Differential Amplifier using NMOS Transistor

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Aim and Objective

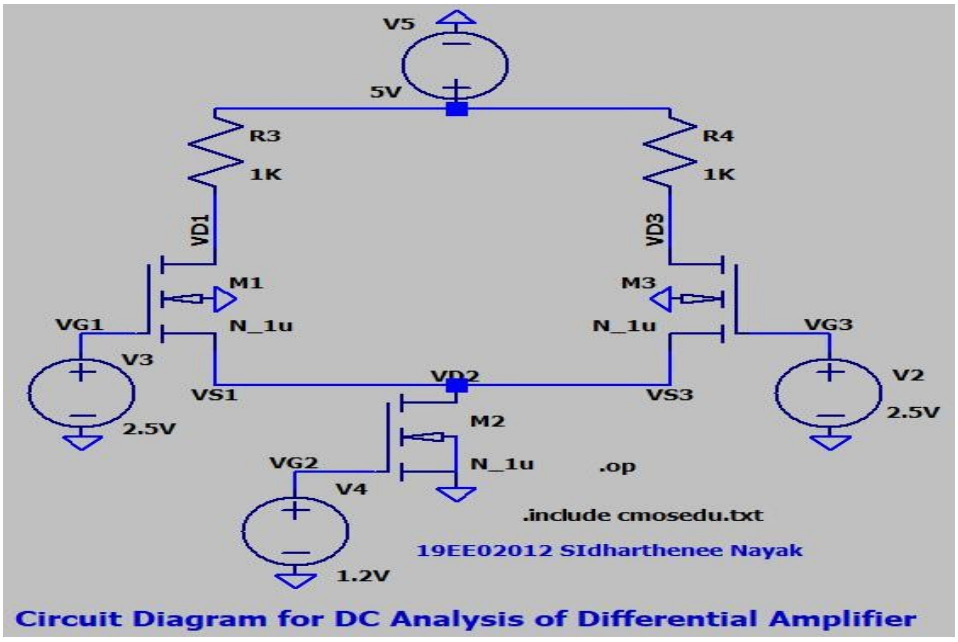
Build and simulate a Differential Amplifier
Find out the differential mode gain Find out the common mode voltage gain Find out CMRR

Theory

The differential amplifier is probably the most widely used circuit building block in analog integrated circuits, principally op amps. The differential amplifier can be implemented with BJTs or MOSFETs. A differential amplifier multiplies the voltage difference between two inputs (Vin+ - Vin-) by some constant factor Ad, the differential gain. It may have either one output or a pair of outputs where the signal of interest is the voltage difference between the two outputs. A differential amplifier also tends to reject the part of the input signals that are common to both inputs (Vin+ + Vin-)/2 . This is referred to as the common mode signal. But for a differential amplifier to work, all the mosfets used should be in saturation.

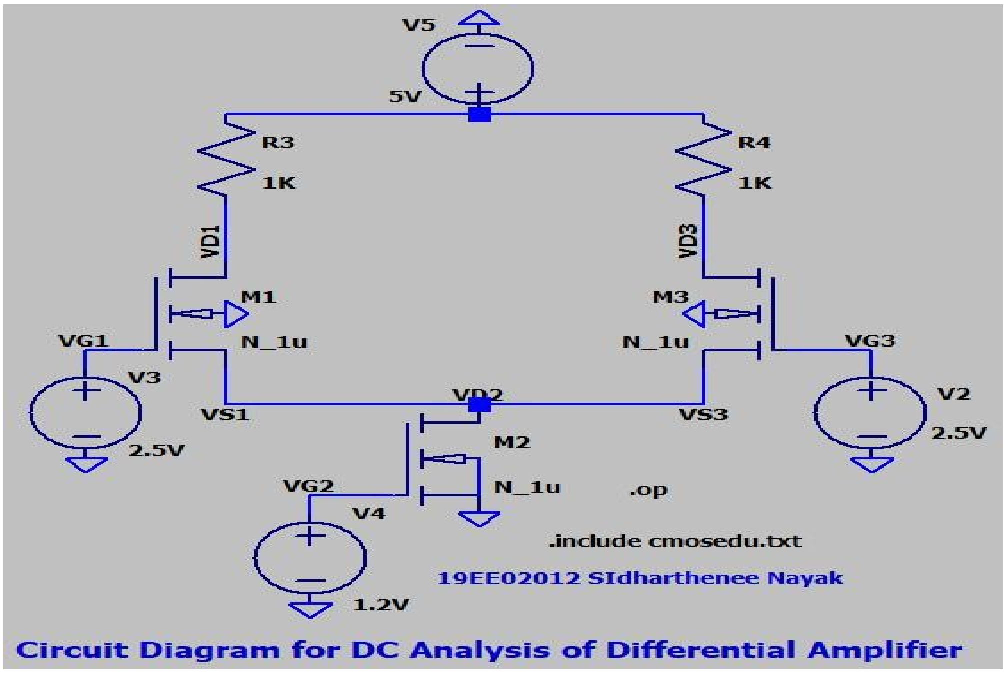
Part 1 – DC Biasing of differential Amplifier

Circuit Diagram



Procedure

1. In LTSpice software, the circuit diagram is drawn with the help of different components like MOSFET, resistors, voltage sources and are joined by wires. Each component is assigned with a specific value as shown in the circuit diagram. Then each of the node is labelled. Here I have chosen N_1u as the mosfet model .



2. Click on “Edit Simulation Command” window and choose ‘DC op pt’ . The output will be shown of voltages and current through all parts of the circuit.

```
--- Operating Point ---

V(vd1):          4.41696          voltage
V(vg1):          2.5              voltage
V(vs3):          1.24231          voltage
V(vg2):          1.2              voltage
V(n002):         0.119698         voltage
V(vd3):          4.41696          voltage
V(vg3):          2.5              voltage
V(n001):         5                voltage
Id(M3):          0.000583036      device_current
Ig(M3):          0                device_current
Ib(M3):          -5.67927e-012    device_current
Is(M3):          -0.000583036     device_current
Id(M2):          0.00116607       device_current
Ig(M2):          0                device_current
Ib(M2):          3.76603e-019     device_current
Is(M2):          -0.00116607      device_current
Id(M1):          0.000583036      device_current
Ig(M1):          0                device_current
Ib(M1):          -5.67927e-012    device_current
Is(M1):          -0.000583036     device_current
I(R4):           0.000583037      device_current
I(R3):           0.000583037      device_current
I(V5):           -0.00116607      device_current
I(V4):           0                device_current
I(V3):           0                device_current
I(V2):           0                device_current
```

3. Check whether all MOSFETs are in saturation or not.

<u>Observation and Calculation</u>


```
--- Operating Point ---

V(vd1):          4.41696          voltage
V(vg1):          2.5              voltage
V(vs3):          1.24231          voltage
V(vg2):          1.2              voltage
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I(V5):           -0.00116607      device_current
I(V4):           0                device_current
I(V3):           0                device_current
I(V2):           0                device_current
```


<u>For MOSFET 1</u>

V_{D1} = 4.417V , V_{G1} = 2.5V, V_{S1} = V_{S3} = 1.242V, V_T = 0.8V

V_{DS1} = 4.417V - 1.242V = 3.175V AND $V_{GS1} - V_T$ = 2.5V - 1.242V - 0.8V = 0.458V

<u>For MOSFET 2</u>

$V_{D2} = V_{S3} = 4.242V$, $V_{G2} = 1.2V$, $V_{S2} = 0V$, $V_T = 0.8V$

$V_{DS2} = 4.242V - 0V = 4.242V$ and $V_{GS2} – V_T = 1.2V - 0V - 0.8V = 0.4V$

For MOSFET 3

$V_{D3} = 4.417V$, $V_{G3} = 2.5V$, $V_{S3} = 1.242V$, $V_T = 0.8V$

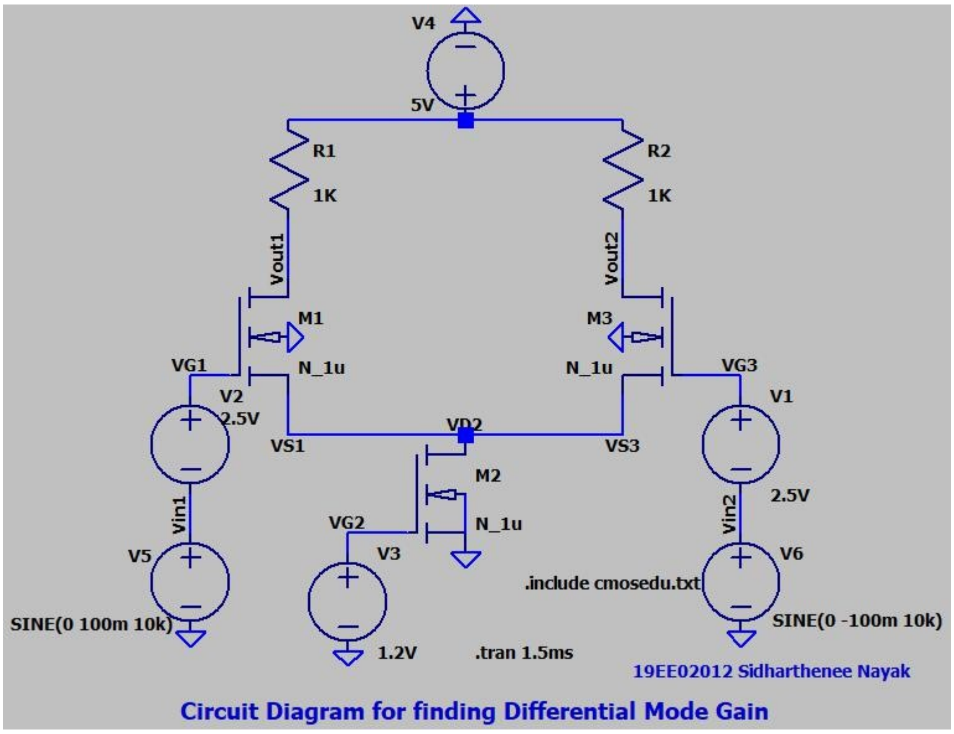
$V_{DS3} = 4.417V - 1.242V = 3.175V$ and $V_{GS2} – V_T = 2.5V – 1.242V - 0.8V = 0.458V$

Conclusion

Since in all the mosfets, V_{DS} is greater than $V_{GS} – V_T$, all of them are in saturation.

Part 2 – Finding the Differential Mode Gain

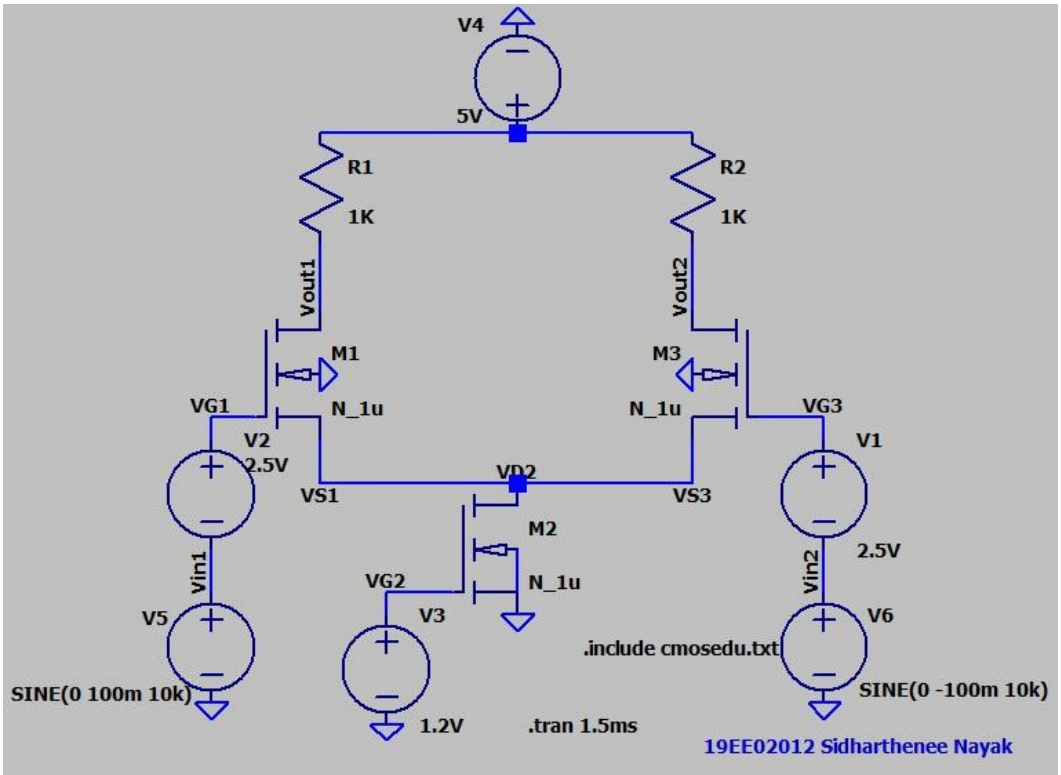
Circuit Diagram



Circuit Diagram for finding Differential Mode Gain

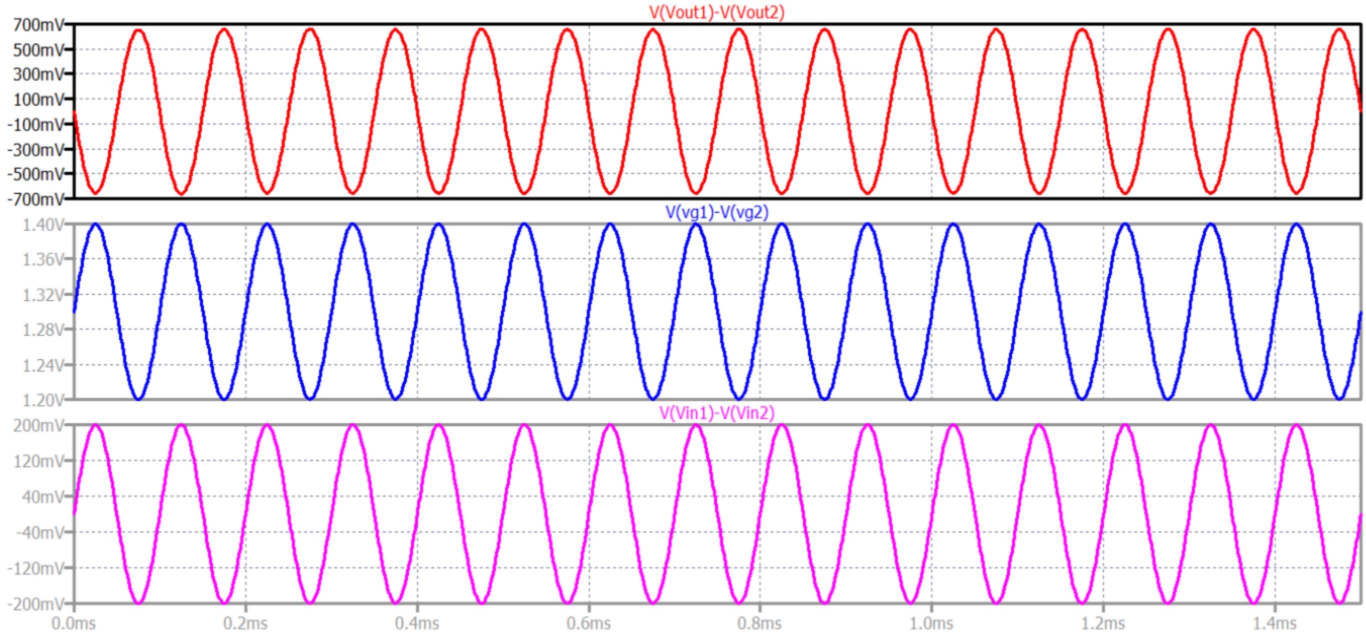
Procedure

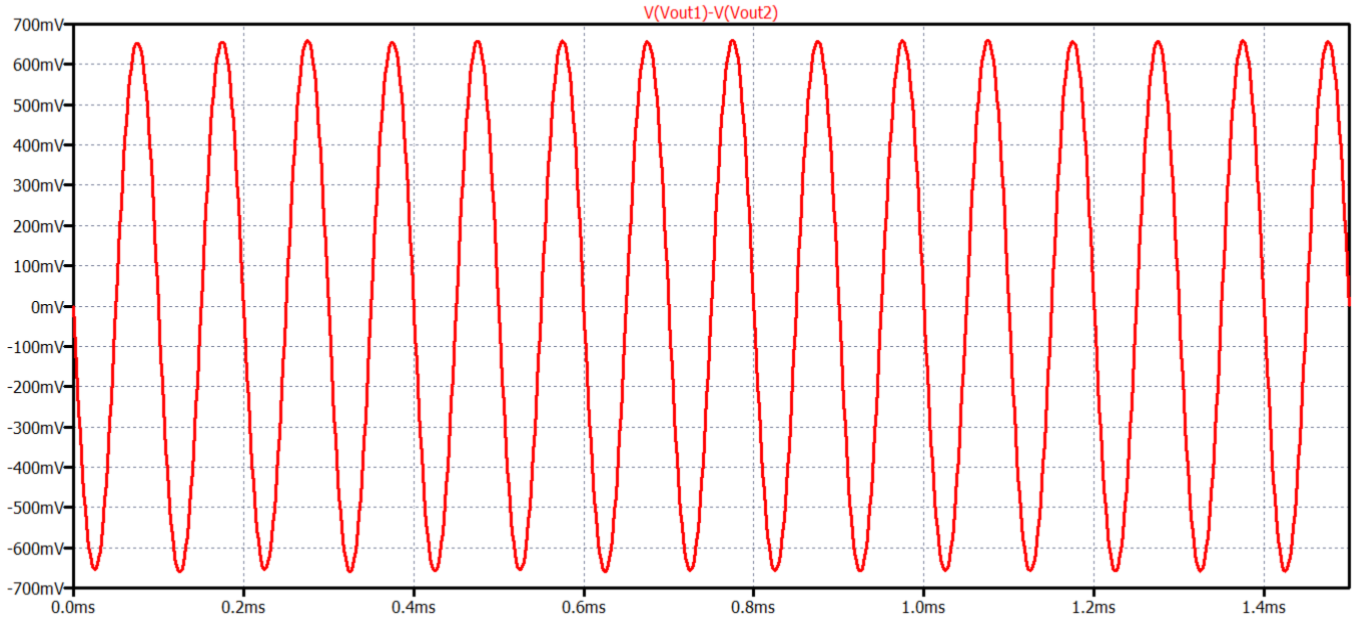
1. In LTSpice software, the circuit diagram is drawn with the help of different components like MOSFET, resistors, voltage sources and are joined by wires. Each component is assigned with a specific value as shown in the circuit diagram. Then each of the node is labelled. Here I have chosen N_1u as the mosfet model .



Circuit Diagram for finding Differential Mode Gain

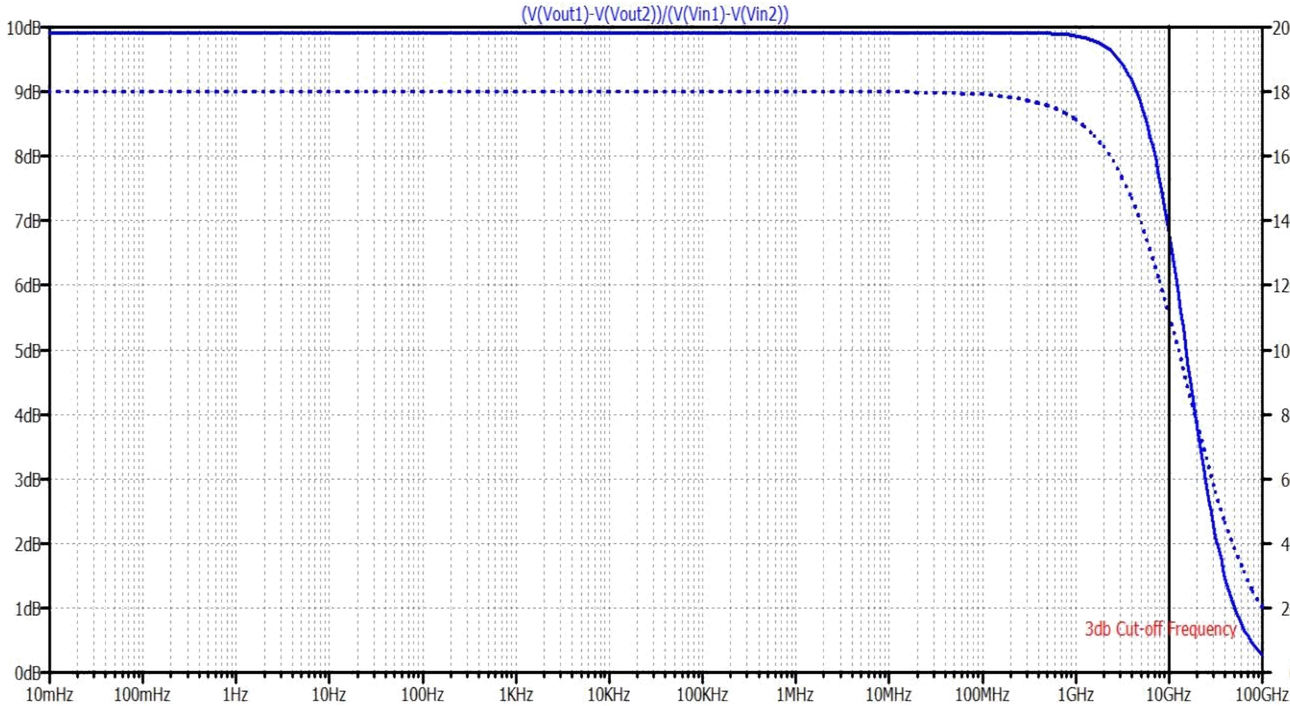
2. First perform a transient analysis and find out the waveform of (Vout1-Vout2) , (VG1-VG2) and the difference in the AC input signal which is (Vin1-Vin2) .





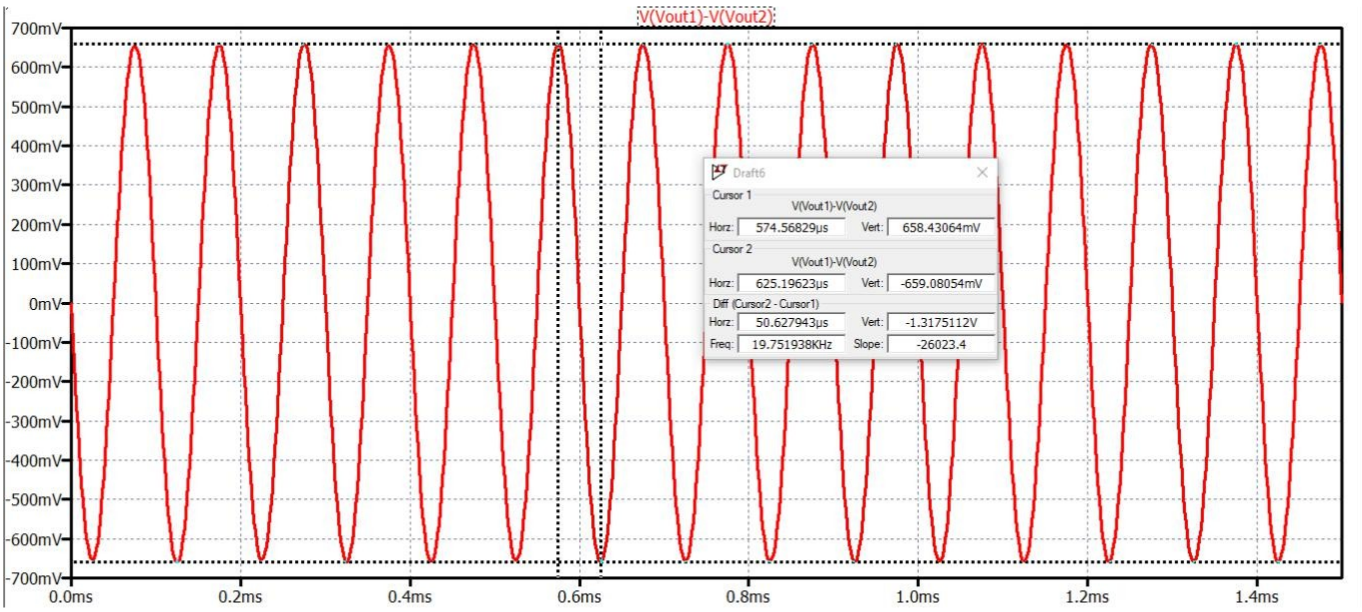
3. Then perform an AC Sweep to find out the difference mode gain in db and the cut-off frequency.

Gain in dB



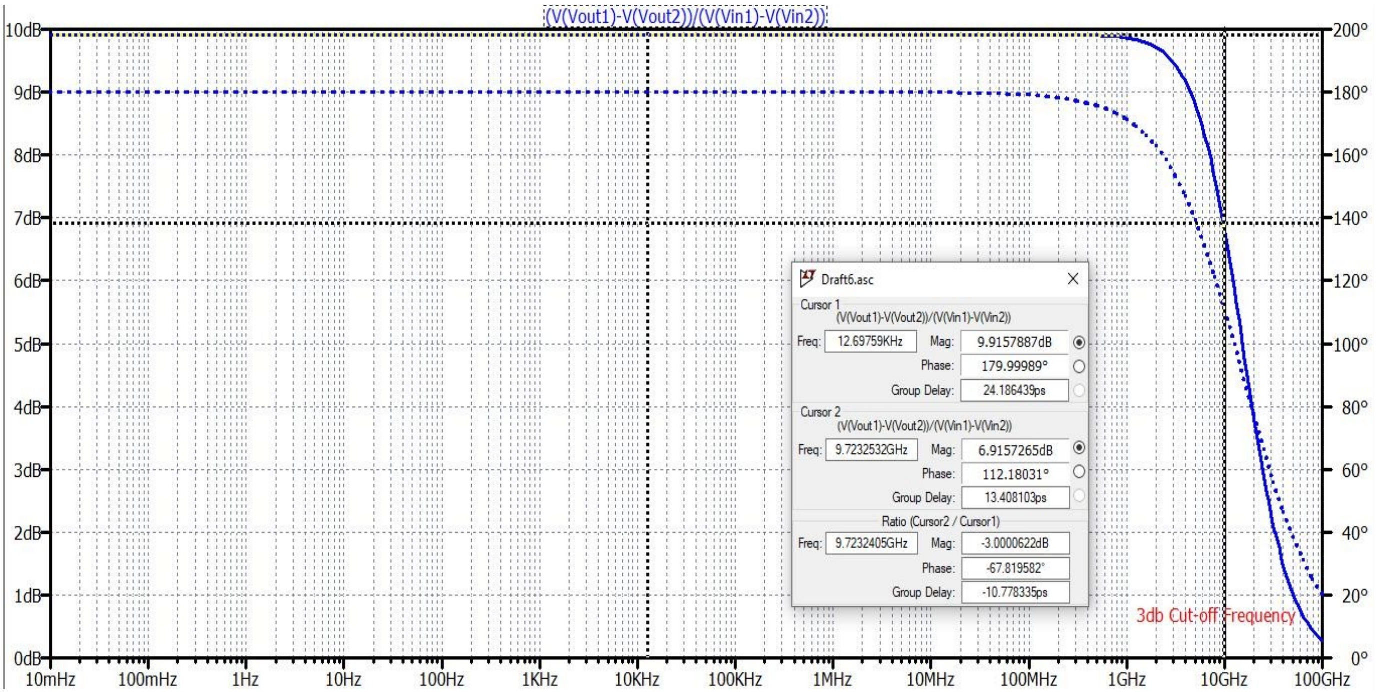
4. From the graph, find out the difference mode gain.

Observation



From the above graph, **$(Vout1\text{-}Vout2)_{Max}$ = 658.42064mV** and **$(Vout1\text{-}Vout2)_{Min}$ = -659.081 mV**

- **(Vout1-Vout2)PP** = 658.42064 mV – (-659.081 mV) = **1317.501 mV**



Differential Mode Gain = Ad in dB = 9.9157887dB

3db Higher Cut-off Frequency = 9.723GHz

Calculation

Ad = (V(Vout1)-V(Vout2))pp / (V(Vin1)-V(Vin2))pp

- **Ad** = 1317.5016 mV / 200*2mV = **3.2937 mV/mV**

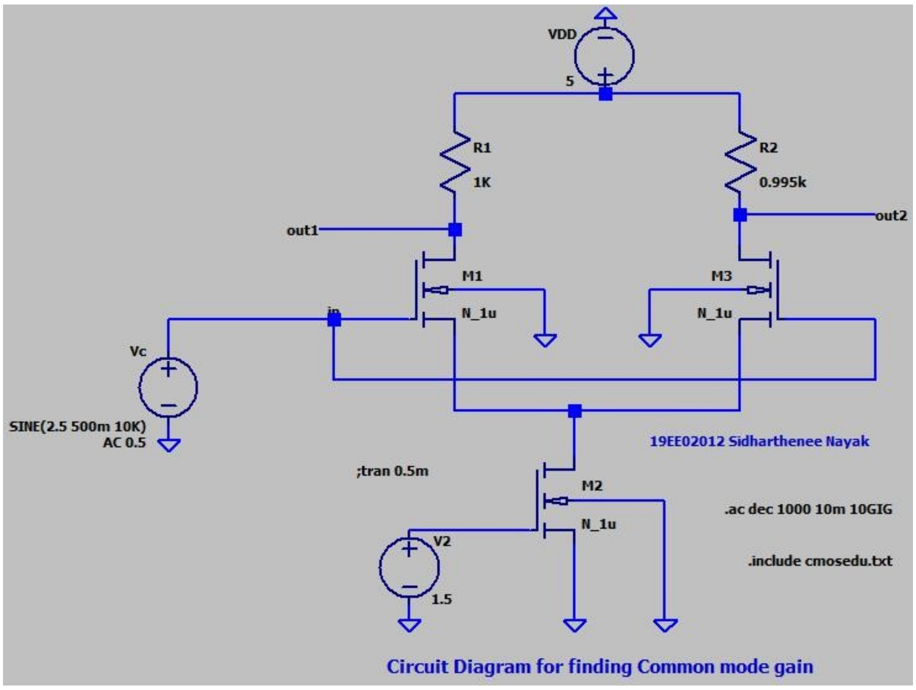
Ad in dB **= 9.9157887dB**

Conclusion

The Differential mode gain was found out to be 9.9157dB and cut-off frequency was find out to be 9.723GHz.

Part 3 – Finding Common Mode Gain

Circuit Diagram



Procedure

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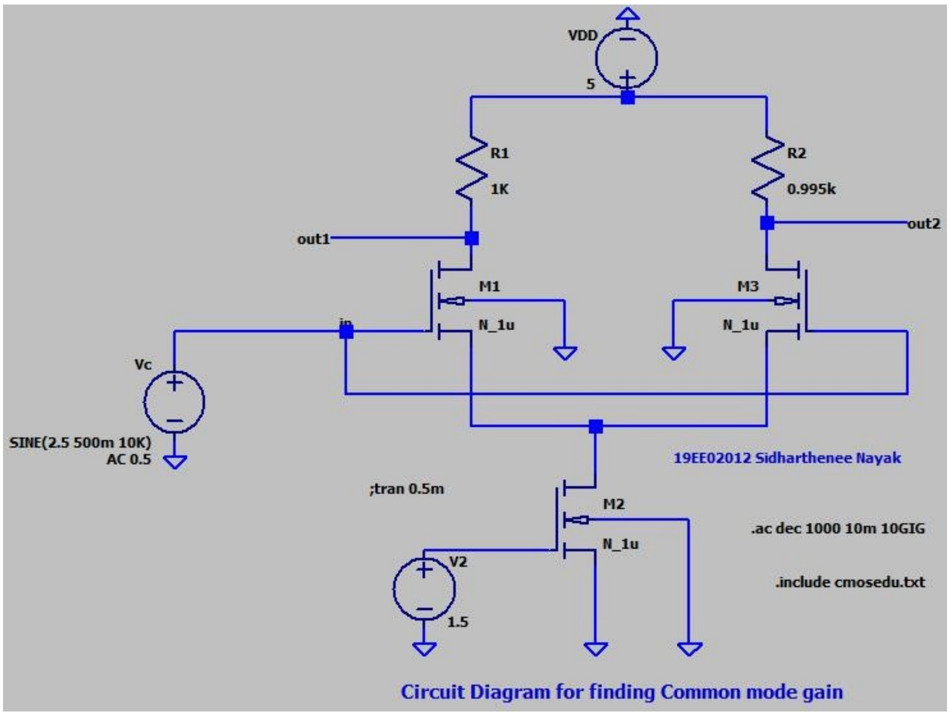
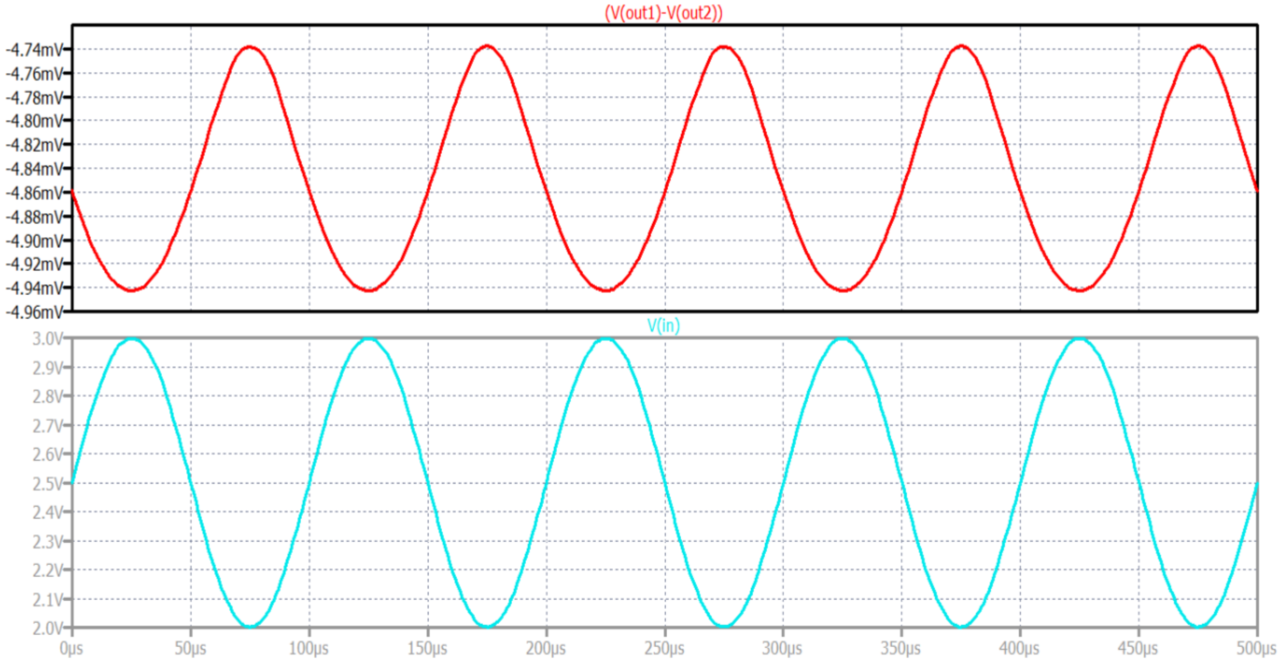
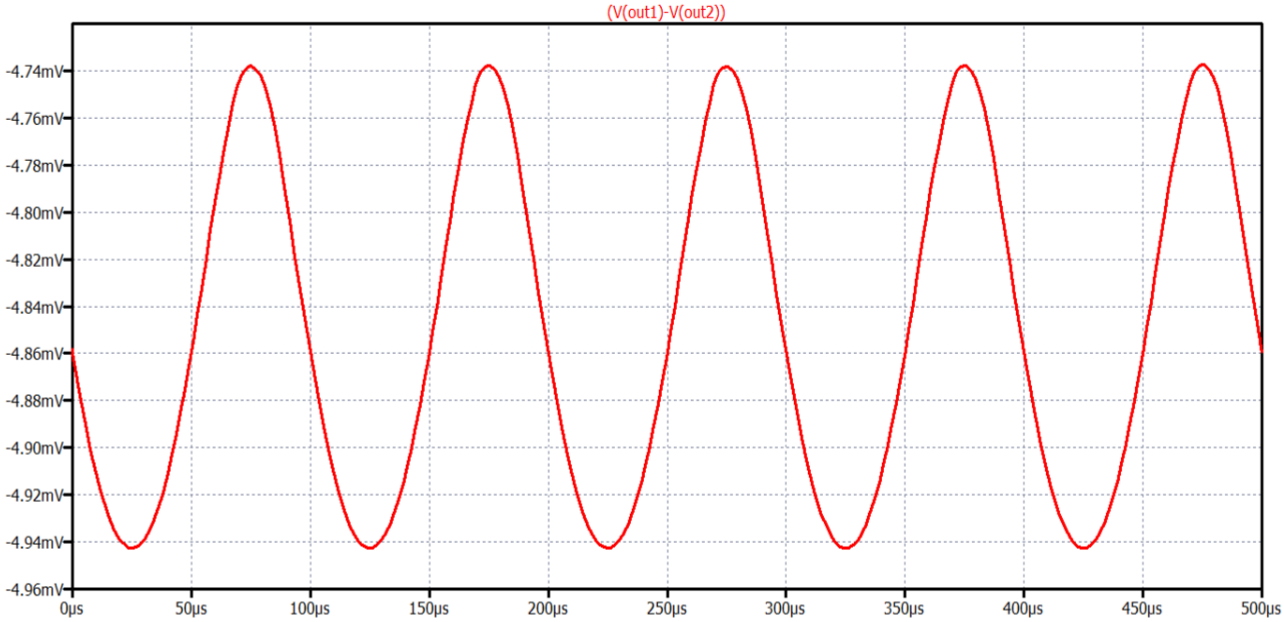


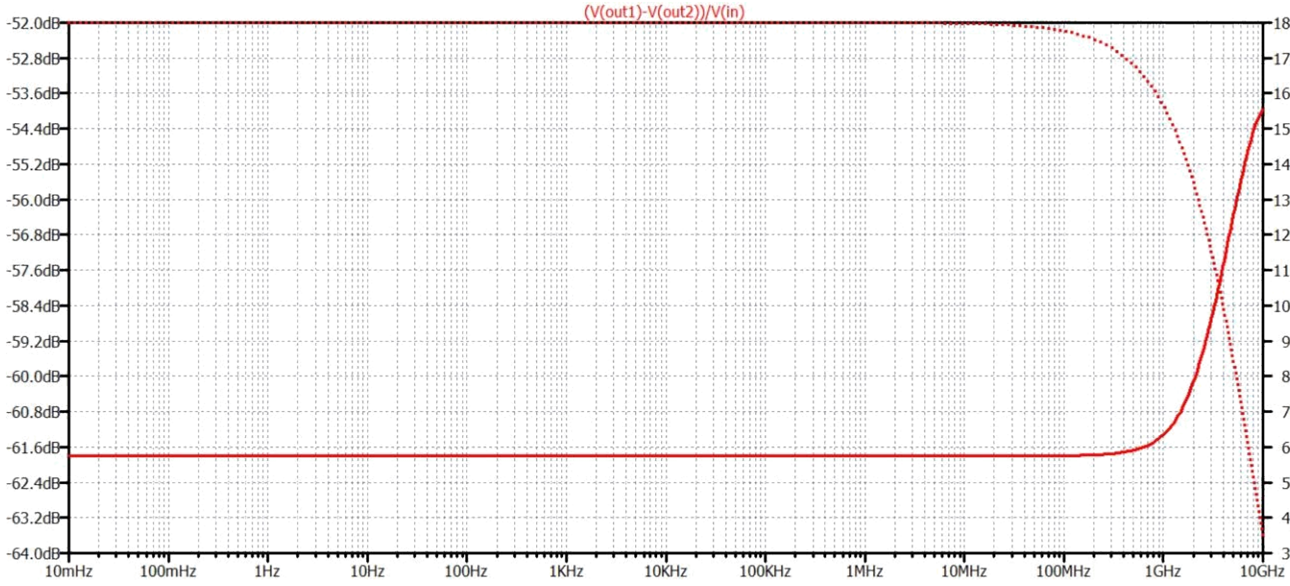
2. First perform a transient analysis and find out the waveform of (Vout1-Vout2) , VG1 and the common AC input signal which is (Vc) .





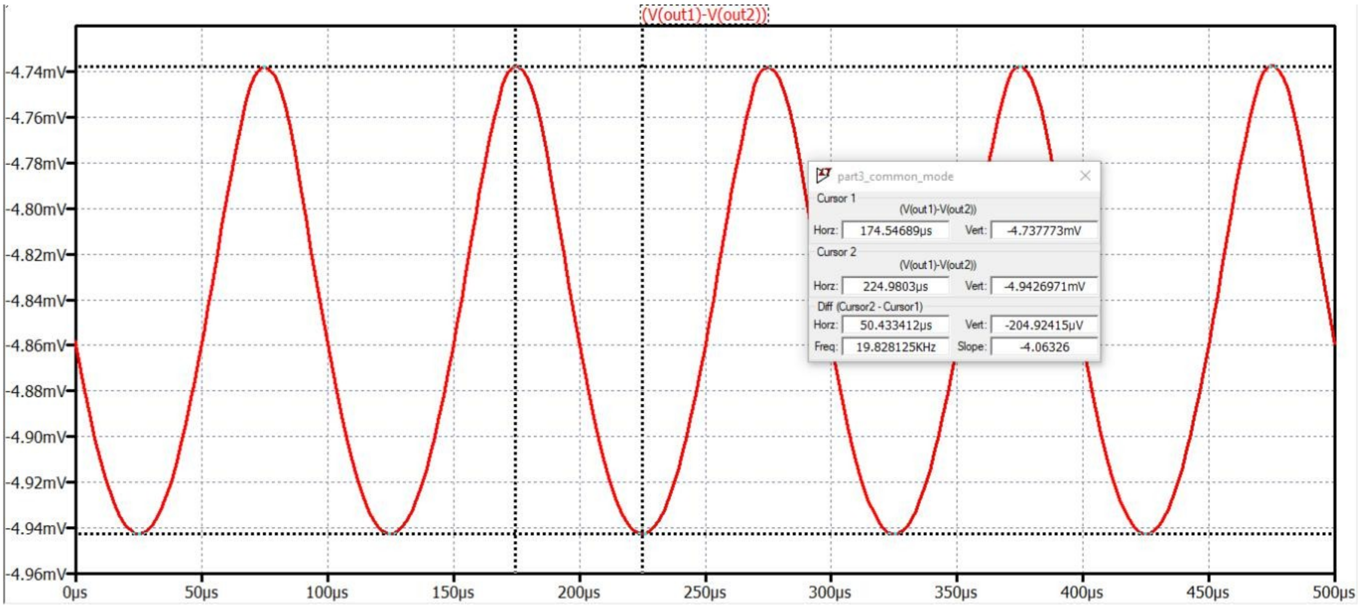
3. Then perform an AC Sweep to find out the common mode gain.

Gain in dB



4. From the graph, find out the common mode gain.

<u>Observation</u>



(V(out1)-V(out2))pp = -4.737773mV – (-4.9426971mV) = 0.2049

mV We know that (Vin)pp = 500mV – (-500mV) = 1V

Ac = **(V(out1)-V(out2))pp/V(in)pp** = 0.2049 mV/1000mV = **0.2049e-3 mV/mV**

Calculation

Ac = 0.2049e-3 mV/mV and **Ad = 3.2937 mV/mV**

- CMRR = (Ad/Ac) = **1.6074686 * 10^4**
- **CMRR in dB = 20 log(1.606686 * 10^4) = 64.122 dB**

Conclusion

From the above simulation, **common mode gain** was found out to be **0.2049e-3 mV/mV** , **difference mode gain** was found out to be **3.2937 mV/mV and CMRR was found out to be 1.6074686 * 10^4** and in dB it was **64.122 dB.**

Discussion

MOSFET differential amplifiers are used in integrated circuits, such as operational amplifiers, they provide a high input impedance for the input terminals. The advantages to a differential amplifier are many. First, if there is a noise signal that is common to both inputs, it will be cancelled, so differential designs are useful for processing signals that could be subject to interference. Second, when used in a high-gain configuration like an op-amp, it makes programming a highly repeatable, linear amplifier extremely straightforward. This is because one input can be used for negative feedback from the output. The feedback will compensate for gain variations in the individual components, as well as any non-linearities. The disadvantage is complexity - it takes at least two transistors to make a balanced differential amplifier, using a configuration known as a long-tailed pair. And in practice you need even more components to further amplify the output, provide biasing and so on. Differential amplifiers find many applications in analogue systems, including DC and audio amplifiers, analogue computers, servo control systems, etc. They are a fundamental building block of analogue design in general.