ANALOG ELECTRONIC CIRCUITS

LAB REPORT-8

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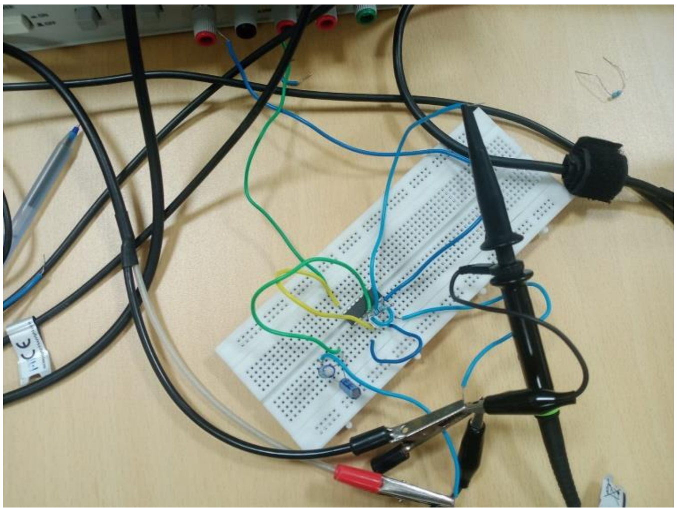
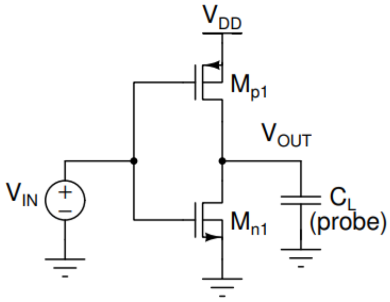
Operational Amplifiers

1) CMOS Inverter with Feedback :

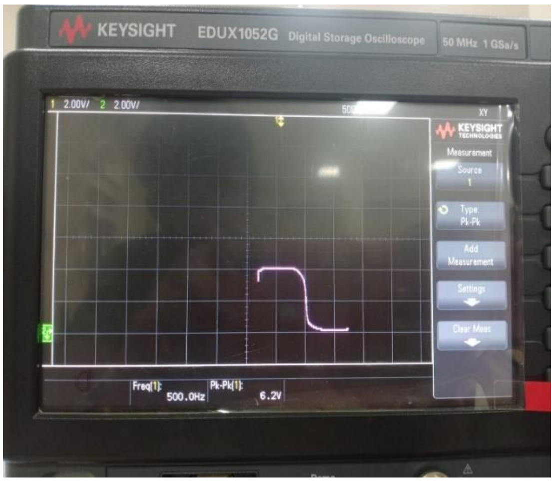
Given that CC =10 µF, RBIAS ≈ 1 MΩ (very high value) and VDD = 5 V. We used the below circuit to plot the voltage transfer characteristics (VOUT vs VIN)

a)





(a)



We have identified the valid input output region for the circuit to act as an amplifier.

slope |dvout/dvin|>1

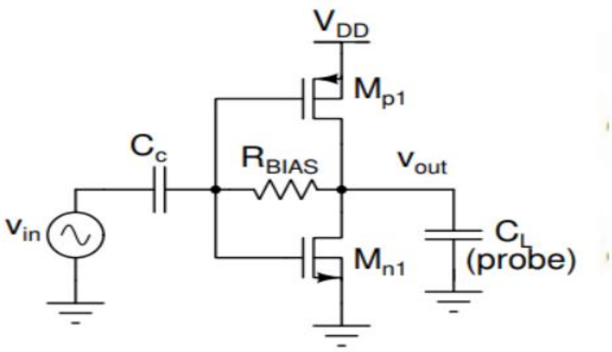
-1.07 V < Vin <1.20V

-2.27V< Vout< 2.50V

Therefore, The CMOS inverter configuration functions as an amplifier when the input voltage ranges from 1.07V to 1.20V. During this voltage range, the circuit amplifies the input signal.

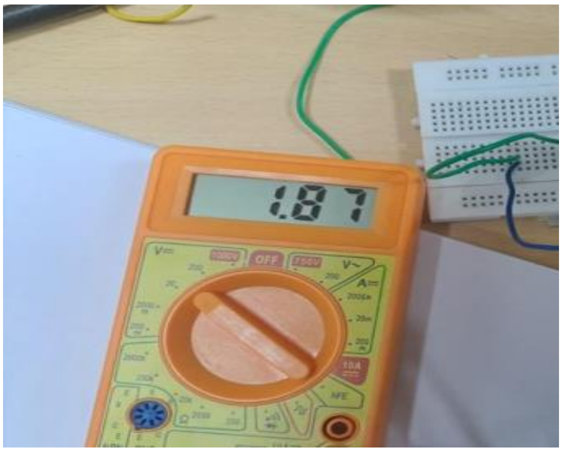
b)
We have connected the circuit as shown in the below figure:

INPUT:-
We have applied an AC signal
Vin=100m Vpp(peak to peak)
Freq(f)=1k Hz



(b)

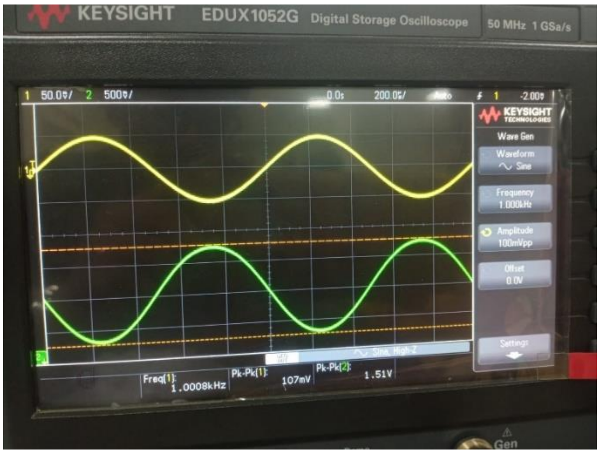
DC values---- >



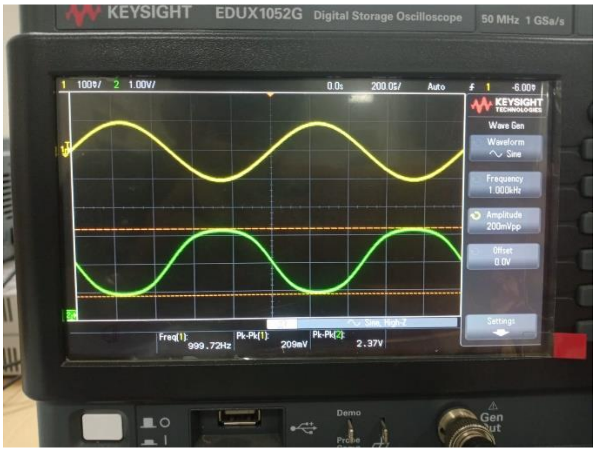
DC value at drain terminal=1.87V
DC value at gate terminal=2.3V

which are nearly equal.
As gate currents are zero and RBIAS is very large and current flows through it is nearly equal to zero
From MOSFET Conditions
Current through gate =0
Therefore, VGS-VDS=0
VGS=VDS.
ALWAYS IN **SATURATON** MODE.

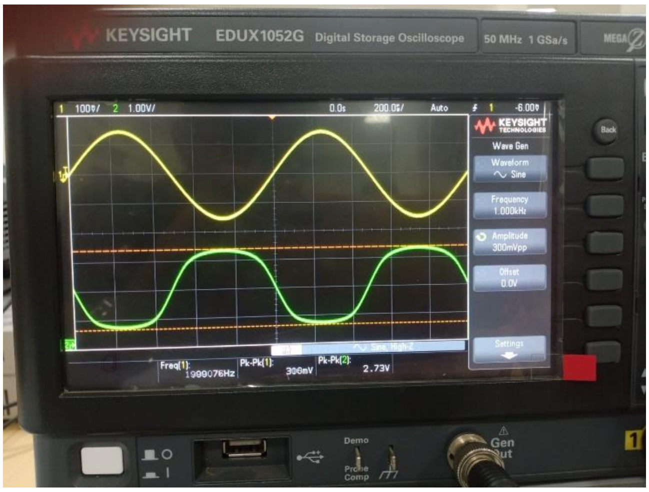
Vgs =100mV



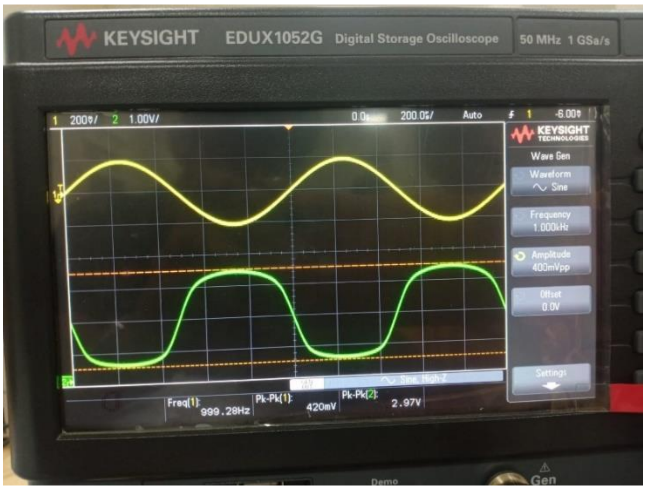
Vgs =200mV



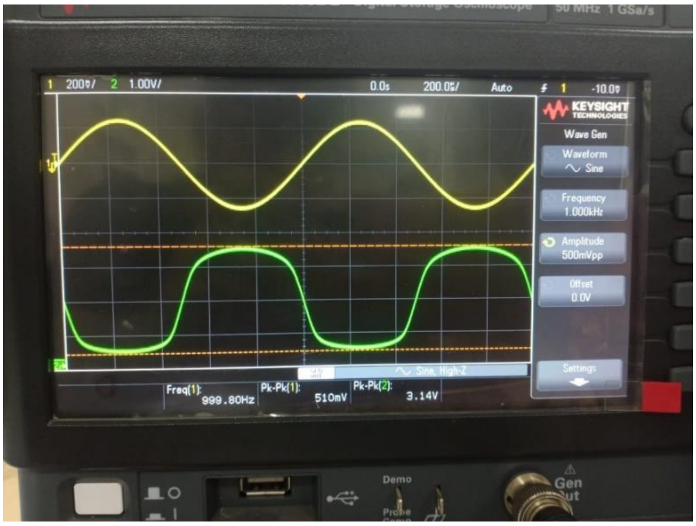
Vgs =300mV



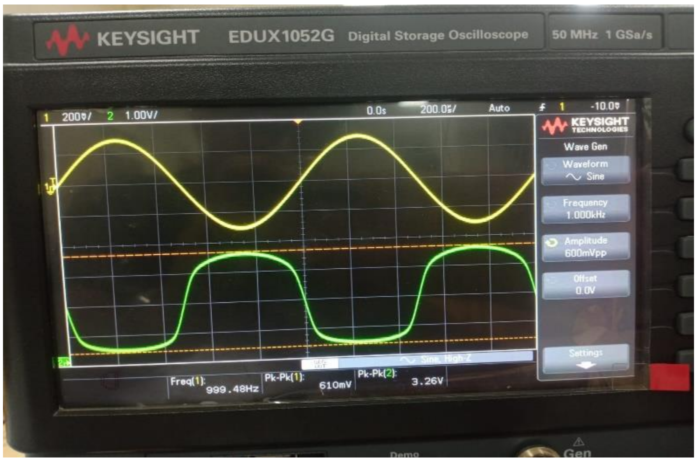
Vgs =400mV



Vgs =500mv



Vgs =600mV



Vin	Vout	Gain
100mV	1.51V	15.1
200mV	2.37V	11.85
300mV	2.73V	9.1
400mV	2.97V	7.425
500mV	3.14V	6.28
600mV	3.26V	5.43

We observed that as we increased Vgs ,gain is decreased.

We have observed clipping of the output signal as the input is increased at Vin=300mV.

This is because the signal point that exceeds the swing range would extend beyond the saturation region, where no amplification occurs. As we increase the input amplitude, a larger portion of the output signal goes beyond the saturation region, resulting in more clipping.

The Mode of Mosfet changing in swing of input Voltages. Therefore clipping is happening.

This causes a decrease in gain, as the circuit cannot amplify signals that exceed the saturation limits effectively.

2) Characterization of Operational Amplifier:

a)

We built the circuit given in the below figure:

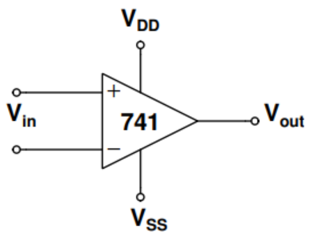
INPUT:-

Vin = 12 V (peak-to-peak),

frequency = 100 Hz,

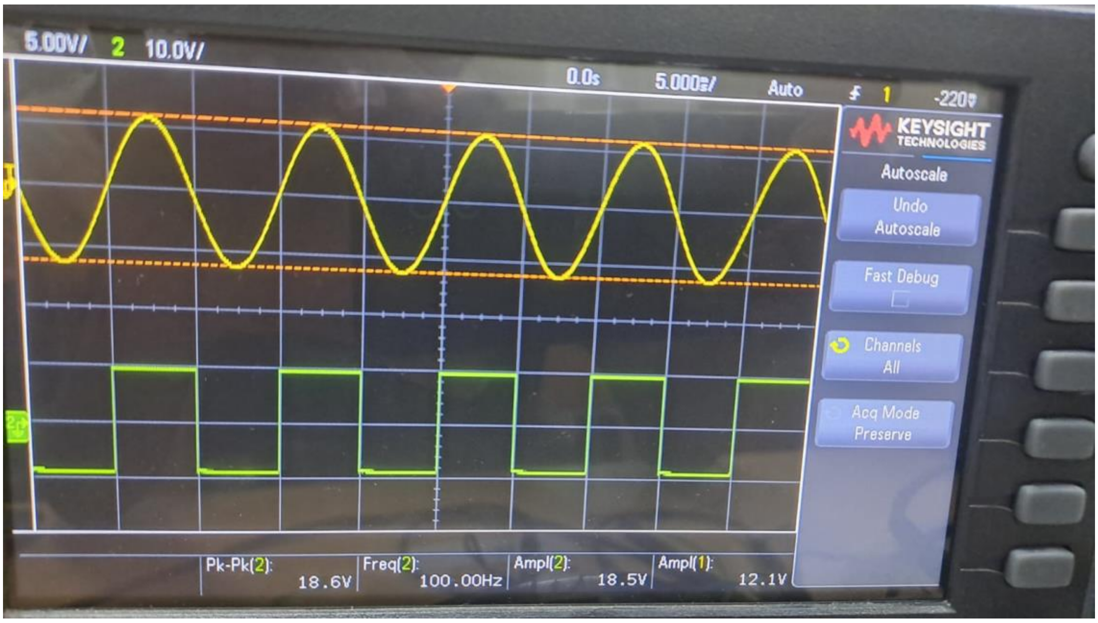
offset 0 V from the function generator,

VDD = 10 V, VSS = −10 V.

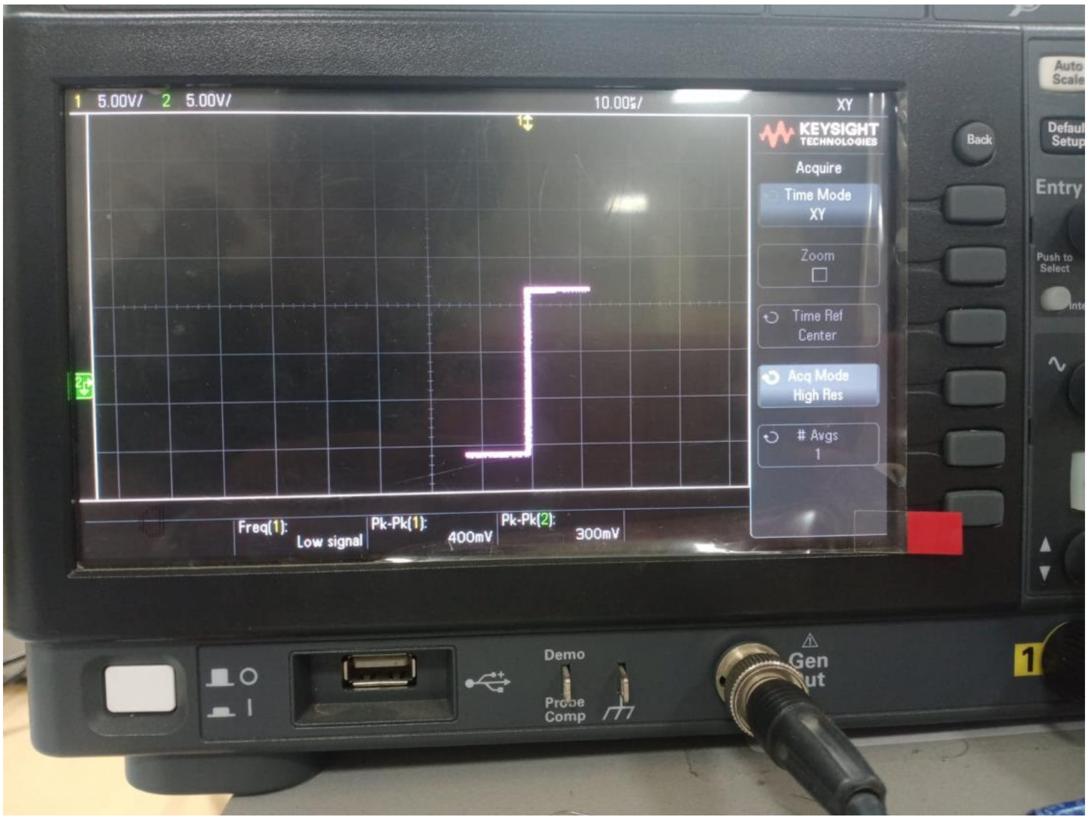


(a)

Vin and Vout :

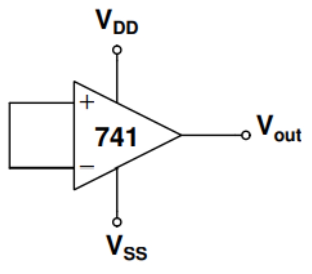


Voltage Transfer Characteristics:-



b)

We have connected the inverting and non-inverting terminals as shown in the below figure and observed the output.



(b)

Voffset=800 mV

In this experiment, by shorting both input terminals of the Operational Amplifier, we expect an output of 0V based on the ideal behavior of a differential amplifier.

However, due to imperfections of the device, such as an intrinsic DC offset at the input, we observe a saturated output instead. This occurs because the gain of the Op Amp is theoretically infinite and practically very high, amplifying even the smallest input offsets and resulting in a non-zero output voltage.

I observed 800mV of DC offset voltage as output if the both terminals of Operational Amplifier are shorted.

As a consequence of the imperfections in the op amp, the initial output voltage observed in the experiment is 0.8V, deviating from the ideal value of 0V.

However, by adjusting the input voltage to 0.48V, we successfully achieve an output voltage of 0V.

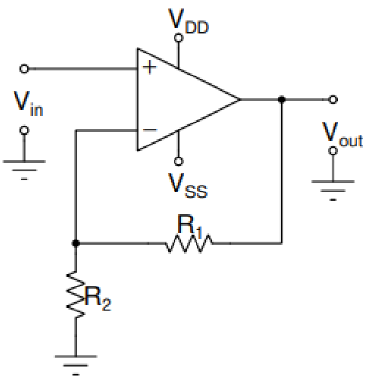
For VIN = 0.48 V, we got VOUT = 0 V

This adjustment makes the DC offset of op-amp to zero.

3) Non Inverting Amplifier :

a)

In the circuit shown in below figure output is fed back to inverting terminal (IN-) at input through a resistor divider. This is called negative feedback. Due to the very high gain of the opamp, in negative feedback, voltages at inverting and non-inverting terminal become equal and hence they are considered as virtually shorted (no current flows between IN+ and IN− but voltages are same)

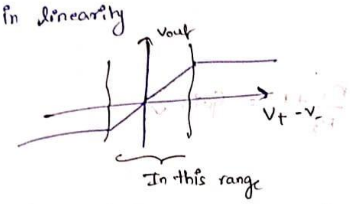


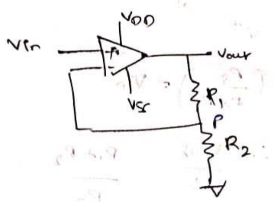
((a))

a)

3(a)

The op-amp is Assumed to be in linearity





And the circuit is Negative feedback.

→ so we can say that the op-amp is virtually shorted/ground.

∴ At point P

$$\text{Voltage} = V_P = V_{out}\left(\frac{R_2}{R_1+R_2}\right) \Rightarrow \text{(Voltage divider)}$$

$$V_P = V^- = V_{out}\left(\frac{R_2}{R_1+R_2}\right)$$

$$V^+ = V_{in}$$

We know that $V_{out} = A(V_+ - V_-)$

$$V_{out} = A\left(V_{in} - V_{out}\left(\frac{R_2}{R_1R_2}\right)\right)$$

$$V_{out}\left(1 + \frac{AR_2}{R_1+R_2}\right) = AV_{in}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{A}{1+\frac{AR_2}{R_1+R_2}}$$

Assump^n : $\frac{AR_2}{R_1R_2} \gg 1$ (because A is in order $10^5 - 10^6$)

$$\therefore \frac{V_{out}}{V_{in}} = \frac{\cancel{A}}{\frac{\cancel{A}R_2}{R_1R_2}} = \frac{R_1+R_2}{R_2} \cdot h = 1 + \frac{R_1}{R_2}$$

(or) since it is virtually shorted

$$V^- = V^+$$

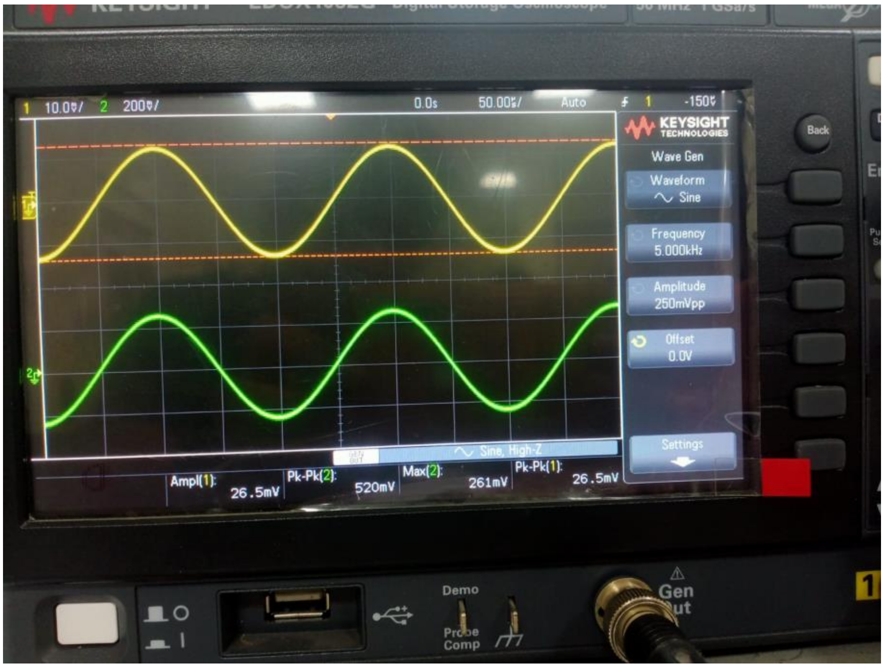
$$V_{out}\left(\frac{R_2}{R_1+R_2}\right) = V_{in}$$

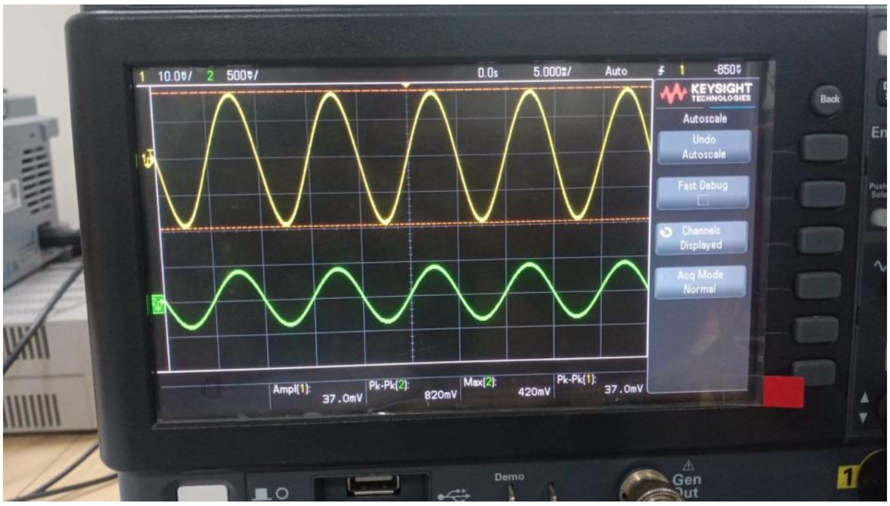
$$\therefore \frac{V_{out}}{V_{in}} = \frac{R_1+R_2}{R_2} = \frac{R_1}{R_2} + 1 = \text{Gain}$$ ✓

b)

We have realised the circuit given in 3(a), with Vin = 250 mV peak-topeak, frequency = 5 kHz from the function generator, VDD = 12 V, VSS = −12V.

We have connected the resistors R1 and R2 according to below table and calculated the gain obtained in each case.





(b) calculated

(i) $R_1 = 10k\Omega$, $R_2 = 10k\Omega$

calculated gain $= 1 + \frac{R_1}{R_2}$

$= 1 + \frac{10}{10} = 2$

Measured gain $= \frac{V_{out}}{V_{in}} = \frac{520\,mV}{261\,mV} = 1.992$

(ii) $R_1 = 10k\Omega$, $R_2 = 4.7k\Omega$

calculated gain $= 1 + \frac{R_1}{R_2}$

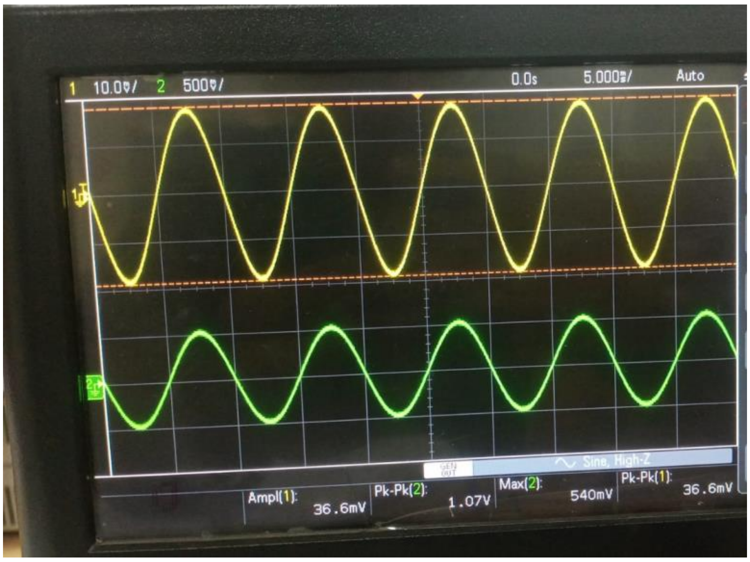
$= 1 + \frac{10}{4.7} = 3.127$

Measured gain $= \frac{V_{out}}{V_{in}} = \frac{820\,mV}{261\,mV} = 3.141$

R1	R2	Vin	Vout	Calculated Gain	Measured Gain
10kΩ	10kΩ	261mV	520mV	2	1.992
10kΩ	4.7kΩ	261mV	820mV	3.127	3.141

c)

We have calculated R1 and R2 values to obtain gain of 4 and 5.



(c) Gain = 4

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2} = 4$$

$$\frac{R_1}{R_2} = 4 - 1 = 3$$

$$\boxed{\frac{R_1}{R_2} = 3}$$

$R_1 = 10K\Omega$, $R_2 = 3.3K\Omega$ } used Resistors

Gain = 5

$$\frac{V_{out}}{V_{in}} = \frac{R_1}{R_2} + 1 = 5$$

$$\frac{R_1}{R_2} = 4 \Rightarrow \boxed{R_1 = 4R_2}$$

if $R_1 = 10K\Omega$

$R_2 = 2.5K\Omega$ (but used $2.7K\Omega$) approx.

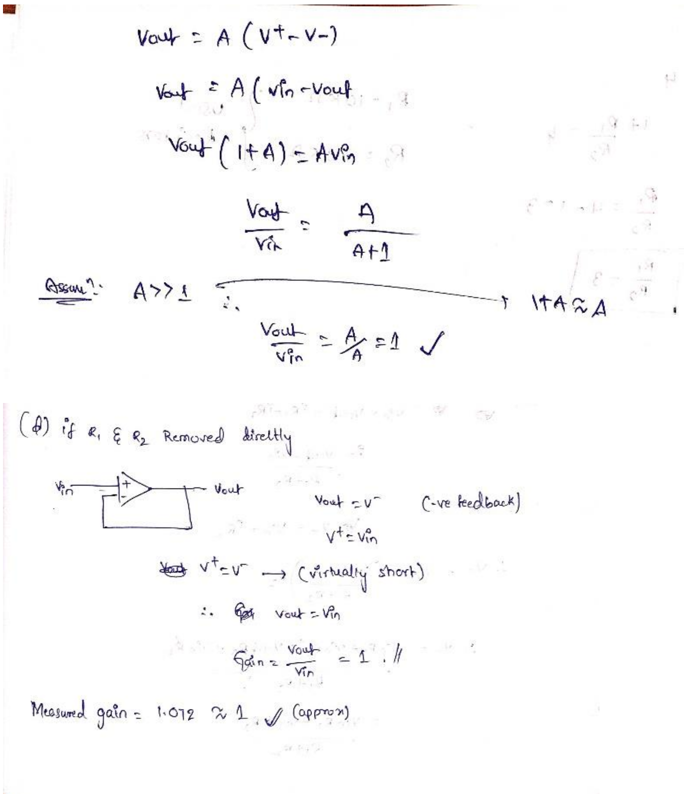
$R_1 = 10K\Omega$, $R_2 = 2.7K\Omega$ } used Resistors

EXPECTED GAIN	R1	R2	Vin	Vout	Obtained Gain
4	10kΩ	3.3kΩ	250mV	1.07 V	4.28
5	10kΩ	2.7kΩ	257mV	1.25 V	4.86

d)

We have removed R1 and R2 and connected Vout to the inverting input terminal directly.

Calculating the gain using the formula: Gain = Vout/Vin,



$V_{out} = A(V^+ - V^-)$

$V_{out} = A(V_{in} - V_{out})$

$V_{out}(1+A) = A V_{in}$

$\frac{V_{out}}{V_{in}} = \frac{A}{A+1}$

Assum^n: $A >> 1$ ∴ $\longrightarrow 1+A \approx A$

$\frac{V_{out}}{V_{in}} = \frac{A}{A} = 1$ ✓

(d) if R_1 & R_2 Removed directly

$V_{out} = V^-$ (-ve feedback)

$V^+ = V_{in}$

$V^+ = V^- \longrightarrow$ (virtually short)

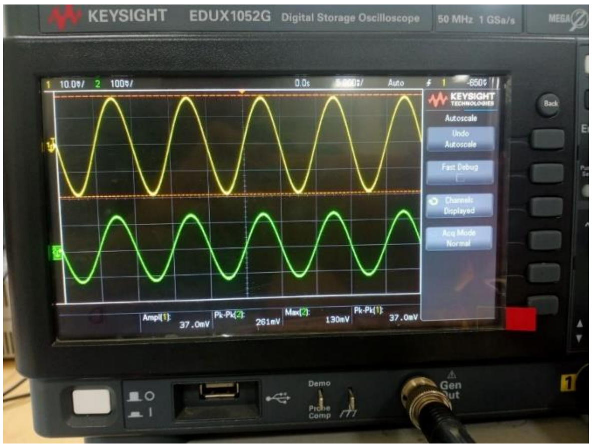
∴ $V_{out} = V_{in}$

Gain $= \frac{V_{out}}{V_{in}} = 1$ //

Measured gain = 1.072 ≈ 1 ✓ (approx)

we got: Gain=1.0727 which is nearly equal to 1. Hence, with this configuration, the obtained gain is very close to 1, indicating that there is minimal amplification or attenuation of the input signal.

Vout=Vin



The observed gain is nearly equal to 1 indicating that the input signal is transferred to the output as it is. This circuit is known as a BUFFER circuit.

The buffer circuit exhibits a high input impedance, meaning it draws minimal current, resulting in minimal disturbance to the connected circuitry at its input terminals. It can function as an impedance matcher, matching the impedance between different parts of a circuit to ensure efficient signal transfer. It can also act as a signal isolator, providing electrical isolation between different sections of a circuit to prevent interference. Additionally, the buffer circuit can serve as a voltage level shifter, adjusting the voltage level of the input signal to match the requirements of the downstream circuitry. Finally, it can function as an active filter stage within a larger filter circuit, actively manipulating the signal to achieve desired filtering characteristics.

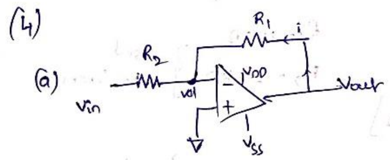
High input Impedence and Low output Impedence

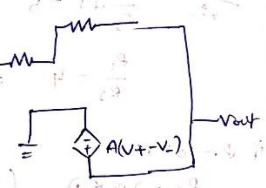
4) Inverting Amplifier:

a)

(4)

(a)





$$V_d = V_{out} - V_{in}$$

$$V_+ = 0$$

$$V_{in} = V_{out} - iR_1 - iR_2$$

$$i = \frac{V_{out} - V_{in}}{R_1 + R_2}$$

$$V_- = V_{in} + iR_2$$

$$\therefore V_- = V_{in} + \left(\frac{V_{out} - V_{in}}{R_1 + R_2}\right) R_2$$

$$\therefore V_- = \frac{V_{in}R_1 + \cancel{V_{in}R_2} + V_{out}R_2 - \cancel{V_{in}R_2}}{R_1 + R_2}$$

$$= \frac{V_{in}R_1 + V_{out}R_2}{R_1 + R_2}$$

as $V_{out} = A(V_+ - V_-)$

$$= A\left(0 - \left(\frac{V_{in}R_1 + V_{out}R_2}{R_1+R_2}\right)\right) = V_{out}$$

$$V_{out} = \frac{-AV_{in}R_1}{R_1+R_2} - \frac{R_2 A V_{out}}{R_1+R_2}$$

$$V_{out}\left(1+\frac{AR_2}{R_1+R_2}\right) = -\frac{AV_{in}R_1}{R_1+R_2}$$

$$\frac{V_{out}}{V_{in}} = \frac{-AR_1}{AR_2+R_1+R_2} = -\frac{AR_1}{R_2(A+1)+R_1}$$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{-R_1}{R_2+\frac{R_1}{A}}$$

-ve sign represents Inverting Amplifier ☺

Assump^n $A \gg 1$

$$\frac{R_1}{A} \approx 0 \quad \therefore \boxed{\frac{V_{out}}{V_{in}} = \frac{-R_1}{R_2}} = \text{Gain}$$

b)

We have realised the circuit given in the below figure with Vin = 250 mV peak-to-peak from the function generator, VDD=12V, VSS=−12V We have connected the resistors R1 and R2 according to the below table and calculated the gain obtained in each case

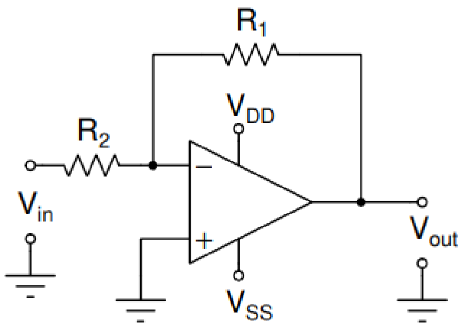
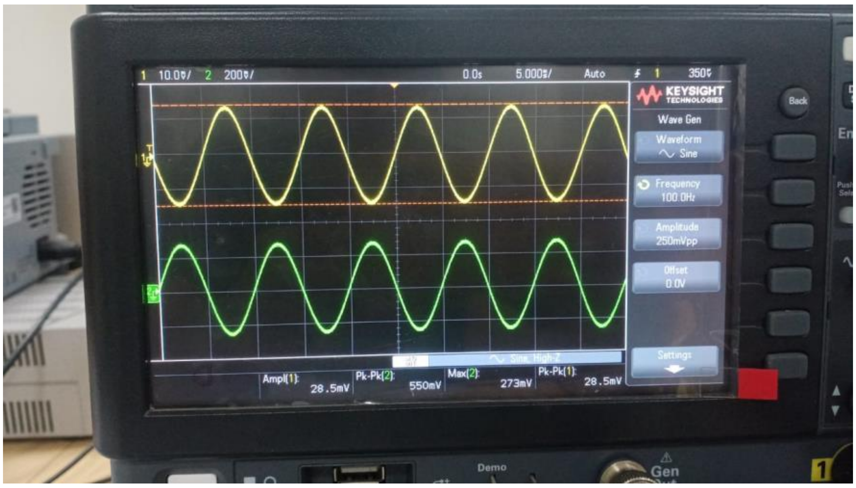
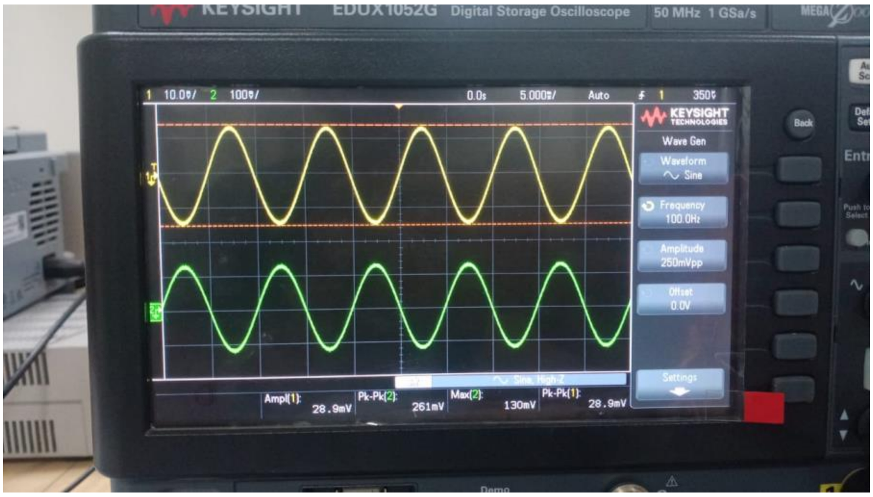


Figure 4: Inverting amplifier





(b) $R_1 = 10K\Omega \quad R_2 = 10K\Omega$

Gain calculated $= \frac{-R_1}{R_2} = \frac{-10}{10} = -1$

$= 1$

$|A_V| = 1$

Measured Gain $= \frac{V_{out}}{V_{in}} = \frac{280mV}{261mV} = 1.07 \approx 1$

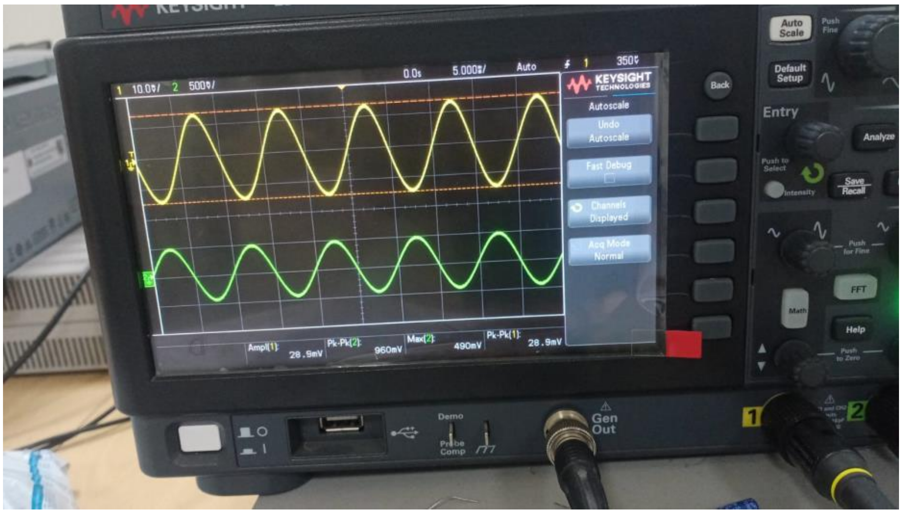
$R_1 = 10k\Omega$ $R_2 = 4.7k\Omega$

Gain measured $= \frac{550mV}{261mV} = 2.10\ V$

Calculated $= \frac{-10}{4.7} = 2.12$

R1	R2	Vin	Vout	Calculated Gain	Measured Gain
10kΩ	10kΩ	261mV	280mV	1	1.07
10kΩ	4.7kΩ	261mV	550mV	2.12	2.10

c)



EXPECTED GAIN	R1	R2	Vin	Vout	Obtained Gain
4	10kΩ	2.7kΩ	250mV	960mV	3.84
5	10kΩ	2.2kΩ	250mV	1.17 V	4.68

(c) Gain = 4

$\left|\frac{R_1}{R_2}\right| = 4$

$R_1 = 4R_2$

$R_1 = 10\,K\Omega$
$R_2 = 2.7\,K\Omega$
used resistors

Let $R_1 = 10\,K\Omega$
then $R_2 = 2.5\,K\Omega$
(but used $2.7\,K\Omega$)

Gain = 5

$\frac{R_1}{R_2} = 5$ $\boxed{R_1 = 5R_2}$

if $R_1 = 10\,K\Omega$
then $R_2 = 2\,K\Omega$
(but used $2.2\,K\Omega$)

$R_1 = 10\,K\Omega$
$R_2 = 2.7\,K\Omega$
used resistors