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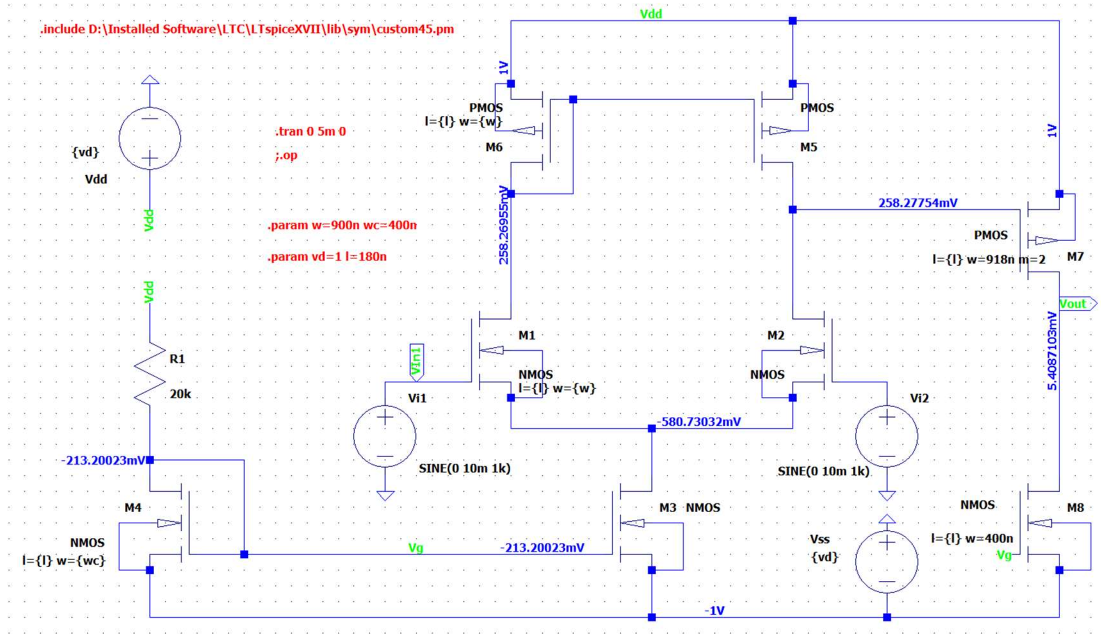
LTSpice Analog Electronics Project

Step 1: Design an Operational transconductance amplifier (OTA)

L=180nm

Circuit Diagram:



Tail Current = **59.17 uA**

Operating Point:

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       --- Operating Point ---

V(vdd):                  1                    voltage
V(n005):                 -1                   voltage
V(vg):                   -0.2132              voltage
V(n001):                 0.25827              voltage
V(vin1):                 0                    voltage
V(n003):                 -0.58073             voltage
V(n002):                 0.258278             voltage
V(n004):                 0                    voltage
V(vout):                 0.00540871           voltage
V(m7#dbody):             1                    voltage
V(m7#sbody):             1                    voltage
V(m6#dbody):             1                    voltage
V(m6#sbody):             1                    voltage
V(m5#dbody):             1                    voltage
V(m5#sbody):             1                    voltage
V(m8#dbody):             -1                   voltage
V(m8#sbody):             -1                   voltage
V(m4#dbody):             -1                   voltage
V(m4#sbody):             -1                   voltage
V(m3#dbody):             -1                   voltage
V(m3#sbody):             -1                   voltage
V(m2#dbody):             -0.58073             voltage
V(m2#sbody):             -0.58073             voltage
V(m1#dbody):             -0.58073             voltage
V(m1#sbody):             -0.58073             voltage
Id(M7):                  -6.12769e-005        device_current
Ig(M7):                  -2.93257e-009        device_current
Ib(M7):                  5.42978e-012         device_current
Is(M7):                  6.12798e-005         device_current
Id(M6):                  -2.95609e-005        device_current
Ig(M6):                  -1.45193e-009        device_current
Ib(M6):                  2.41195e-012         device_current
Is(M6):                  2.95623e-005         device_current
Id(M5):                  -2.95609e-005        device_current
Ig(M5):                  -1.45193e-009        device_current
Ib(M5):                  2.41194e-012         device_current
Is(M5):                  2.95623e-005         device_current
Id(M8):                  6.12769e-005         device_current
Ig(M8):                  1.76519e-010         device_current
Ib(M8):                  -6.06648e-012        device_current
Is(M8):                  -6.12771e-005        device_current
Id(M4):                  6.06595e-005         device_current
Ig(M4):                  1.77291e-010         device_current
Ib(M4):                  -5.81574e-012        device_current
Is(M4):                  -6.06597e-005        device_current
Id(M3):                  5.91277e-005         device_current
Ig(M3):                  1.78536e-010         device_current
Ib(M3):                  -5.39527e-012        device_current
Is(M3):                  -5.91279e-005        device_current
Id(M2):                  2.95638e-005         device_current
Ig(M2):                  6.91628e-011         device_current
Ib(M2):                  -1.09694e-012        device_current
Is(M2):                  -2.95639e-005        device_current
Id(M1):                  2.95638e-005         device_current
Ig(M1):                  6.9163e-011          device_current
Ib(M1):                  -1.09693e-012        device_current
Is(M1):                  -2.95639e-005        device_current
I(R1):                   6.066e-005           device_current
I(Vi2):                  -6.91628e-011        device_current
I(Vi1):                  -6.9163e-011         device_current
I(Vss):                  -0.000181065         device_current
I(Vdd):                  -0.000181065         device_current
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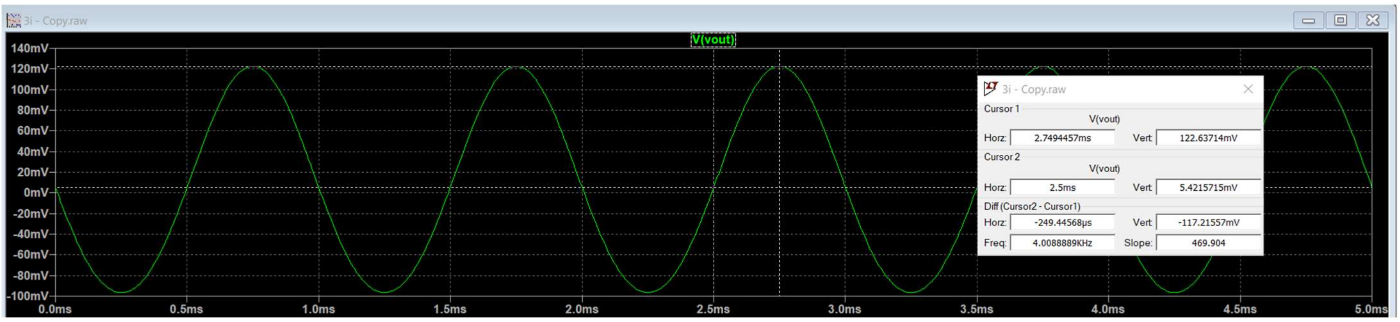
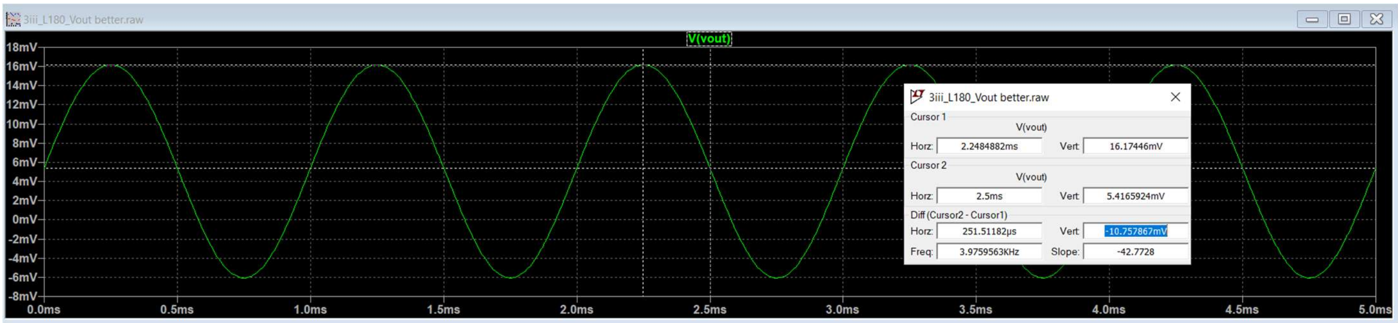
Calculation for Differential Gain:



Vi1 = 10 uV
Vi2= -10 uV
Vout= -117.21557 mV
(Vout is out of phase with Vi1)

Vi=Vi1-Vi2 =20 uV
Differential gain(**Ad)** = Vout/Vi **=** **-**117.21557/20 *1000 = **5860.78**
Calculation for Common Mode Gain:



Vi1 = 10 mV
Vi1=Vi2=10 mV
Vout= -10.757867mV
Common Mode Gain= Acm = Vout / Vi1 = **1.075**
(Vout is in phase with Vi1)

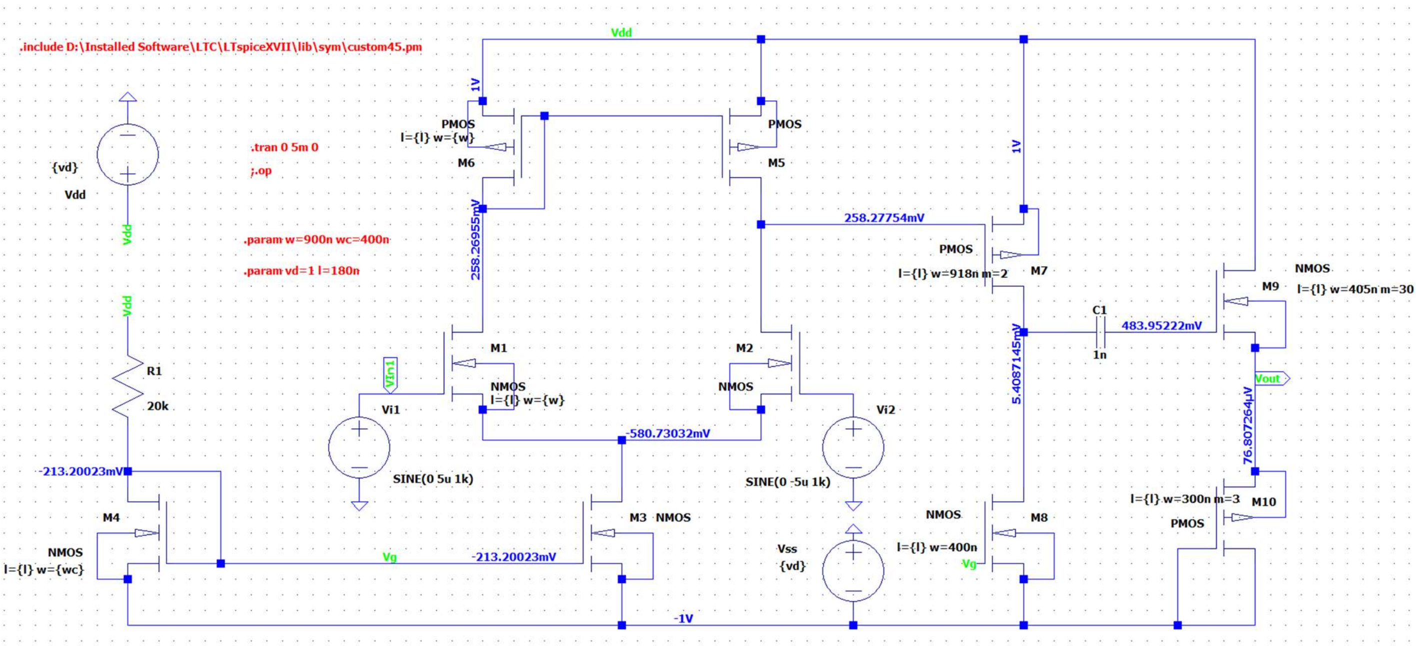
CMRR= |Ad/Acm| = 5860.78/1.075 = **5451.9**

Parameter	Value
Ad	5860.78
Acm	1.075
CMRR	5451.9
UGB	12.34 GHz

- The Operational Transconductance Amplifier (OTA) is an amplifier similar to a standard operational amplifier in that it has a high impedance differential input stage and that it may be used with negative feedback.
- Increasing the tail current will increase the speed of the circuit but that will reduce the gain of the OTA. We increase the MOSFET dimensions to compensate for the reduction in the gain
- In the final stage we have attached a Common Drain amplifier where the PMOS has 2 fingers to ensure current matching. The tail current is 2Id because the NMOS is directly connected to the Vg of the current mirror
- We have studied the input output characteristics of the MOSFET and then got the range of the current for a particular voltage
- We use the **L=180nm** because with L=45nm it was not possible to obtain a high gain above 1000(60dB)
- The tail current was chosen to be **59.17 uA** which is less than 100uA
- There is a trade-off between getting a high gain and keeping the Vout DC =$V_{DD} - V_{SS}/2$
- We keep the Vout DC =$V_{DD} - V_{SS}/2$ for a good output voltage swing
- The Extra gain stage was added to increase the gain by a factor of **gm*(ron|| rop).**
- For output resistance A_d = constant x R_{Load} / (R_{Load} + R_{Output}),

Step 2: Design an Operational amplifier(Op-Amp) using Operational transconductance amplifier (OTA)

Circuit Diagram:



Required specifications:

- Ad > 60 dB
- CMRR > 60 dB
- UGB > 5 MHz

Operating Point

--- Operating Point ---

V(vdd):	1	voltage
V(n007):	-1	voltage
V(vg):	-0.2132	voltage
V(n001):	0.25827	voltage
V(vin1):	0	voltage
V(n005):	-0.58073	voltage
V(n002):	0.258278	voltage
V(n006):	0	voltage
V(n003):	0.00540871	voltage
V(n004):	-0.0710808	voltage
V(vout):	-0.000110487	voltage
V(m10#dbody):	-0.000110487	voltage
V(m10#sbody):	-0.000110487	voltage
V(m7#dbody):	1	voltage
V(m7#sbody):	1	voltage
V(m6#dbody):	1	voltage
V(m6#sbody):	1	voltage
V(m5#dbody):	1	voltage
V(m5#sbody):	1	voltage
V(m9#dbody):	-0.000110487	voltage
V(m9#sbody):	-0.000110487	voltage
V(m8#dbody):	-1	voltage
V(m8#sbody):	-1	voltage
V(m4#dbody):	-1	voltage
V(m4#sbody):	-1	voltage
V(m3#dbody):	-1	voltage
V(m3#sbody):	-1	voltage
V(m2#dbody):	-0.58073	voltage
V(m2#sbody):	-0.58073	voltage
V(m1#dbody):	-0.58073	voltage
V(m1#sbody):	-0.58073	voltage
Id(M10):	1.02853e-011	device_current
Ig(M10):	1.89919e-010	device_current
Ib(M10):	1.00009e-012	device_current
Is(M10):	-2.01205e-010	device_current
Id(M7):	-6.12769e-005	device_current
Ig(M7):	-2.93257e-009	device_current
Ib(M7):	5.42978e-012	device_current
Is(M7):	6.12798e-005	device_current
Id(M6):	-2.95609e-005	device_current
Ig(M6):	-1.45193e-009	device_current
Ib(M6):	2.41195e-012	device_current
Is(M6):	2.95623e-005	device_current
Id(M5):	-2.95609e-005	device_current
Ig(M5):	-1.45193e-009	device_current
Ib(M5):	2.41194e-012	device_current
Is(M5):	2.95623e-005	device_current
Id(M9):	2.01134e-010	device_current
Ig(M9):	-1.89848e-010	device_current
Ib(M9):	-3.03295e-012	device_current
Is(M9):	-8.25247e-012	device_current
Id(M8):	6.12769e-005	device_current
Ig(M8):	1.76519e-010	device_current
Ib(M8):	-6.06648e-012	device_current
Is(M8):	-6.12771e-005	device_current
Id(M4):	6.06595e-005	device_current
Ig(M4):	1.77291e-010	device_current
Ib(M4):	-5.81574e-012	device_current
Is(M4):	-6.06597e-005	device_current
Id(M3):	5.91277e-005	device_current

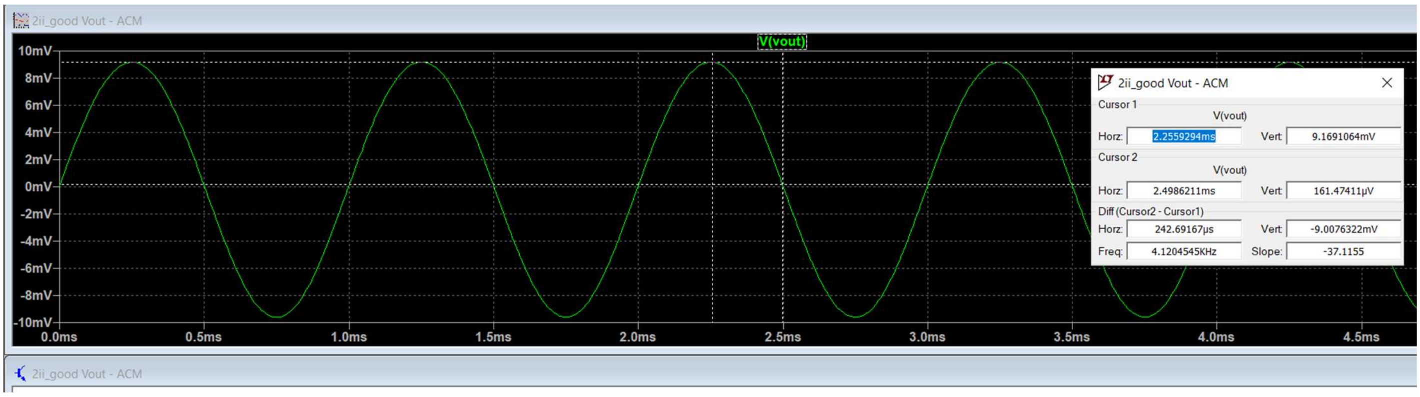
Ig(M3):	1.78536e-010	device_current
Ib(M3):	-5.39527e-012	device_current
Is(M3):	-5.91279e-005	device_current
Id(M2):	2.95638e-005	device_current
Ig(M2):	6.91628e-011	device_current
Ib(M2):	-1.09694e-012	device_current
Is(M2):	-2.95639e-005	device_current
Id(M1):	2.95638e-005	device_current
Ig(M1):	6.9163e-011	device_current
Ib(M1):	-1.09693e-012	device_current
Is(M1):	-2.95639e-005	device_current
I(C1):	-7.64895e-023	device_current
I(R1):	6.066e-005	device_current
I(Vi2):	-6.91628e-011	device_current
I(Vi1):	-6.9163e-011	device_current
I(Vss):	-0.000181065	device_current
I(Vdd):	-0.000181065	device_current

Calculation for Differential Gain:

Vi1 = 5 uV
Vi2= -5 uV
Vout= -49.094043mV
(Vout is out of phase with Vi1)

Vi=Vi1-Vi2 =10 uV
Differential gain(**Ad)** = Vout/Vi **=** 49.094043/10 *1000 = **4909.4**

Calculation for Common Mode Gain:



Vi1 = 10 mV
Vi1=Vi2=10 mV
Vout= -9.0959715mV
Common Mode Gain= Acm = Vout / Vi1 = **0.909**
(Vout is in phase with Vi1)
CMRR= |Ad/Acm| = 4909.4/0.909 = **5400.9**

Parameter	Value
Ad	4909.4
Acm	0.909
CMRR	5400.9
UGB	5.1833 GHz
Routput	608 Ohm

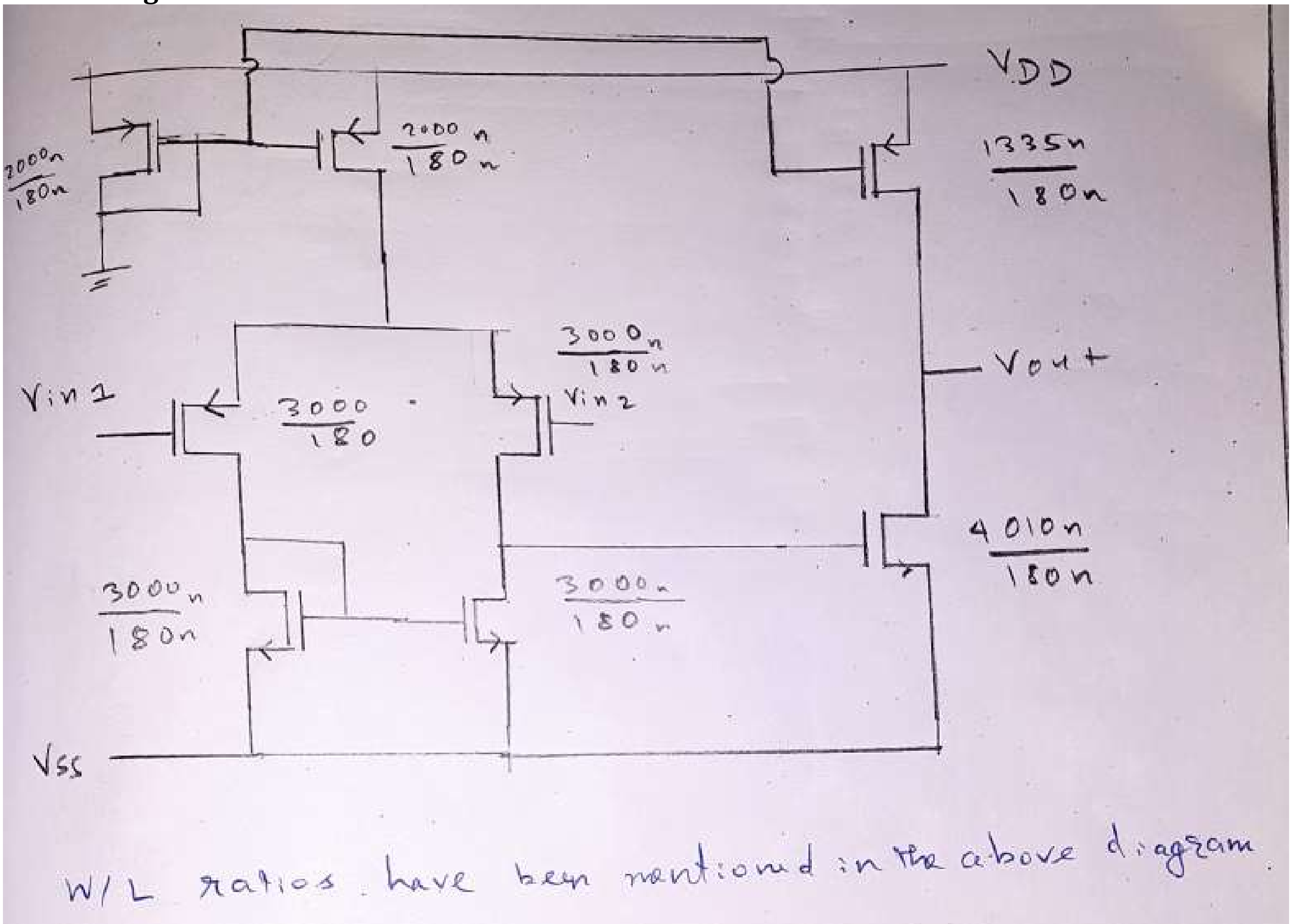
Differential Gain (Ad) = **73.438863dB**
This is clearly greater than 60dB

- We keep the L=180nm same as the previous OTA circuit, and just connect an extra stage of common drain amplifier to increase the reduce the output resistance while maintaining the high gain obtained from the OTA
- And then scale the common drain circuit so that the Vout is exactly at 0
- We can clearly observe that we have met the required specifications for the Differential Gain,

Extra Analysis: Hand-drawn Layout of Operational Transconductance Amplifier

Aim: To draw the layout diagram of the Operational Transconductance Amplifier implemented

Circuit Diagram of the OTA:



Layout Diagram of the OTA: