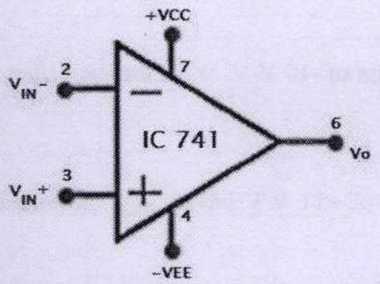
EXPERIMENT #1 BASICS OF OPERATIONAL AMPLIFIER

I OBJECTIVES

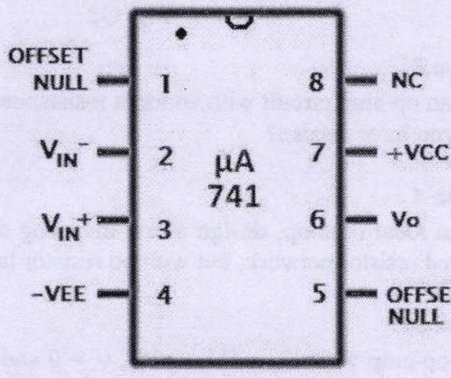
The primary objective of this experiment is to familiarize the student with the basic properties and applications of the integrated-circuit operational amplifier, (the "op-amp" in short), one of the most versatile building blocks available to electronic-circuit designers. The emphasis will be primarily on the nearly ideal op-amp.

II COMPONENTS AND INSTRUMENTATION

The focus will be on the 741-type op amp provided one per IC, in an 8-pin dual-in-line (DIP) package whose schematic connection diagram and packaging are shown in Fig. 1.1. For power, you will use two supplies, ±15 V for short. As well, you need a variety of resistors and capacitors, with emphasis on ones simply specified: 1kΩ, 10kΩ, 100kΩ, 1MΩ, 10MΩ and 0.1μF, 0.01μF, 1nF, and the like. Note that it is important to bypass the two power supplies directly on your prototyping board, using, for each supply, a parallel combination of a 100μF tantalum or electrolyte capacitors, and or 0.1 μF low inductance ceramic capacitor. For measurement, you will use a bench multimeter, a two channel oscilloscope with probes and a waveform generator.



μA 741 Symbol



PIN Diagram

Fig. 1.1 Circuit symbol of op-Amp and the pin diagram

III PREPARATION

Preparation is intended to help familiarize you with the experimental work to follow, ideally, by raising questions about the specific circuits you will later explore, it will help you in thinking about the experiments you will perform and the results you will obtain, **as you proceed.** We will refer directly to the steps of the experimental work to follow, using the numbering of procedures and circuit figures found there. Unless otherwise specified, in what follows, assume all op amps to be ideal. (You may write the answers on the reverse of this page.)

Question1.
In Fig. Q1 a practical voltage source v_s with internal resistance R_s feeds a load R_l through an amplifier with input and output resistances R_i and R_o respectively. Find v_2/v_1 .

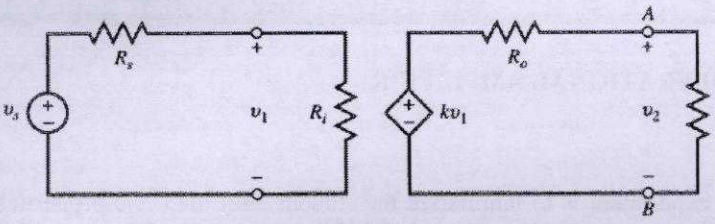


Fig. Q1

Question2.

In the inverting amplifier circuit below, compute v_1 and v_2 and sketch v_s, v_1 and v_2 if v_s = sin100t.

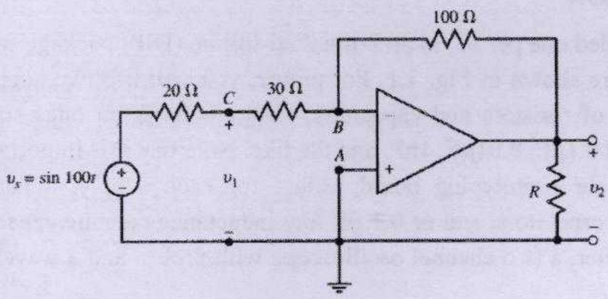


Fig. Q2

Question 3

Design an op-amp circuit with an input resistance of 2.2 kΩ and a gain of -10 V/V. What are the values of R_1 and R_2 you have chosen?

Question 4

Using an ideal op-amp, design a non-inverting amplifier with gain of +11 V/V having low currents in the associated resistor network, but with no resistor larger than 10 kΩ.

Question 5

For the op-amp with V_{cc} = 5V, $A=10^5$, v^- = 0 and v^+ =100sin2πt (μV). Find and sketch the open-loop output v_o .

Question 6

The output voltage of an op-amp decreases by 10% when a 5 kΩ load is connected at the output terminals. Compute the output resistance R_{out}.

Question 7

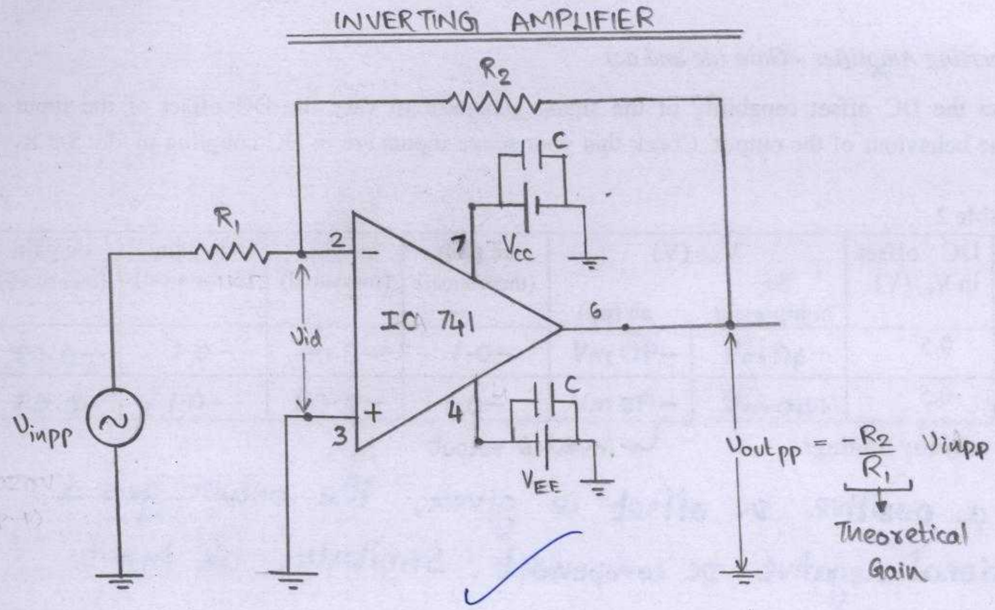
An op-Amp has a common mode amplification A_{cm}=0.0002. Find the magnitude of the output voltage if the input voltages are V^- = V^+= 2V.

IV EXPERIMENTATION

4.1– *Inverting Amplifier*

4.1.1 – Inverting Amplifier – AC Gain

Draw the basic inverting amplifier circuit (using μA 741) with appropriate power supply connections, input signal source etc (denote input and feedback resistors using R_1 and R_2 respectively).



Measurements
Table 1

→ -ve sign indicates that the output is 180° out of phase with the input.

R_1 ($K\Omega$)	R_2 ($K\Omega$)	V_{inpp} (V)	V_{outpp} (V)	Experimental Gain	Theoretical Gain
1	10	0.020	-0.17	-8.5	-10
1	100	0.020	-1.90	-95	-100
1	1000	0.020	- 16.00	-800	-1000

Using the resistors specified in the table , wire the circuit drawn. Use your signal generator to apply a sine wave voltage at 1000 Hz (as V_{in}) and channel 1 of the scope to monitor it. Use channel 2 to observe the output. Measure the output voltage for the various combinations of resistors shown in the table above. Use the formulae to calculate the theoretical gain in the last column. **Comment on the agreement of two sets of gains.**

The experimental gain observed is less than the theoretical gain that is calculated. However, in the $R_2 = 100k\Omega$ case, the experimental gain follows the theoretical gain closely. The reason for low experimental gain is the non-ideal behavior of the µA741.

4.1.2 – Inverting Amplifier - Gain (dc and ac)

Use the DC offset capability of the signal generator to vary the DC offset of the input signal. Observe the behaviour of the output. Check that your scope inputs are in DC coupling mode. Set R_1=10kΩ, R_2=1kΩ.

Table 2

V_{inpp} (V)	DC offset in V_{in} (V)	V_{out} (V) dc component	V_{out} (V) ac (pp)	ac gain (theoretical)	ac gain (measured)	dc gain (theoretical)	dc gain (measured)
1.0	0.5	−40 mV	−90 mV	−0.1	−0.09	−0.1	−0.08
1.0	-0.5	+40 mV	−90 mV	−0.1	−0.09	−0.1	−0.08

8

→ inverted output

Comment on your findings:

When a positive DC offset is given, the output gets a proportional negative DC component. Similarly, an input with negative DC offset would yield a positively displaced output. Both dc and ac are amplified equally. (ie) i) AC - inverted ii) DC - complemented

4.1.3 – Inverting Amplifier - Linearity

Set the DC offset back to zero. Keep R_1 at 1k, R_2 at 100kΩ and the frequency at 1000 Hz. Measure V_{out} for the various values of V_{in} shown in the table below. (Do not fail to observe the waveforms).

Table 3

V_{inpp} (V)	V_{outpp} (V)	Experimental Gain (V/V)
0.020	−2.1	−105
0.100	−10	−100
0.150	−15	−100
0.200	−20	−100
0.250	−23	−92
0.300	−23	−76.66
0.400	−23	−57.50

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Bottom clipping

Top + Bottom clipping

Clipping of the output waveform starts at V_{inpp} = 0.23V (p-p)

depends on V_o.

Extend the table until you get clipping at the top and bottom of the waveform. Determine the output voltage where clipping occurs on both the top and bottom. Measure the actual voltage of the +15 and -15 power supplies and calculate the differences between the clipping voltage and the power supply voltage. Explain why the Op-Amp is unable to output voltages near the power supply levels. **Make a graph of V_{out} Vs V_{in} from your data. Determine the circuit gain from the slope of the graph. Is your amplifier linear? Comment on the linearity.**

in terms of Va

The amplifier (op-amp) shows linear characteristics upto $V_{inpp} = 0.23\,V\,(PP)$

After this, the output gets saturated since $+V_{sat} < +V_{CC}$ and $-V_{sat} < -V_{EE}$

The bottom part of the output gets clipped initially, following which, both top and bottom get clipped, after 0.30 V (P-P). This non-uniformity in clipping may arise due to imperfections and mis-match between the transfer characteristics of two similar transistors, while manufacturing.

4.1.4 – Inverting Amplifier - Frequency Response

Continue to use R_1 of 1kΩ and R_2 of 100kΩ. Set the input voltage (sine wave) at 0.1 V_{pp}. Measure the output voltage for the frequencies given in the table below and determine the experimental gain.

Table 4

Frequency (Hz)	Voutpp (V)	Experimental Gain	Gain (dB)
100	- 10.0	- 100	40.00
1000	- 10.0	-100	40.00
3000	- 9.5	- 95	39.55
10K	- 7.0	-70	36.90
20K	- 4.4	-44	32.87
40K	- 2.4	-24	27.60
50K	- 2.0	-20	26.02
100K	- 1.0	- 10	20.00
300K	- 0.44	-4.4	12.87
1M	- 0.20	-2.0	6.02

S.

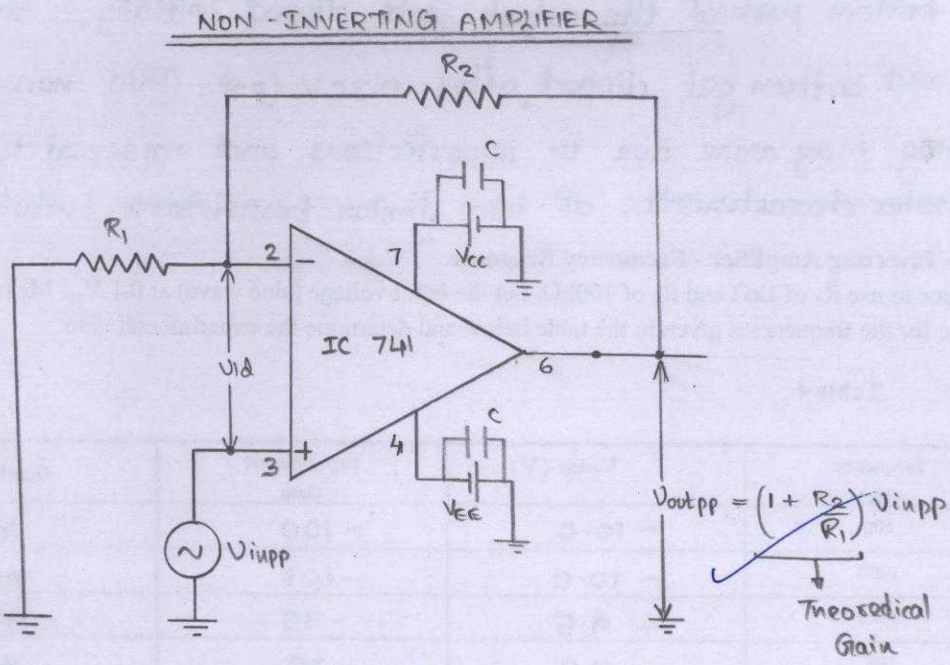
Make a log-log plot of your results with gain on the vertical axis and frequency on the horizontal axis. **Comment on the frequency response of the Op-Amp circuit compared to that of the transistor amplifier.**

In a transistor amplifier, both low frequency signals and high frequency signals get attenuated. At low frequencies, because of high capacitive reactance and at high frequencies, because of junction capacitances. However, an op-amp amplifies even low frequency signals such as DC signals (f=0). This is because an op-amp uses direct coupling (without employing capacitors), hence low frequency signals dont get attenuated.

4.2 – The Non-inverting Amplifier

4.2.1 – The Non-inverting Amplifier - Gain

Draw the circuit diagram and construct the basic non- inverting amplifier circuit (using μA741) with appropriate power supply connections and input signal source etc.



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Connect a signal generator to V_{in} and set it to a frequency of 1000 Hz. Check that the DC offset is zero. For the values of R1 and R2 in the table below, set an appropriate input voltage and measure the corresponding V_{out}. **Adjust V_{in}** as you change the resistors to get easily measured voltages **with no clipping**. Use your data and the theory to calculate the data for the remaining columns in the following table.

Table 5

Output is in phase with the input.

R_1 (KΩ)	R_2 (KΩ)	V_{inpp} (V)	V_{outpp} (V)	Experimental Gain	Theoretical Gain
1	10	0.025	0.26	+10.4	+11
1	100	0.025	2.4	+96	+101

S..

Comment on the differences you found between the theoretical and measured gain for the non-inverting amplifier circuit.

The gain of the above amplifier in non-inverting configuration is positive, since the output is in phase with the input.
It is also seen that the experimental gain closely follows the theoretical gain, for the time the output voltage doesn't cross saturation levels. Hence the closed loop gain $\left(1+\frac{R_2}{R_1}\right)$ is a nominal value of gain.

4.3 - The Difference Amplifier - Common Mode Rejection Ratio (CMRR)

The quality of the amplifier is measured (in part) by the common-mode rejection ratio (CMRR), based on the ratio of the differential voltage gain and common-mode voltage gain. The common-mode voltage gain is determined by applying identical signals to both inputs and observing the output voltage: Theoretically, the common mode gain of such a circuit should be very close to zero. In practice, in this basic circuit 1.4, using resistors of 1% tolerance, the ratios $R_2/R_1 \neq R_4/R_3$. This resistance ratio unbalance is the main cause for the common mode gain being significant, therefore easily measurable.

Construct the circuit shown at the right. Connect the inputs, V_A and V_B, together and connect to one signal generator. Set the generator to 1000 Hz (sine) and 15 V_{pp} amplitude. Measure and record the input and output voltages (peak to peak). Calculate the common-mode gain that results.

$A_{CM} = V_{outCM}/V_{inCM}$ where $V_{inCM} = V_A = V_B = 15\ V_{pp}$. $V_{out\,CM} = 0.24V$

A_{CM}= 0.016 (V/V)

To measure the differential voltage gain, ground one input while applying a 1 kHz sine wave of amplitude 1 V (pp) at the other input. Measure the differential voltage gain. Compute

$A_{diff} = V_{outdiff}/V_{indiff}$ $V_{outdiff} = 9.6V$

A_{diff}= 9.6 (V/V)

CMRR = $20\log_{10}(A_{diff}/A_{CM})$.

It is customary to give the CMRR in decibels

CMRR 600

CMRR (dB) 55.56 dB

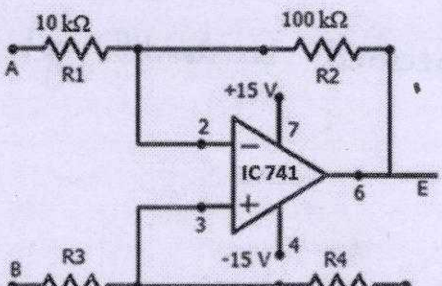

Fig. 1.4

V. INFERENCE/CONCLUSIONS

The basic characteristics of an ideal op-amp have been seen in various modes of operation (inverting, non-inverting, differen-tial). Theoretical gains are compared with experimental results. The capability of amplifying a 'dc' signal is verified.

Its linearity is questioned and saturation observed. Frequency response shows an attenuation (steep fall in gain) at high frequencies (above 10 KHz). The common-mode rejection ratio of differential mode is found.

- Output of an inverting amplifier is 180° out of phase with input.
- It amplifies both dc and ac equally.
- The output gets clipped at the saturation levels.
- Frequency response plot shows that low frequency signals are allowed unattenuated. But high-frequency signals beyond the specified bandwidth get deteriorated.

Integrated Circuits Lab	Credit	Maximum Marks
Preparation	5	5
Experimentation	9	10
Reporting	4.5	5
Total Marks	18.5	20

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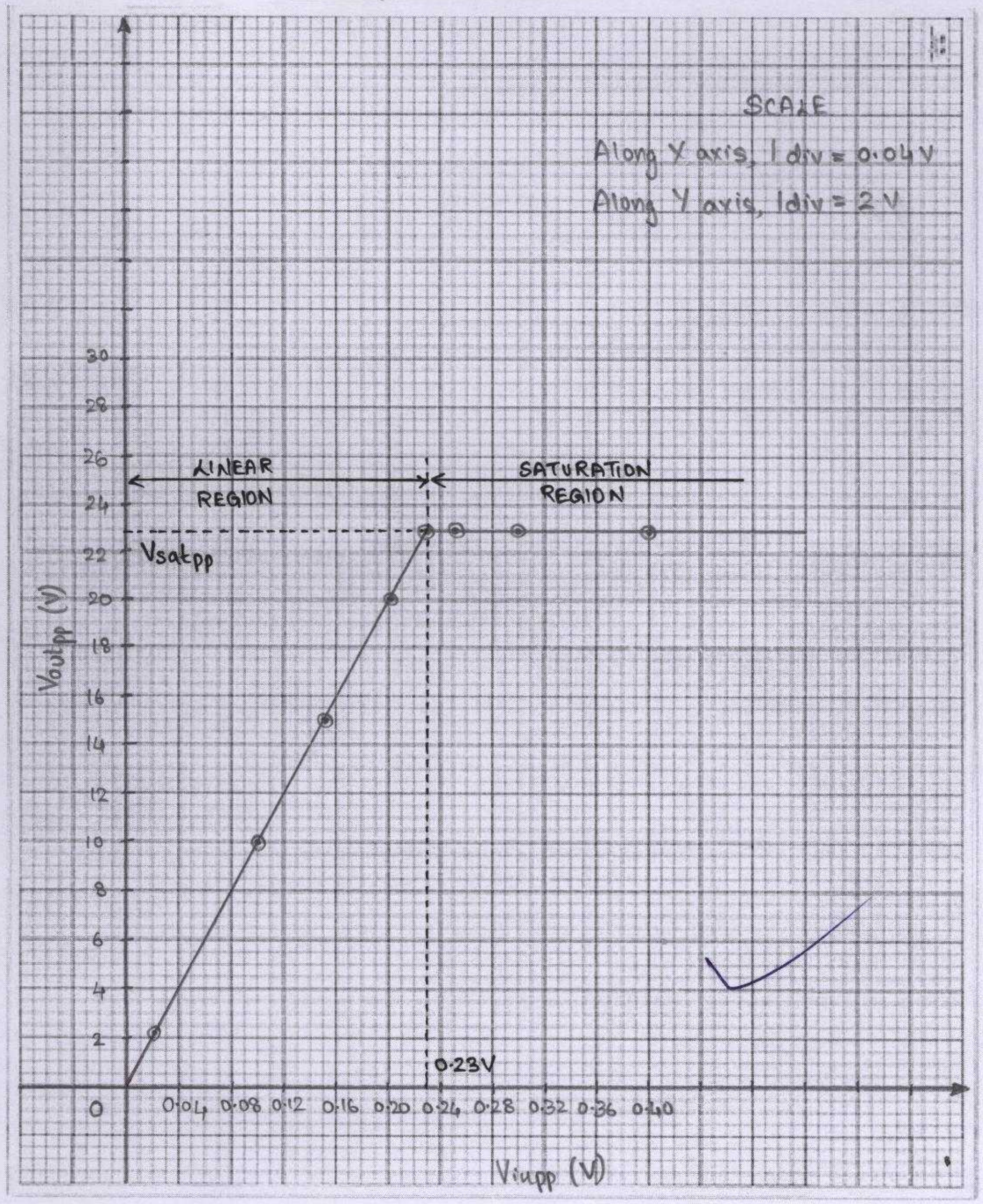
EXP NO : 1

Voutpp v/s Vinpp



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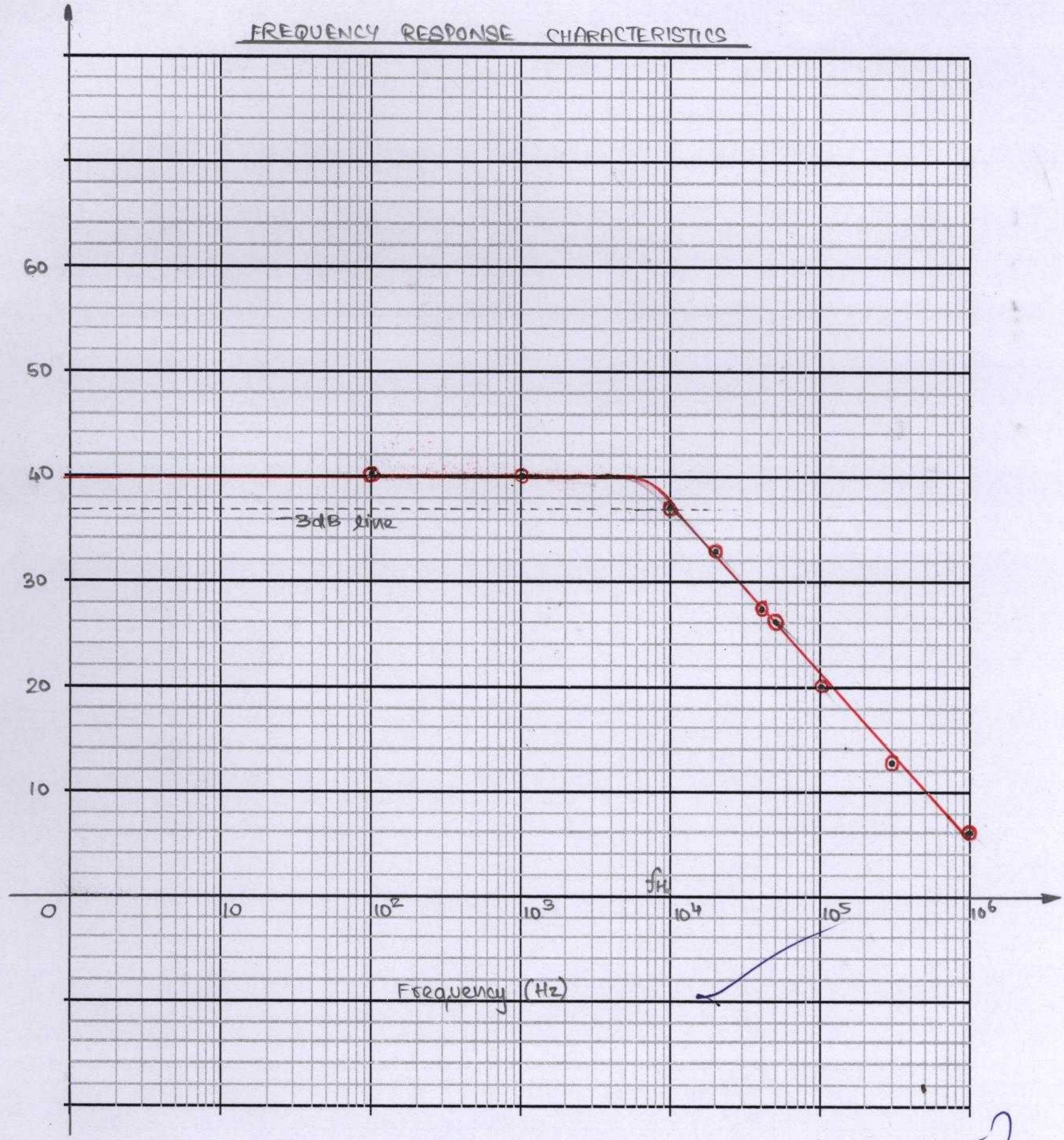


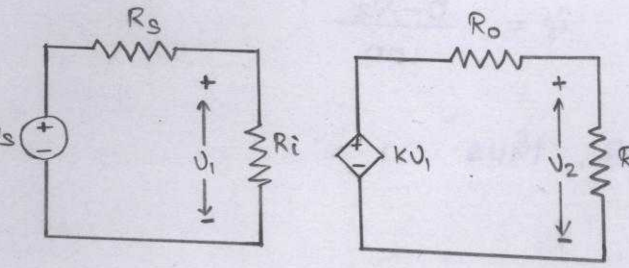
f_{3dB} = ?

$f_{3dB} = \frac{UBW}{A_{CL}}$ =

EXPERIMENT - 1 PREPERATION:

Question 1:

In fig. a practical voltage source v_s with internal resistance R_s feeds a load R_l through an amplifier with input and output resistances R_i and R_o respectively. Find v_2/v_1.



Figure

$v_s = i_1 (R_s + R_i)$

$v_1 = i_1 R_i$

$K v_1 = i_2 (R_o + R_l)$

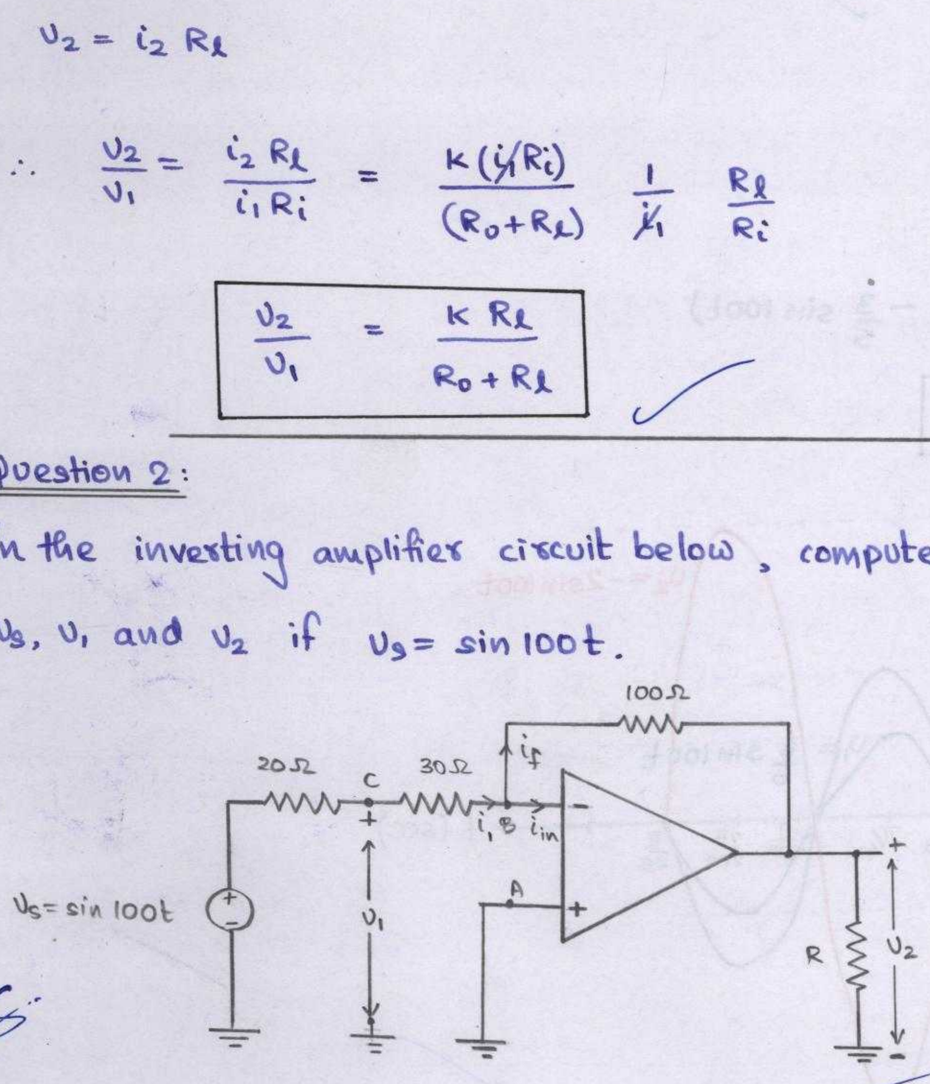
$v_2 = i_2 R_l$

$$\therefore \frac{v_2}{v_1} = \frac{i_2 R_l}{i_1 R_i} = \frac{K(\cancel{i_1} R_i)}{(R_o + R_l)} \frac{1}{\cancel{i_1}} \frac{R_l}{R_i}$$

$$\boxed{\frac{v_2}{v_1} = \frac{K R_l}{R_o + R_l}}$$

Question 2:

In the inverting amplifier circuit below, compute v_1 and v_2 and sketch v_s, v_1 and v_2 if $v_s = \sin 100t$.



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Assumptions :

i) $i_{in} = 0 \Rightarrow i_1 = i_f$

ii) $V_A = V_B = 0$ (grounded)

Since $i_1 = \frac{v_s - v_1}{20}$ and $i_f = \frac{0 - v_2}{100}$

Also, i_1 flows through $30\,\Omega$, thus

$$\frac{v_s - v_1}{20} = \frac{v_1 - 0}{30}$$

$$\Rightarrow v_1 = \frac{3}{5} v_s$$

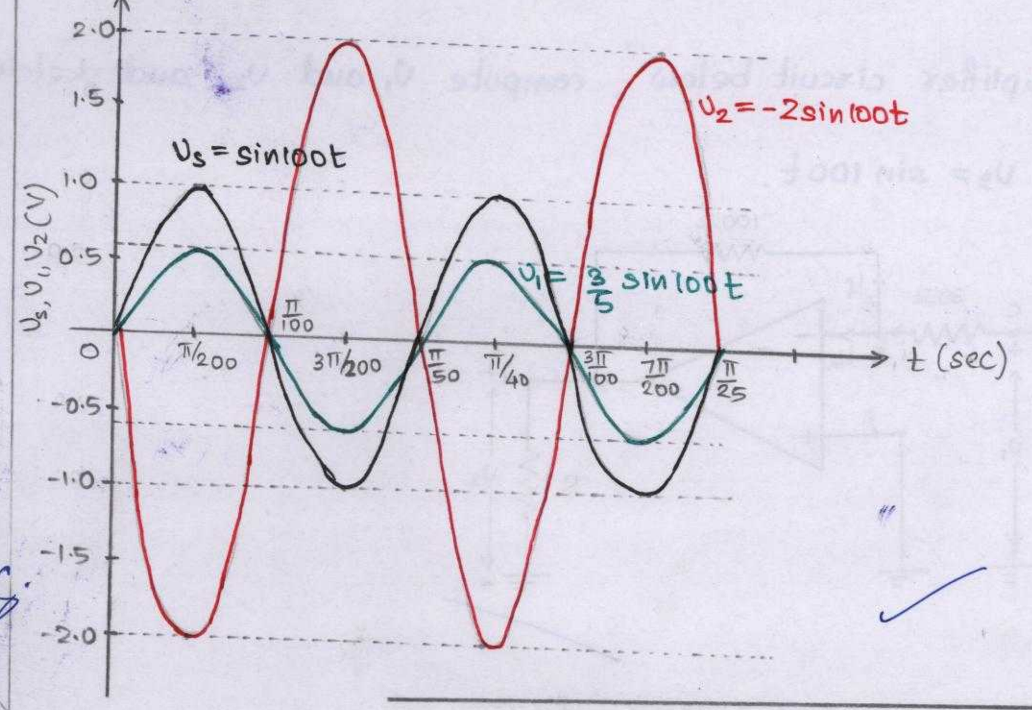
$$\boxed{v_1 = \frac{3}{5} \sin 100t}$$

Now, $i_1 = i_f$, thus

$$\frac{v_s - v_1}{20} = \frac{-v_2}{100}$$

$$v_2 = -5\left(\sin 100t - \frac{3}{5}\sin 100t\right)$$

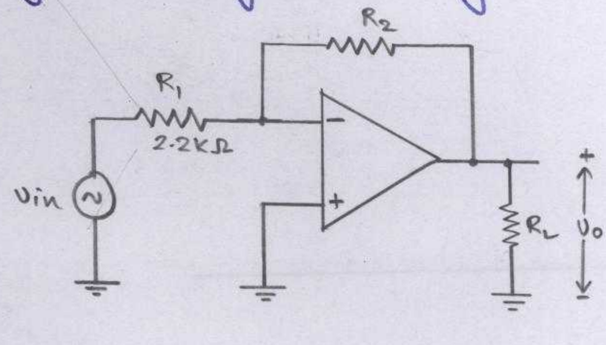
$$\boxed{v_2 = -2\sin 100t}$$



Question 3:

Design an op-amp circuit with an input resistance of 2.2kΩ and a gain of -10 V/V. What are the values of R_1 and R_2 you have chosen?

An inverting amplifier gain is negative. Hence we chose:



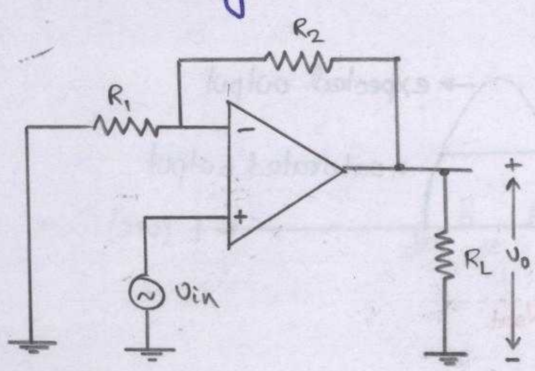
Op-amp (inverting) gain $= -\frac{R_2}{R_1} = -10$ V/V

$\frac{R_2}{R_1} = 10$

Since $\boxed{R_1 = 2.2K\Omega, \quad R_2 = 22K\Omega}$ ✓

Question 4:

Using an ideal op-amp, design a non-inverting amplifier with gain of +11 V/V having low currents in the associated resistor network, but with no resistor larger than 10kΩ



Op-amp (non-inverting) gain = $1 + \frac{R_2}{R_1}$

$$11 = 1 + \frac{R_2}{R_1}$$

$$R_2 = 10 R_1$$

max. resistance = $10 k\Omega$.

(ie) if $\boxed{R_2 = 10 k\Omega, \ R_1 = 1 k\Omega}$

Question 5:

For an op-amp with $V_{cc} = 5V$, $A = 10^5$, $v^- = 0$ and $v^+ = 100 \sin 2\pi t$ (μV)

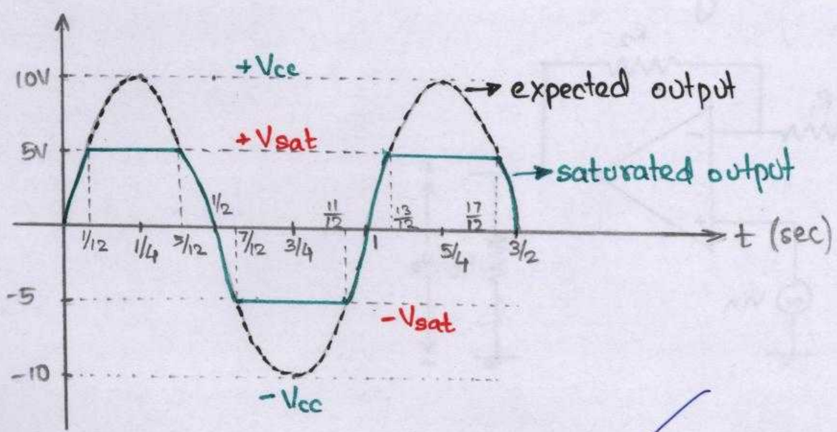
Find and sketch the open loop output V_o.

$$v_{id} = v^+ - v^- = 100 \sin 2\pi t \ (\mu V).$$

$$V_o = A v_{id} = 10^5 (100 \sin 2\pi t) \ \mu V$$

$$V_o = 10 \sin 2\pi t \ (V)$$

However, $+V_{sat} < +V_{cc}$ and $-V_{sat} < -V_{EE}$



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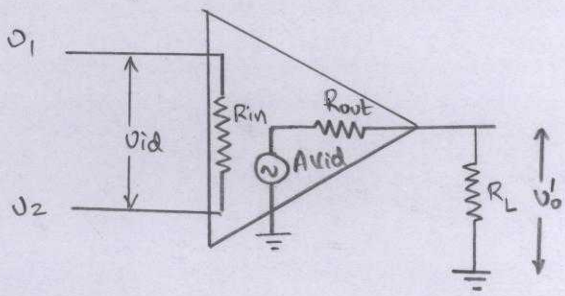
Question 6:

The output voltage of an op-amp decreases by 10% when a 5kΩ load is connected at the output terminals. Compute the output resistance Rout.

Low frequency equivalent circuit:



When no load is connected,

$$V_o = AV_{id}$$

When 5kΩ load is connected,

$$V_o' = 0.9\,V_o = AV_{id} - i\,R_{out}$$

$$0.9V_o = V_o - i\,R_{out}$$

$$0.1V_o = i\,R_{out}$$

$$0.1V_o = \frac{V_o'}{5\times10^3}\,R_{out}$$

$$\frac{0.1\times5\times10^3}{0.9} = R_{out}$$

(ie) $\boxed{R_{out} = 555.55\ \Omega}$

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Question 7:

An op-amp has a common mode amplification $A_{cm} = 0.0002$. Find the magnitude of the output voltage if the input voltages are $V^- = V^+ = 2V$.

$$V_{cm} = \frac{V^+ + V^-}{2} = \frac{2+2}{2} = 2\,V$$

Now, $V_o = A_{cm} V_{cm}$

$= (0.0002)(2)$

$= 0.0004$

(ie) $\boxed{V_o = 0.4\ mV}$

8