be 1μ m and the value of Cc to be greater than 0.22 CL .

Specification	Price for AEM: 9471
CL	2.71pF
MR	>18.71v/ m S
Vdd	2.013V
Vs	-2.013V
GB	>7.71MHz
A	>20.71dB
P	<50.71mW

Based on the above, the algorithm approximately calculated that:

- Cc=0.62pF
- Iref =I5= 11.67 μA
- L=1 m A
- W1=1 μA (S1=0.4467)
- W2=1 μA (S2=0.4467)
- W3=1 μA (S3=1)
- W4=1 μA (S4=1)
- W5=1 μA (S5=0.3819)
- W6=11 μA (S6=10.91)
- W7=2 μA (S7=2.08)
- W8=1 μA (S8=1.0294)

This is how the following original circuit was designed in Spice :



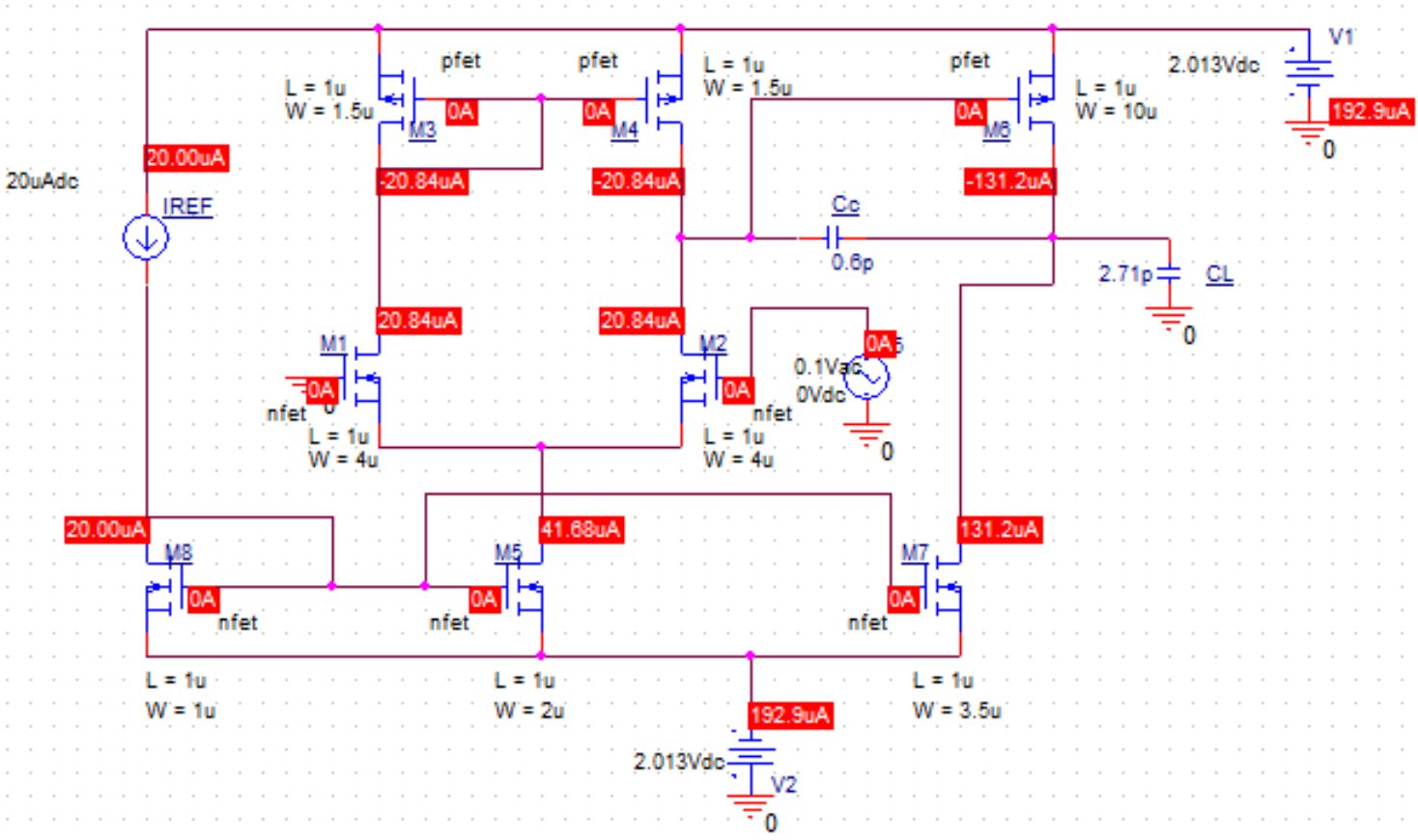
The currents have values close to the theoretical ones, so the next step is tuning .

First we want to increase the GB . Thus we increase W 1, W 2 to 3m. The phase margin is greater than 60 degrees, so we increase W 7 to 3m. Next, we want to increase SR . We increase Iref to 20 uA and τ o W 3 in 2m so I5 becomes 40 uA . We also reduce Cc to 0.6p and increase W 3, W 4 to 1.5m. For temperatures from 0 to 90 degrees Celsius the SR condition is satisfied. But GB was not satisfied for 0 points, so we increase W 1, W 2 to 4m. The phase margin is greater than 60 degrees, so we increase W 7 to 3.5m and decrease W 6 to 10m. Finally the specifications are as follows:

- Cc= 0.6pF
- Iref = 20μA _

- I 5 = 4 1.68 m A
- L=1 m A
- W1= 4 µA
- W2= 4 m A
- W3= 1.5 m A
- W4= 1.5 m A
- W5= 2 µA
- W6= 10 m A
- W7 = 3.5 m A
- W8=1 m A

So the figure is as follows:



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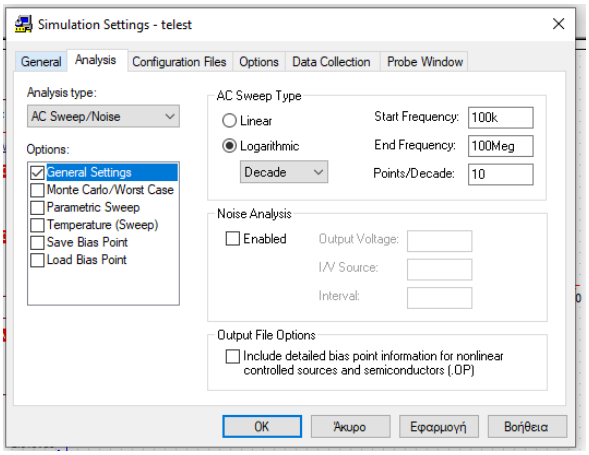
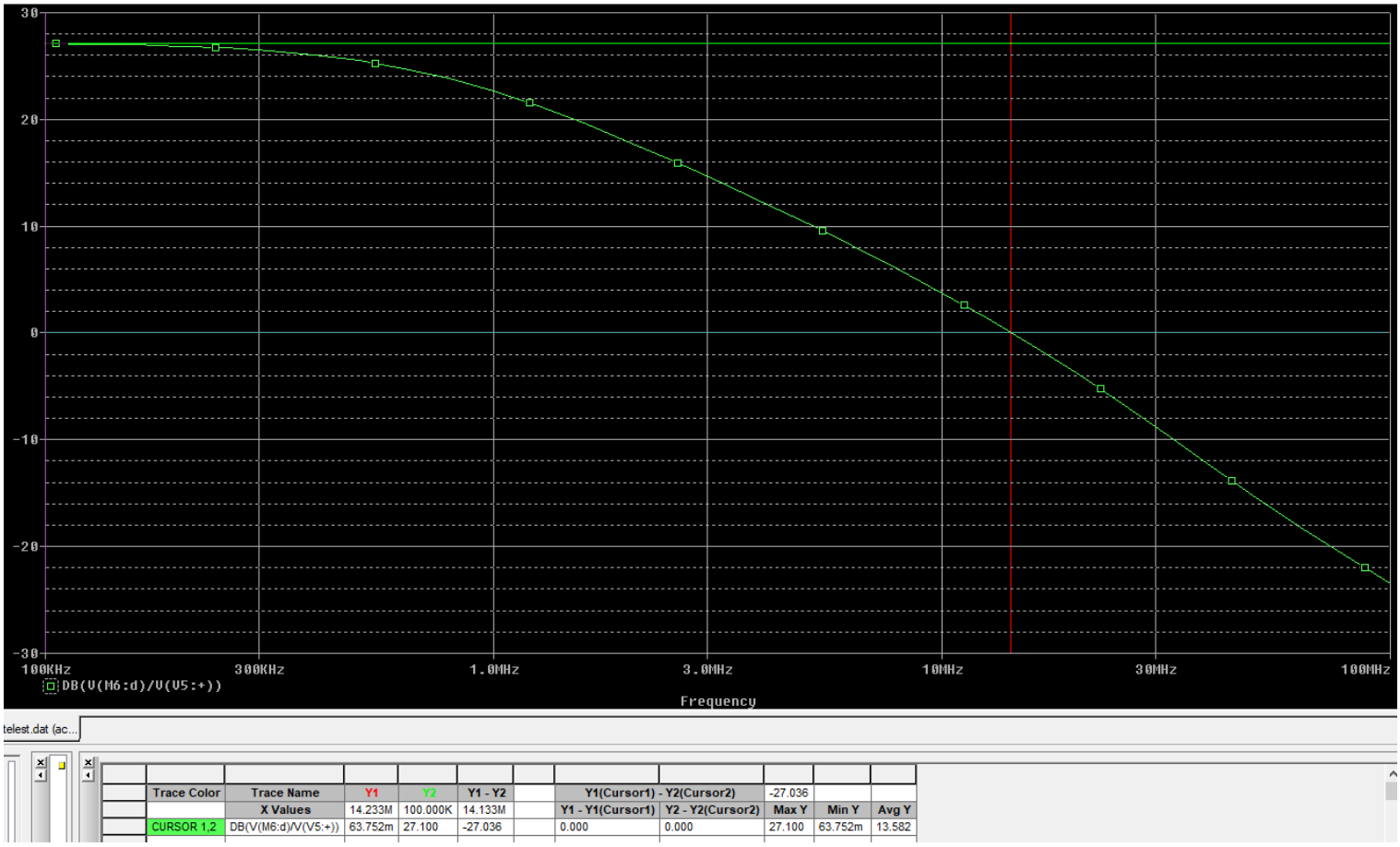
Calculation of A, GB and phase margin

0.1 V Vac source on Vin + and ground Vin - (in the above picture). We do AC sweep and we observe from the dB curve (Vout / Vin) which is the largest A and where the curve intersects 0 and therefore how much GB is .





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Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-27.036		
	X Values	14.233M	100.000K	14.133M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(M6:d)/V(V5:+))	63.752m	27.100	-27.036		0.000	0.000	27.100	63.752m	13.582

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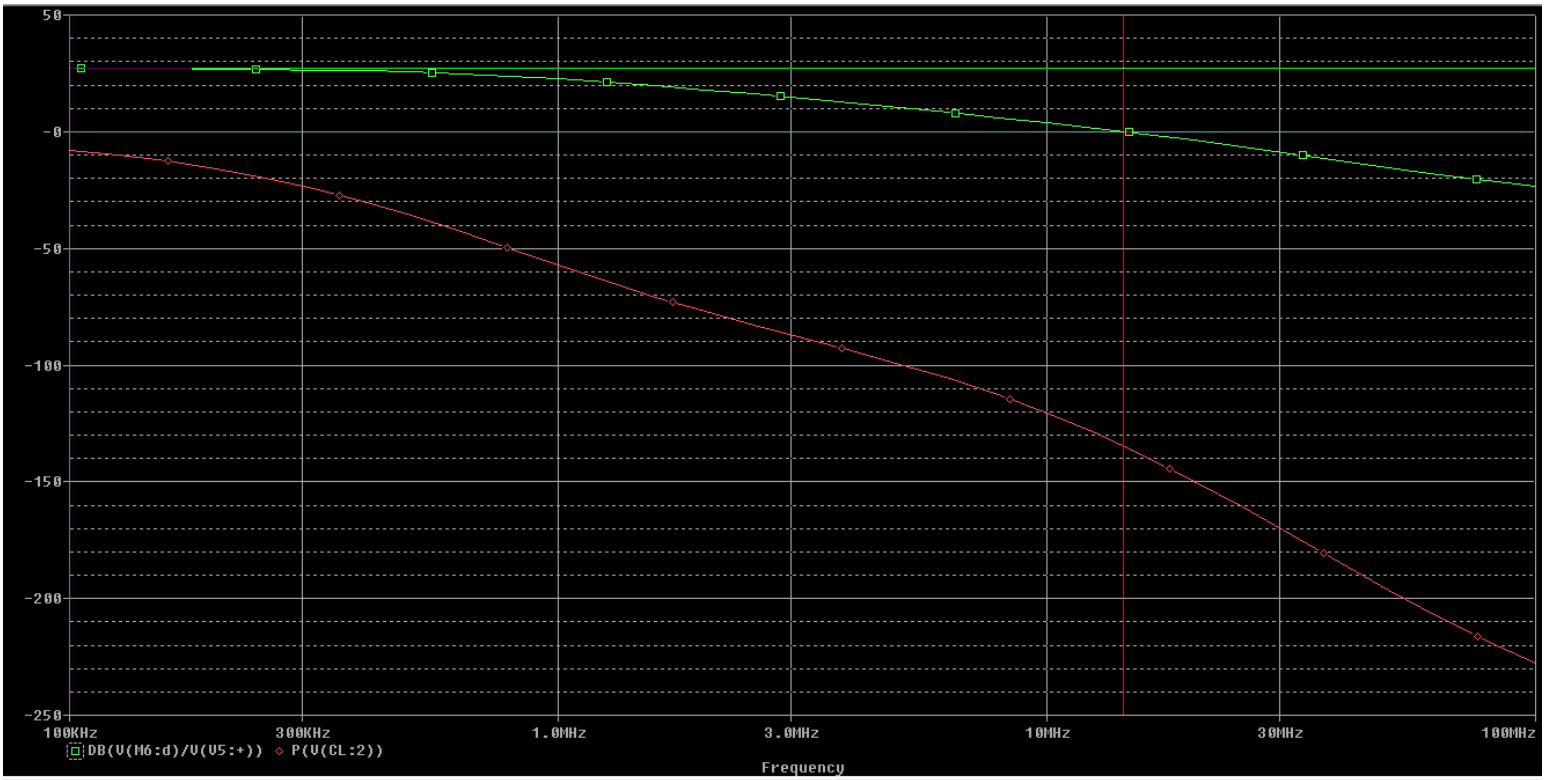
We observe that A=2 7.09 dB > 20.71 dB , which is valid
GB =14.233 MHz > 7.71 MHz , valid

For the phase margin, in the same simulation we also put the phase of the output, and in the area where A becomes 0, we see how many degrees the phase is and subtract their absolute value from 180 degrees.



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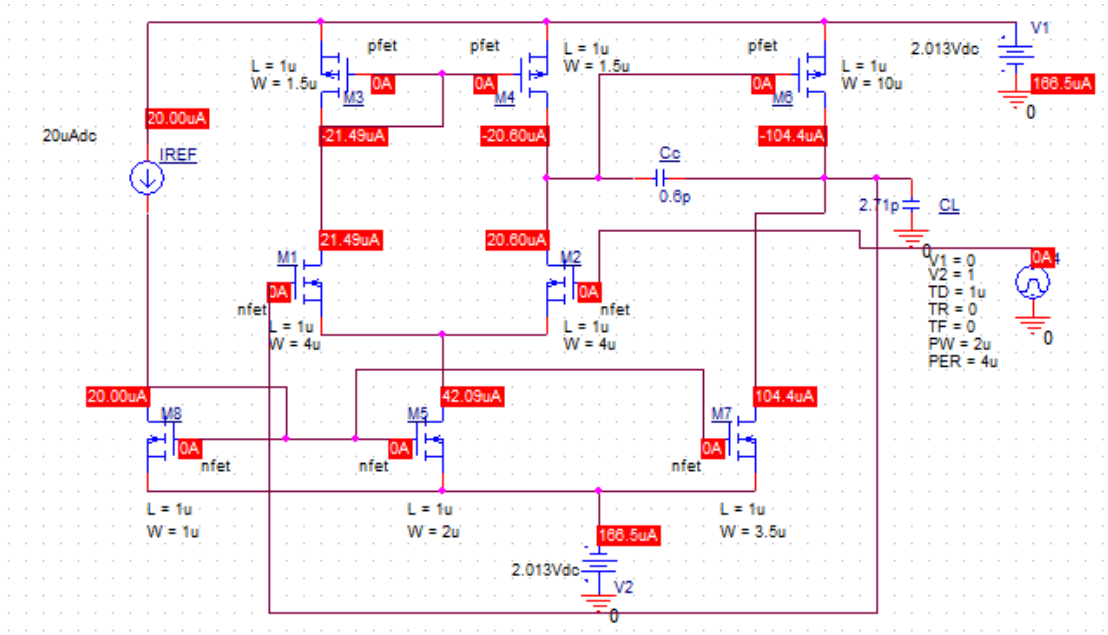
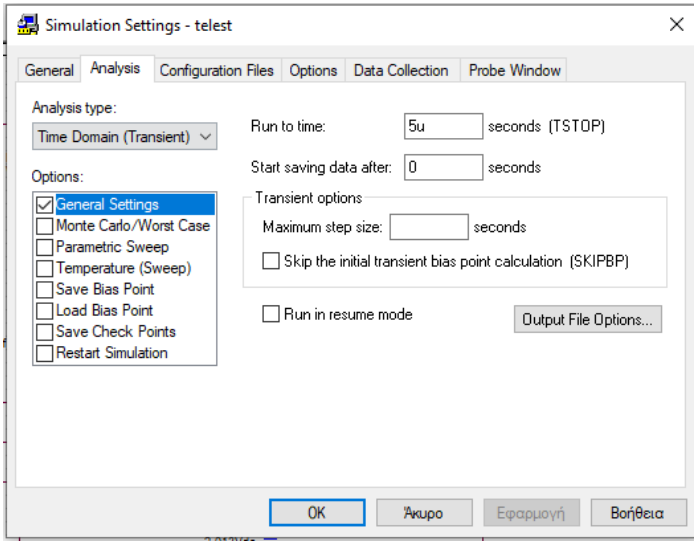
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-27.114		
	X Values	14.335M	100.000K	14.235M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(M6:d)/V(V5:+))	-13.829m	27.100	-27.114		0.000	0.000	27.100	-13.829m	13.543
	P(V(CL:2))	-134.700	-8.0835	-126.617		-134.686	-35.183	-8.0835	-134.700	-71.392

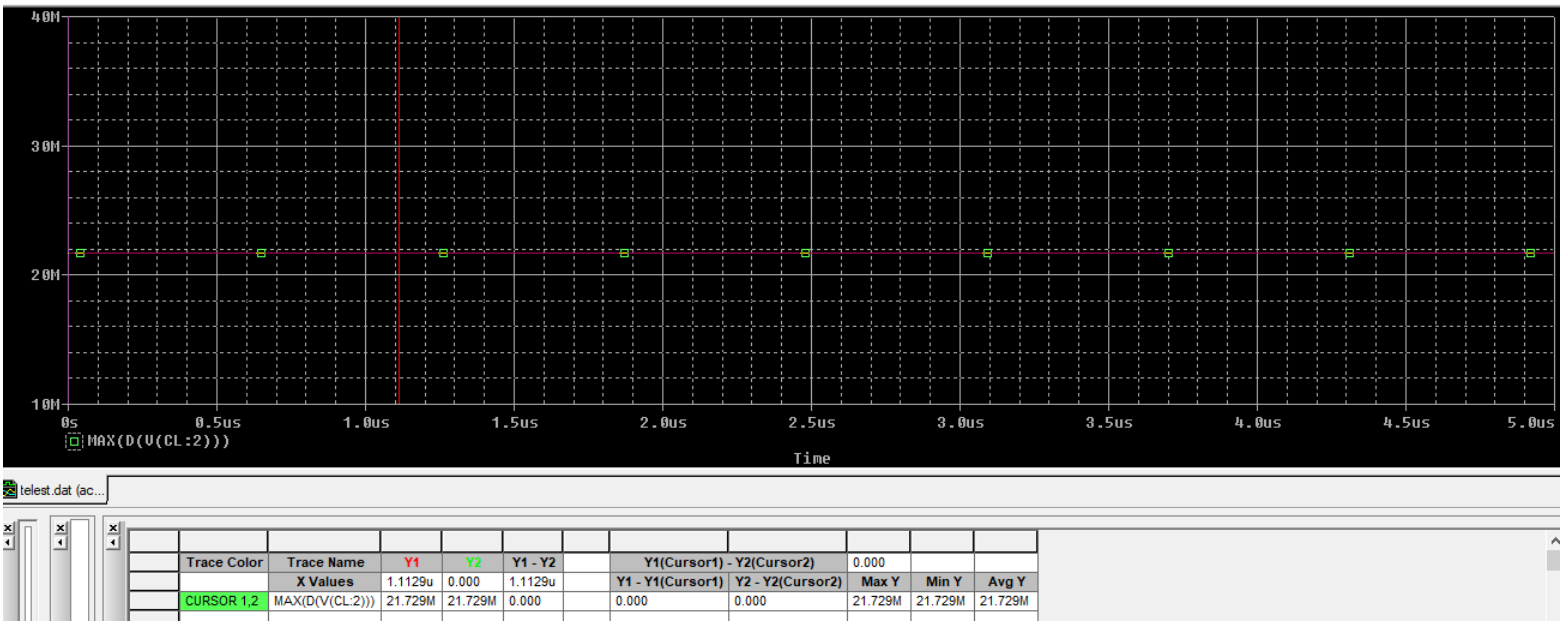
So PM= 180 – 134.7=45.3 degrees, between 45 and 60, accepted.

Calculation of SR

To measure SR we set the operational amplifier in unity gain circuit and apply to the input a square pulse of width 1 V and very short duration. SR is then calculated by finding the maximum slope of the output signal.







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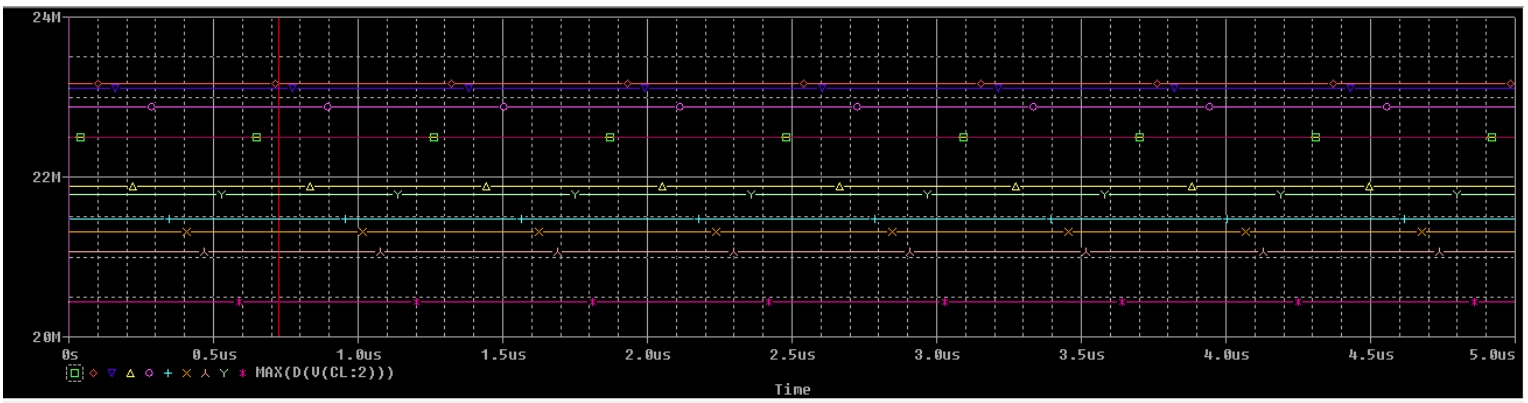
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	1.1129u	0.000	1.1129u		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	MAX(D(V(CL:2)))	21.729M	21.729M	0.000		0.000	0.000	21.729M	21.729M	21.729M

So SR=21.729 V/ uS > 18.71 V/ uS , valid .

We are also looking to check if the above conditions apply to temperatures of 0-90 degrees Celsius.

For the SR :



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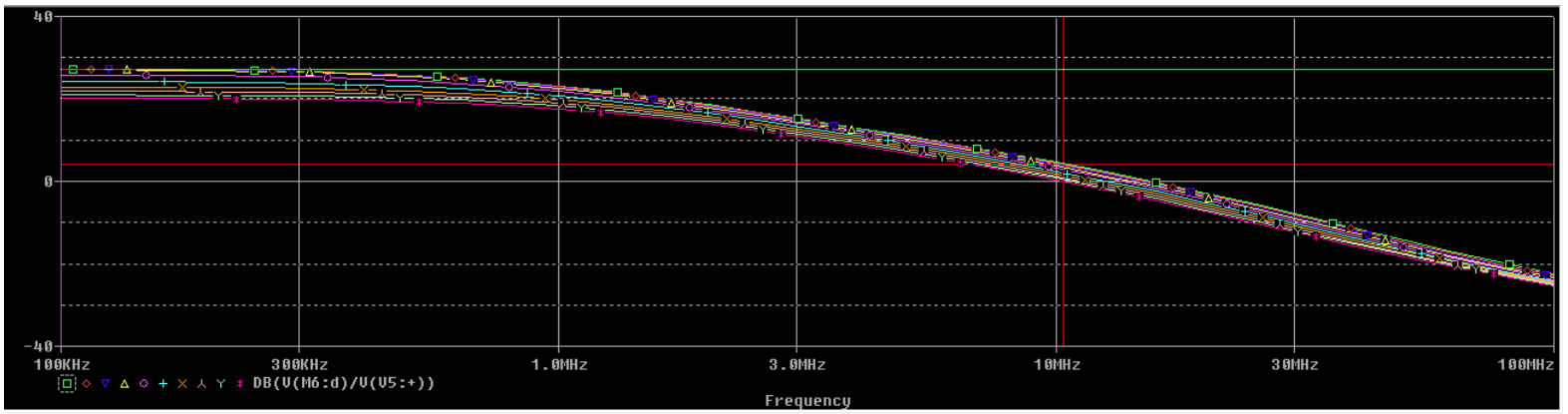
CURSOR 1,2	MAX(D(V(CL:2)))	22.490M	22.490M	0.000		0.000	0.000	22.490M	22.490M	22.490M
	MAX(D(V(CL:2)))	23.173M	23.173M	0.000		682.772K	682.772K	23.173M	23.173M	23.173M
	MAX(D(V(CL:2)))	23.106M	23.106M	0.000		616.394K	616.394K	23.106M	23.106M	23.106M
	MAX(D(V(CL:2)))	21.888M	21.888M	0.000		-601.671K	-601.671K	21.888M	21.888M	21.888M
	MAX(D(V(CL:2)))	22.881M	22.881M	0.000		390.803K	390.803K	22.881M	22.881M	22.881M
	MAX(D(V(CL:2)))	21.470M	21.470M	0.000		-1.0201M	-1.0201M	21.470M	21.470M	21.470M
	MAX(D(V(CL:2)))	21.315M	21.315M	0.000		-1.1744M	-1.1744M	21.315M	21.315M	21.315M
	MAX(D(V(CL:2)))	21.066M	21.066M	0.000		-1.4242M	-1.4242M	21.066M	21.066M	21.066M
	MAX(D(V(CL:2)))	21.781M	21.781M	0.000		-708.352K	-708.352K	21.781M	21.781M	21.781M
	MAX(D(V(CL:2)))	20.432M	20.432M	0.000		-2.0575M	-2.0575M	20.432M	20.432M	20.432M

The smallest is for a temperature of 90 degrees Celsius, but the condition also applies to this, since 20.432>18.71.

For A and GB :

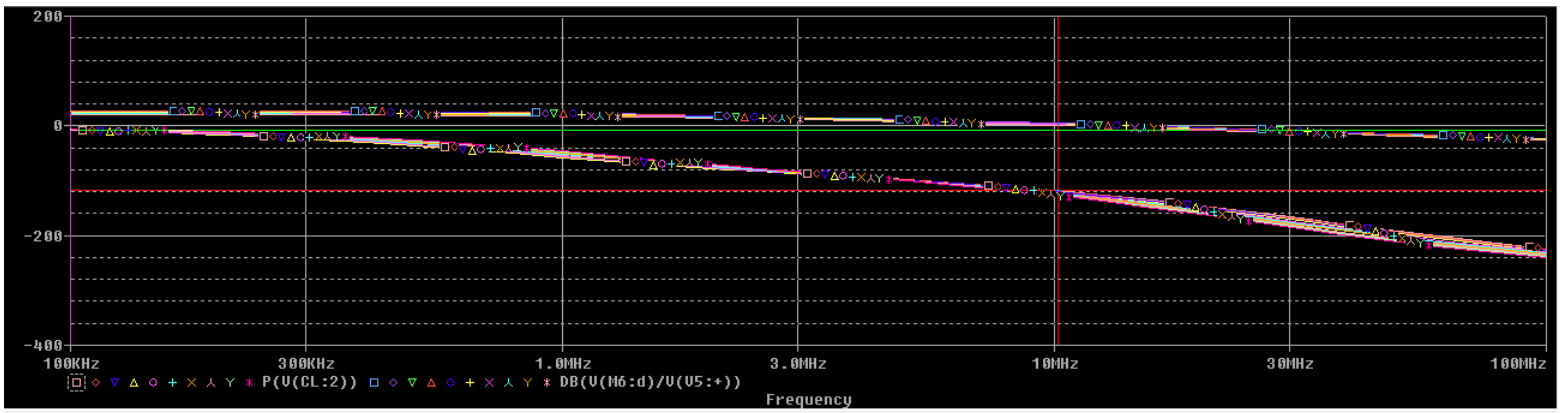


telest.dat (ac...

		X Values	10.339M	100.000K	10.239M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	CURSOR 1,2	DB(V(M6:d)/V(V5:+))	4.2261	27.145	-22.919		0.000	0.000	27.145	4.2261	15.685
		DB(V(M6:d)/V(V5:+))	3.9217	27.125	-23.204		-304.379m	-19.309m	27.125	3.9217	15.524
		DB(V(M6:d)/V(V5:+))	3.6256	27.109	-23.484		-600.469m	-35.360m	27.109	3.6256	15.368
		DB(V(M6:d)/V(V5:+))	3.3301	27.096	-23.766		-895.915m	-48.664m	27.096	3.3301	15.213
		DB(V(M6:d)/V(V5:+))	2.7808	25.822	-23.041		-1.4452	-1.3230	25.822	2.7808	14.301
		DB(V(M6:d)/V(V5:+))	2.1266	24.197	-22.070		-2.0994	-2.9480	24.197	2.1266	13.162
		DB(V(M6:d)/V(V5:+))	1.5226	22.913	-21.390		-2.7035	-4.2322	22.913	1.5226	12.218
		DB(V(M6:d)/V(V5:+))	956.022m	21.845	-20.889		-3.2700	-5.2997	21.845	956.022m	11.401
		DB(V(M6:d)/V(V5:+))	419.381m	20.928	-20.509		-3.8067	-6.2167	20.928	419.381m	10.674

The smallest A is for a temperature of 90 degrees where again the condition (20.92>20.71) applies, while the condition for the GB applies to all temperatures since for each GB temperature >10 MHz >7.71 MHz .

For the phase margin:



telest.dat (ac...

		X Values	10.170M	100.000K	10.070M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	CURSOR 1,2	P(V(CL:2))	-118.106	-7.4931	-110.613		0.000	0.000	-7.4931	-118.106	-62.800
		P(V(CL:2))	-119.237	-7.7100	-111.527		-1.1304	-216.934m	-7.7100	-119.237	-63.473
		P(V(CL:2))	-120.355	-7.9277	-112.427		-2.2482	-434.589m	-7.9277	-120.355	-64.141
		P(V(CL:2))	-121.480	-8.1526	-113.327		-3.3735	-659.500m	-8.1526	-121.480	-64.816
		P(V(CL:2))	-122.452	-7.5057	-114.947		-4.3460	-12.670m	-7.5057	-122.452	-64.979
		P(V(CL:2))	-123.420	-6.7365	-116.684		-5.3139	756.615m	-6.7365	-123.420	-65.078
		P(V(CL:2))	-124.475	-6.2483	-118.227		-6.3685	1.2448	-6.2483	-124.475	-65.362
		P(V(CL:2))	-125.595	-5.9141	-119.681		-7.4886	1.5790	-5.9141	-125.595	-65.755
		P(V(CL:2))	-126.767	-5.6746	-121.092		-8.6605	1.8185	-5.6746	-126.767	-66.221

The phase margin for all values is between 45.3 and 51.8 degrees, which is acceptable.
Fee for the power applies:
Pdiss = (I 6 + I5) × (VDD +VSS)= (131.2+41.68)*10^-6*4.026=0.00069601488W= 0.696mW < 50.71mW, accepted .

So all conditions are met.

Finally, we replace the ideal current source with a wildar current source with 2 N 2222 bipolar transistors with resistances found after testing to be equal to R 1=259 k , R 2=215 k . The above diagrams are recreated for the new current source and are observed below:

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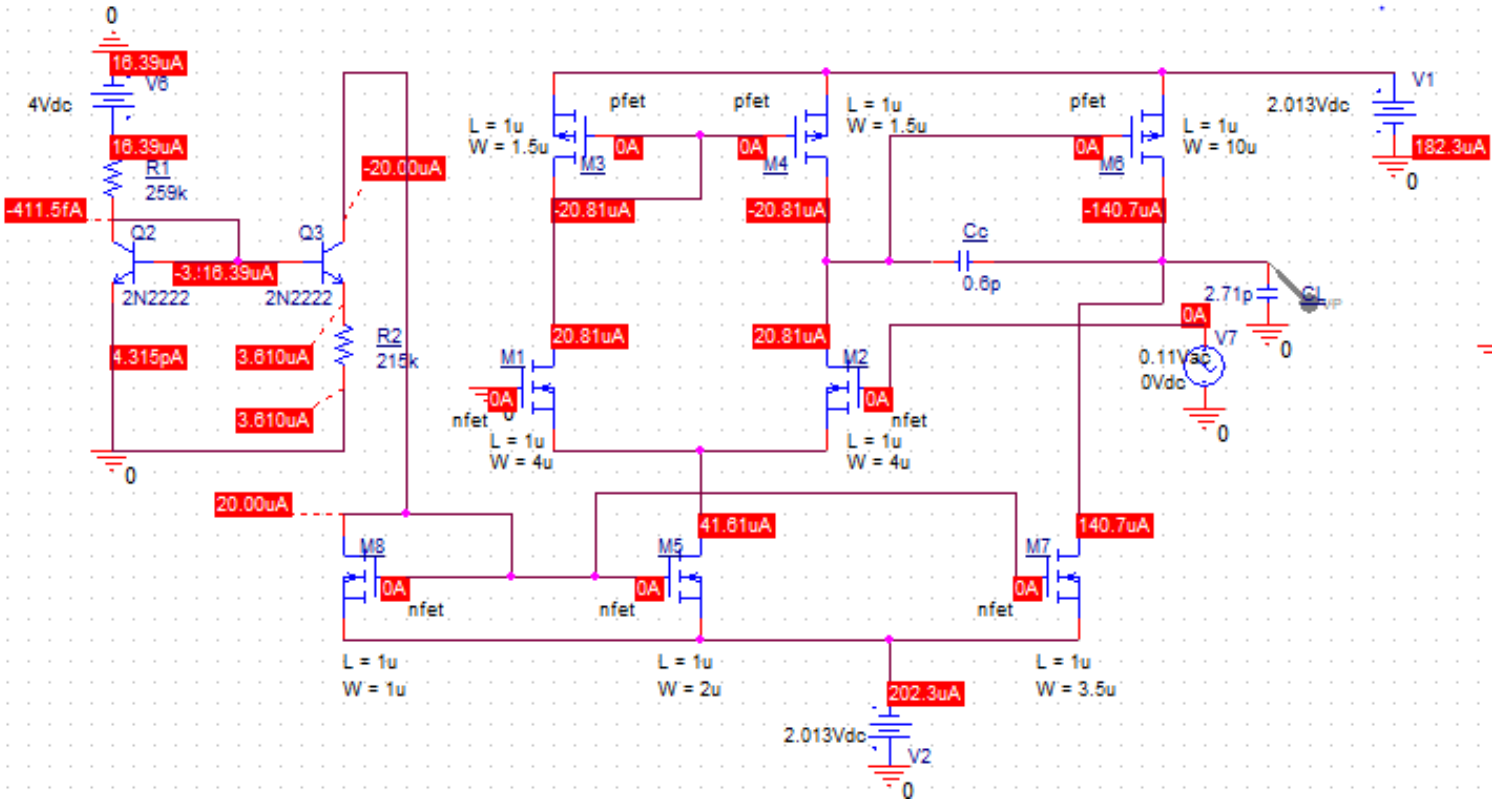

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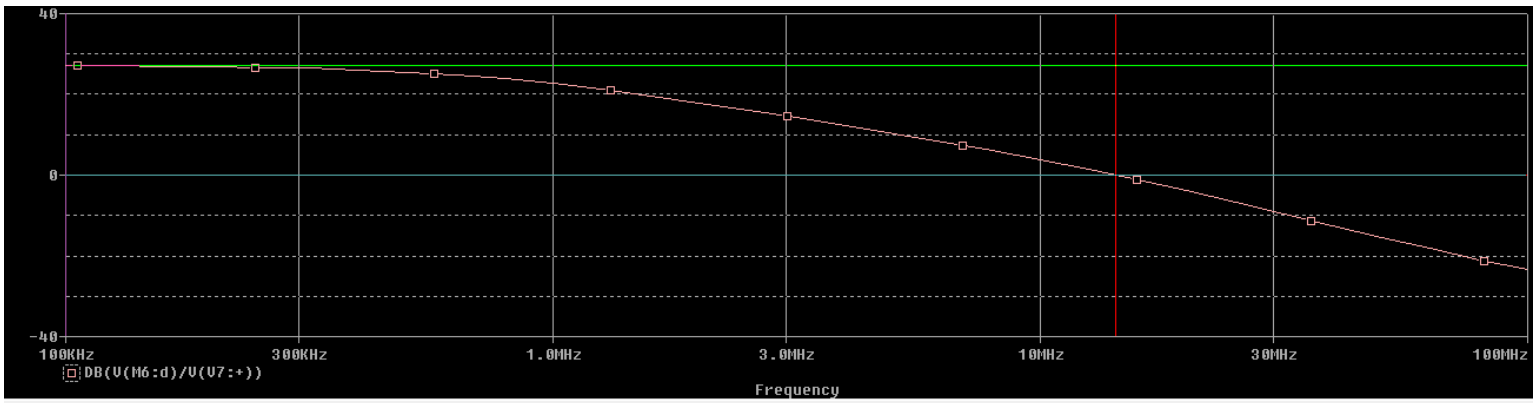

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		X Values	14.275M	100.000K	14.175M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	CURSOR 1,2	DB(V(M6:d)/V(V7:+))	32.852m	27.100	-27.067		0.000	0.000	27.100	32.852m	13.566

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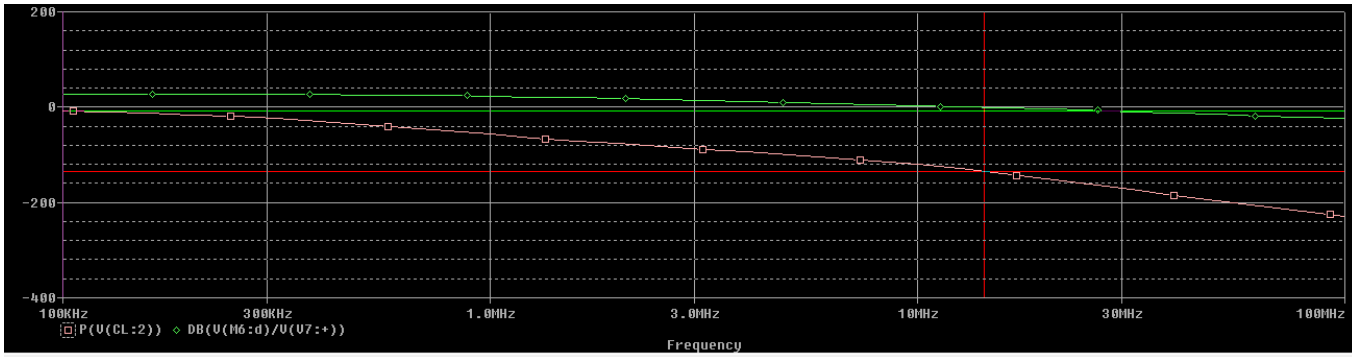

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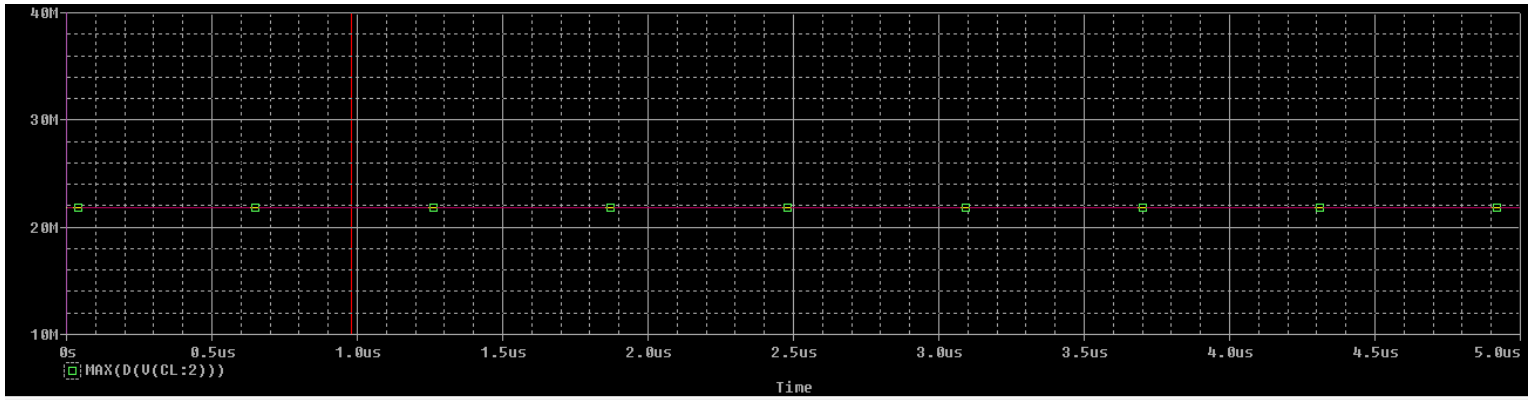
	X Values	14.325M	100.000K	14.225M	Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	P(V(CL:2))	-134.612	-8.0839	-126.528	0.000	0.000	-8.0839	-134.612	-71.348
	DB(V(M6:d)/V(V7:+))	-4.9199m	27.100	-27.105	134.607	35.184	27.100	-4.9199m	13.548



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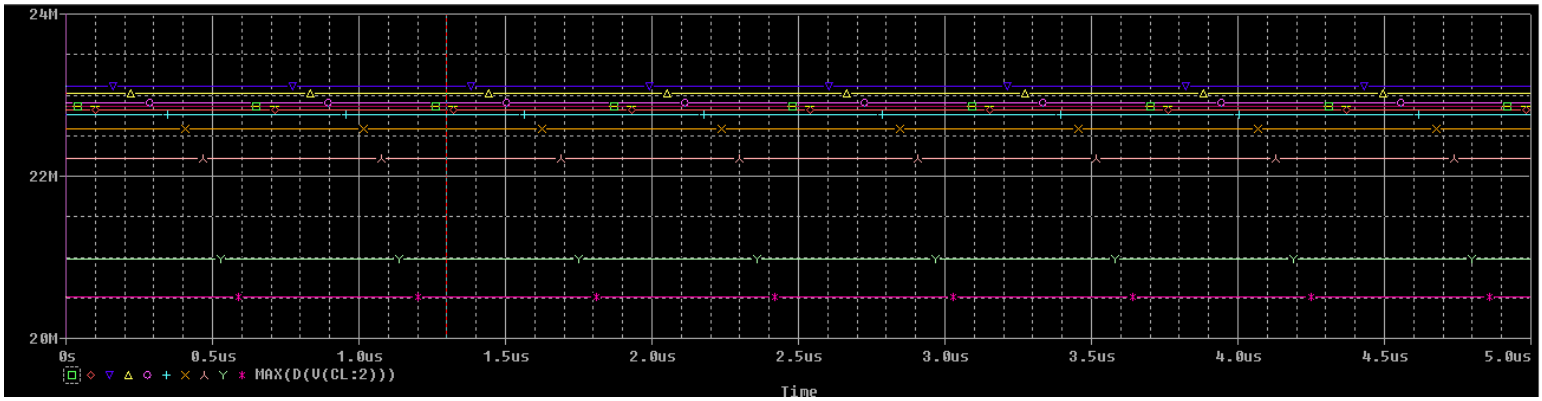
	X Values	979.839n	0.000	979.839n	Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	MAX(D(V(CL:2)))	21.858M	21.858M	0.000	0.000	0.000	21.858M	21.858M	21.858M



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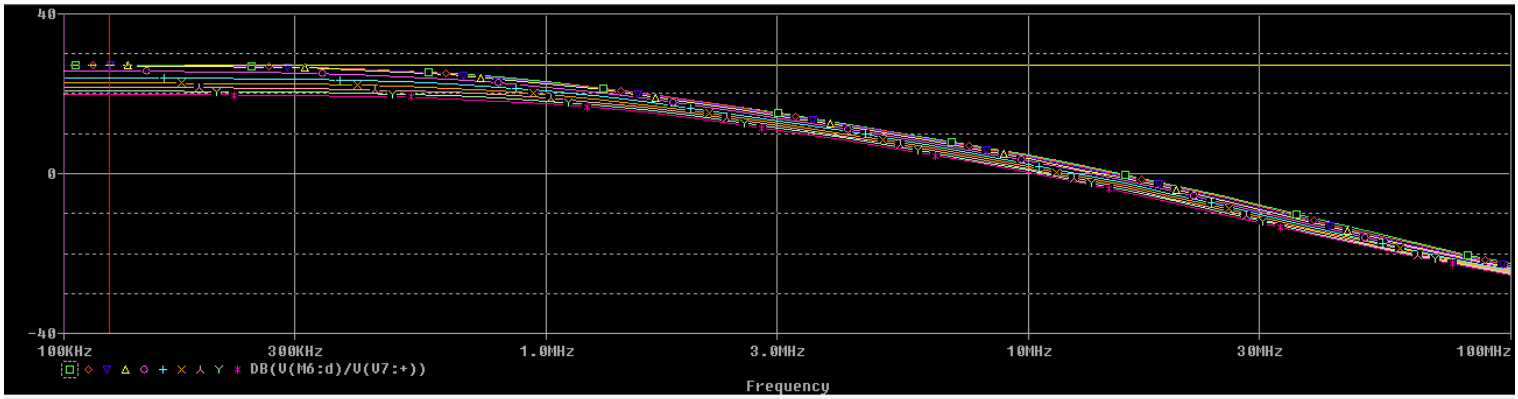

telest.dat (ac...

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		-37.326m		
	X Values	124.223K	100.000K	24.223K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(M6:d)/V(V7:+))	27.115	27.152	-37.326m		0.000	0.000	27.152	27.115	27.133
	DB(V(M6:d)/V(V7:+))	27.091	27.130	-39.365m		-23.958m	-21.919m	27.130	27.091	27.111
	DB(V(M6:d)/V(V7:+))	27.070	27.111	-41.454m		-44.820m	-40.692m	27.111	27.070	27.091
	DB(V(M6:d)/V(V7:+))	27.052	27.095	-43.666m		-63.159m	-56.819m	27.095	27.052	27.073
	DB(V(M6:d)/V(V7:+))	25.667	25.702	-35.772m		-1.4482	-1.4498	25.702	25.667	25.684
	DB(V(M6:d)/V(V7:+))	24.001	24.029	-28.095m		-3.1136	-3.1228	24.029	24.001	24.015
	DB(V(M6:d)/V(V7:+))	22.689	22.713	-23.666m		-4.4257	-4.4394	22.713	22.689	22.701
	DB(V(M6:d)/V(V7:+))	21.599	21.620	-20.809m		-5.5155	-5.5320	21.620	21.599	21.610