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STUDIES ON ANALOG CIRCUITS USING OP-AMP:

AIM: To study analog circuits using operational amplifiers.

APPARATUS REQUIRED:

- Printed circuit board
- DC power supply 12V
- AC signal generator
- Connecting wires
- Cathode Ray oscilloscope
- Multimeter.

THEORY:

Opamp stands for operational Amplifier.

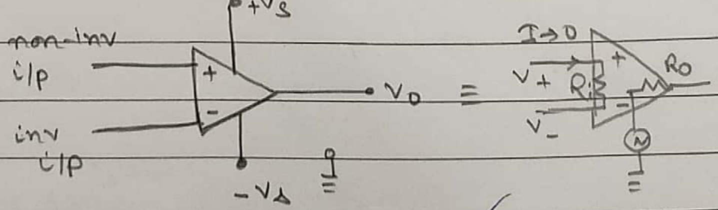
It ideally has high input resistance and low output resistance. Thus, it takes in less power from source due to high r_i and gives maximum power to external circuit due to low output resistance.

Hence it is more advantegous over BJT. in this domain. Also it's gain is infinity (ideally) and thus it tends to reach maximum output value at less input voltages.

$I \to 0$ and thus,

V^+ is also called

virtual ground ($V^+ \to 0$)



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maximum voltage gap is the difference between Vout (max) and V_S. For $V_S = 12V$, Vout (max) is generally $\simeq 9.5V$.

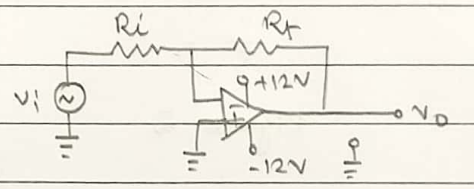
The figure drawn in previous page shows opamp in open-loop circuit. It has uncontrolled gain. Thus, closed loop circuits are used to control gain:

→ Inverting amplifier

→ Non-inverting amplifier.

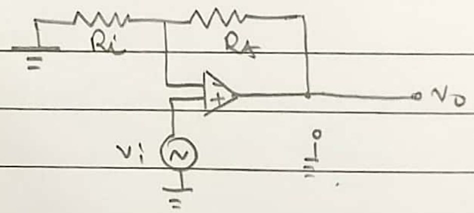
Inverting amplifier:

$$V_0 = -\underbrace{\left(\frac{R_f}{R_i}\right)}_{\text{gain}} V_i$$



Non-inverting amplifier:

$$V_0 = \left(1 + \frac{R_f}{R_i}\right) V_i$$



The frequency responses of the two circuits are observed in this experiment.

Adder circuit is used to add a DC offset to a given V_i.

Integrator and Differential circuits are used to manipulate input wave forms and give Vout according to equations:

$$V_{out} = -(1/RC) \int V_{in}\, dt + \text{const}$$

and

$$V_{out} = -RC \times \frac{dV_{in}}{dt} \text{ respectively.}$$

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OBSERVATIONS AND CALCULATIONS :

I) V_4 grounded (no-load voltages) :

Observed value at given terminals :

$v_1 = 6.6V$

$v_2 = 3.35V$

$v_3 = 2.15V$

$-12V$ applied to V_4:

Observed value at given terminals:

$v_1 = 1.12V$

$v_2 = -5.28V$

$v_3 = 7.66V$.

II) DC GAIN : (Inverting amplifier)

The OPAMP is set up in inverting configuration and bipolar supply is applied to power the opamp.

a) $R_i = 10K\Omega$

R_f (KΩ)	Vin(V)	Vout (V)	Observed gain (Vout/vin)	Theoritical gain $\{-R_f/R_i\}$ ~~Vin~~
10	0.850V	-.850	-1	-1
27	0.848 V	-2.29	-2.7	-2.7
47	0.847V	-4.06	-4.793	-4.7
100	0.847V	-8.78	-10.366	-10

b) with $R_i = 10K\Omega$ and $R_f = 100K\Omega$, we find voltage at inverting input (pin 2) is 15 mV. This is negligible with respect to input and hence can be called virtual ground.

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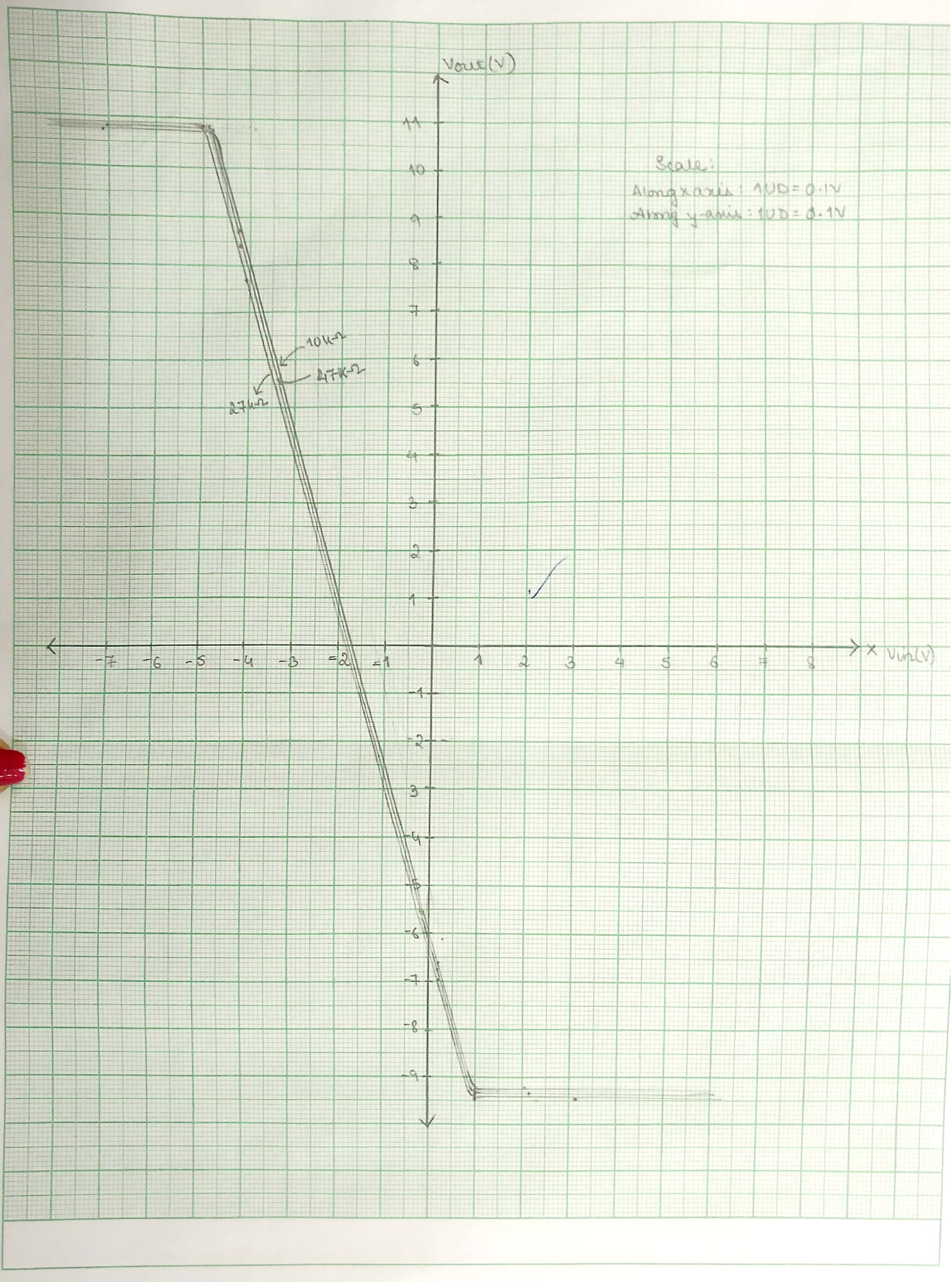
Vout(V)
Vin(V)
Scale:
Along x axis : 1UD = 0.1V
Along y-axis : 1UD = 0.1V
10kΩ
47kΩ
27kΩ

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c) Calculation of input resistance:

Voltage across R_i $(V_i) = 0.856V$,

and we have $R_i = 10K\Omega$.

Thus $I_i = \frac{0.856}{10 \times 10^3}$ A.

Now $R_{in} = \frac{V_{in}}{I_i} = \frac{\cancel{0.847}}{\cancel{10\times10^3}}$ $\frac{10 \times 10^3 \times 0.847}{0.856} = 9.895\ K\Omega$.

Thus we observe that R_{in} has a very close value to R_i.

$R_i = 1K\Omega$

R_f $(K\Omega)$	V_{in} (V)	V_{out} (V)	$(-R_f/R_i)V_{in}$ (V)
10	0.27	-2.73	-2.7
27	0.27	-7.35	-7.29
47	0.49	-9.35	-23.03
100	0.81	-9.36.	-81.

Thus, the OPAMP saturates when value of $R_f \times V_{in}$ increases, since R_i is constant. It ceases to be linear after that. In this case, Opamp saturated with value of $V_0 = -9.37$.

$R_i = 10K\Omega$

R_f $(K\Omega)$	V_{in} (V)	V_{out} (V)	$(-R_f/R_i)V_{in}$ (V)
10	-4.24	4.22	4.24
27	-4.28	10.78	11.56
47	-4.63	10.80	~~50.76~~ 21.761
100	-4.94	10.84	49.4

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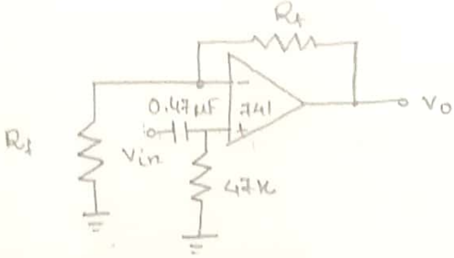
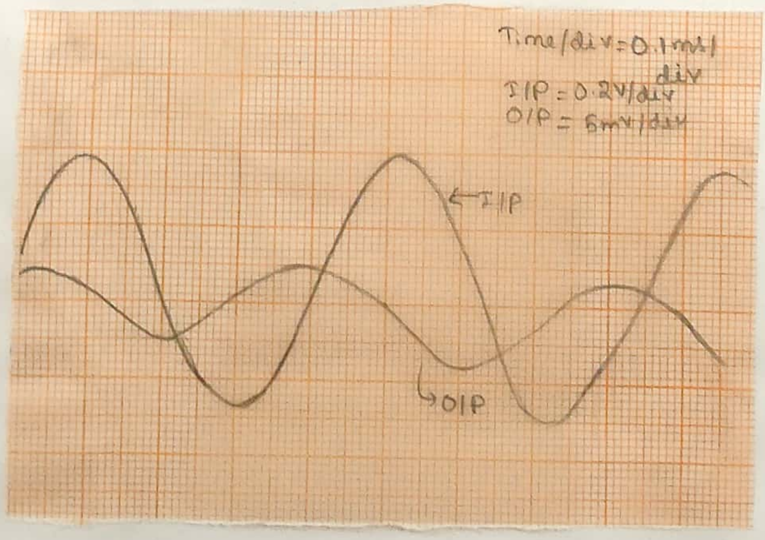


Rf
0.47μF
741
Vo
R1
Vin
47k

Figure-3



Time/div = 0.1ms/div
I/P = 0.2V/div
O/P = 5mV/div
I/P
O/P

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R_f (kΩ)	V_{in} (V)	V_{out} (V)	$(-R_f/R_i)V_{in}$ (V)
10	~~−4.94~~ 6.49	6.47	6.49
27	−6.81	10.77	18.387
47	−7.11	10.79	33.417
100	−7.38	10.83	73.38.

As concluded from above two cases, voltage saturation level increases with increase in power supply voltage.

we also notice that opamp saturates at $V_0 = 10.85$ V and -9.38 V.

III) Non-inverting Amplifier:

$R_i = 10\,k\Omega$, $R_f = 10\,k\Omega$. 1V p-p, 10KHz input is applied.

a) Gain: $A_v = 1 + \frac{R_f}{R_i}$

R_f (kΩ)	V_{out} (V_{p-p})	Expt gain (V_{out}/V_{in})	Theoritical gain $(1+\frac{R_f}{R_i})$	% error
10	2.23	2.23	2	11.5%
27	4.08	4.08	3.7	10.2%
47	6.48	6.48	5.7	13.68%
100	12.12	12.12	11	10.2%

From the oscilloscope, we observe that output is not inverted.

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi \times 10^4 \times (0.47 \times 10^{-6})} = 33.86\,\Omega.$$

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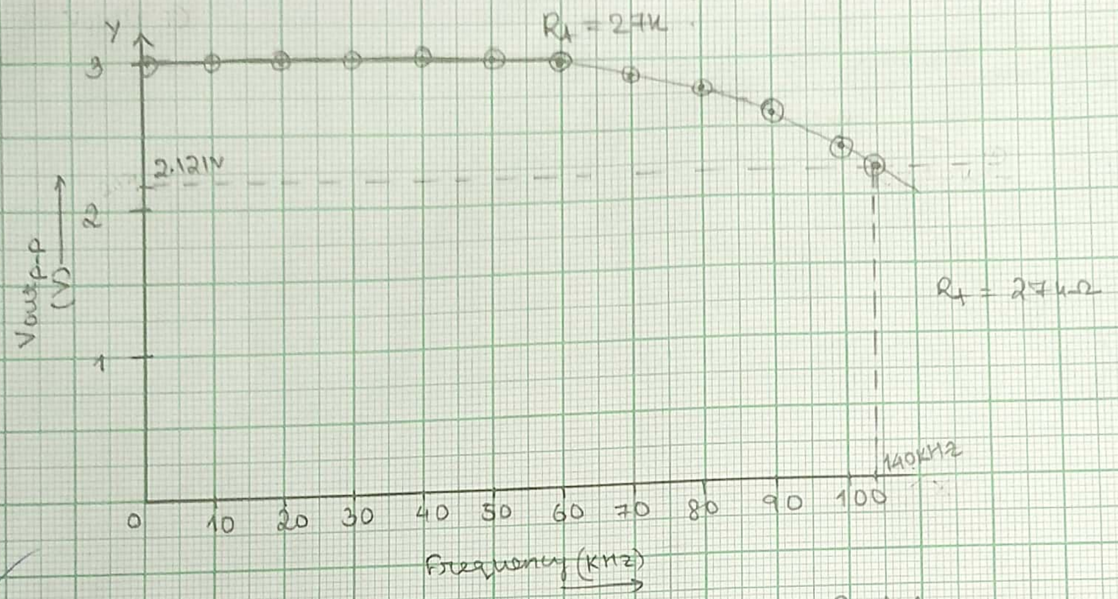
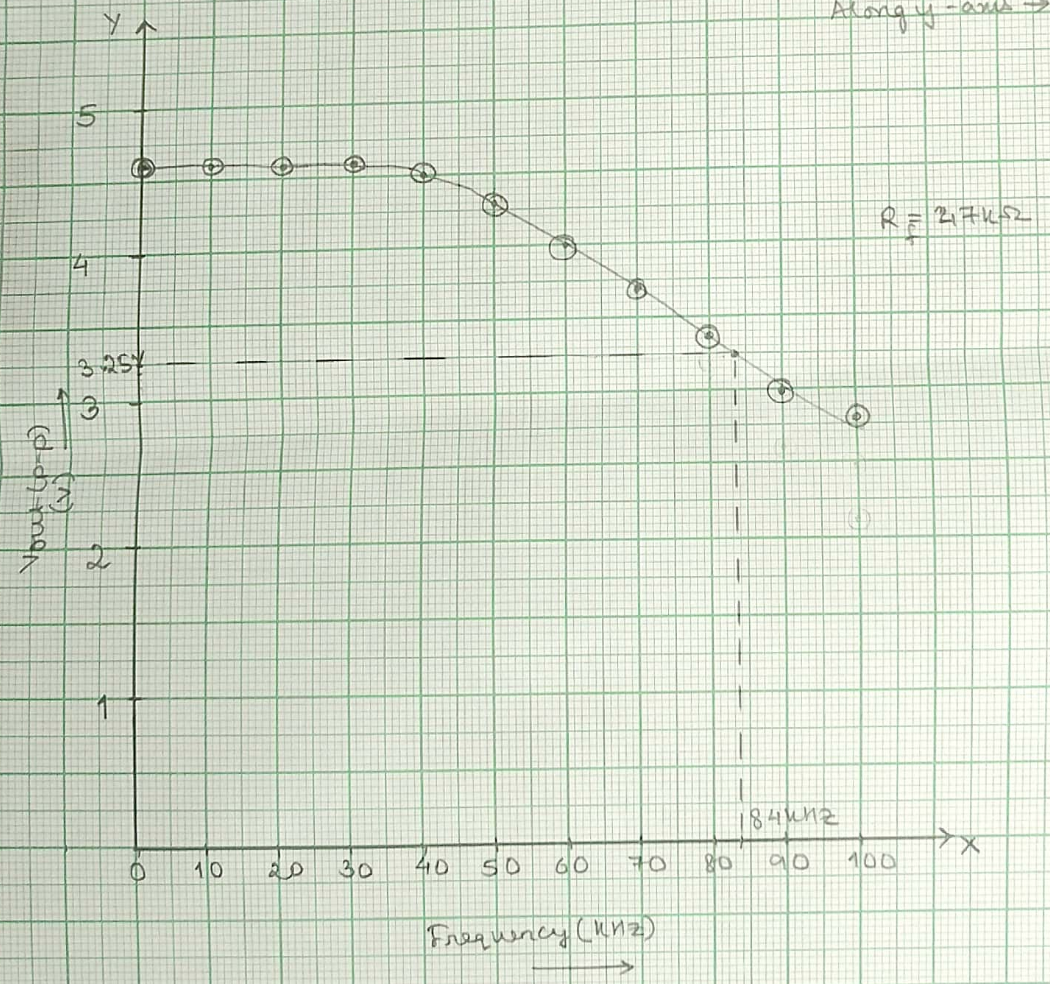
Frequency Response - I



Scale:
Along x-axis → 1UD = 1kHz
Along y-axis → 1UD = 0.05V



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Thus, value of capacitor impedance is negligible compared to values of resistors. Hence we consider them short-circuited for our gain calculations.

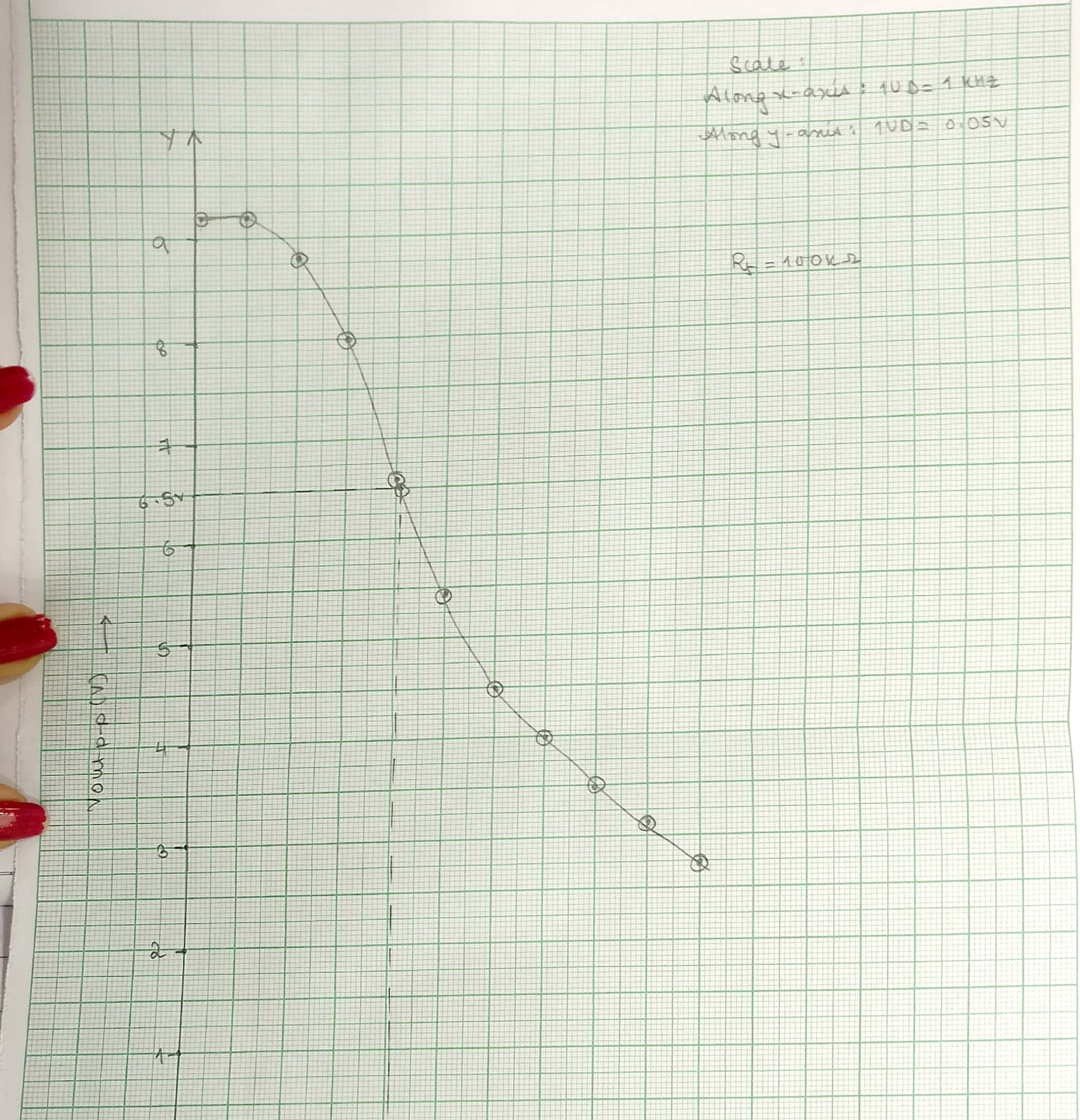
b) Frequency Response :

i) $R_i = 10k\Omega$, $R_f = 27k\Omega$, $v_{in} = \cancel{0.5}\ 1 V (p-p)$.

Frequency (kHz)	$V_{out\ p-p}$ (V)	Gain (v_o/v_i)
1	~~2.2~~ 3	~~4.4~~ 3
10	3	~~4.4~~ 3
20	3	3
30	3	3
40	3	3
50	3	3
60	3	3
70	2.9	2.9
80	2.8	2.8
90	2.7	2.7
100	2.6	2.6

Teacher's Signature :

Frequency response : II



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Frequency	Vout(V) = gain (Ri = 1)	
	$R_f = 47k\Omega$	$R_f = 100k\Omega$
1	4.6	9.2
10	4.6	8.8
20	4.6	8
30	4.6	6.6
40	4.5	5.4
50	4.3	4.5
60	4	4
70	3.7	3.5
80	3.4	3.2
90	3	2.7
100.	2.8	2.3.

$R_i = 10k\Omega$

R_f	$\beta = \frac{R_i}{R_i+R_f}$	Gain(A_f)	$A_o = \frac{A_f}{1-\beta A_f}$	B.W.	Gain x B.W.
27kΩ	0.27	2.121	4.96	140kHz	296.94kHz
47kΩ	0.175	3.252	7.547	84kHz	273.168
100kΩ	0.091	6.5044.	15.94	41kHz	266.5kHz

We measure B.W. by finding out frequency at which $V_o = A_f$ (since ~~Ri = 10~~ vin = 1Vp-p), or by measuring from graph characteristics. numerically.

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IV Voltage follower :

$V_{in} = 1V\,dc$.

No, inverting pin 2 is not at virtual ground.

Sl. No.	V_{in}	V_{out}
1	1.112	1.111
2	~~11.57~~ -7.8	-7.78
3	-5.32	-5.32
4	2.09	2.08
5	3.41	3.41.

Thus, we observe that $V_{out} = V_{in}$ at given ~~f~~ values of V_i. The voltage divider system cannot provide V_i such that $V_{out} \neq V_i$. However for direct input of -12V and +12V supply, we get the following data :

→ V_{in} : 12.08, V_{out} : 11.72 } maximum → V_{in} : -12.03, V_{out} : -9.32 } minimum

V) Adder :

$V_1 = 2V$, $V_2 = 3V$.

a) By theory, $V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$.

Observed values : $V_1 = 1.53$ V, $V_2 = 2.53$V.

V_{out} : -3.96V

calculated value : $-10\left(\frac{1.53}{10} + \frac{2.53}{10}\right) = -4.06 \simeq V_{out}$(observed).

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b) Summing Amplifier:

$V_1 = V_{in}$ = 1Vp-p 1KHz.

$V_2 = V_{offset}$.

Sl. No.	V_2 (V)	V_{out} (V_{p-p})	DC offset (V)	
			oscilloscope	multimeter
1.	5.08	1.05	+5.27	+5.31
2.	2.72	1.07	+3	2.96
3.	1.84	1.09	1.8	1.92
4.	0.85	1.09	1	0.92
5.	-4.27	1.11	-5	-4.97
6.	-6.53	1.12	-7	-7.01

VI Superposition:

a)

R_f (kΩ)	V_1 (V)	V_2 (V)	observed V_{out} (V)	calculated V_{out} (V_1+V_2).
	3.12	0	-3.12	-3.12+4.09
10	0	2	4.09	= 0.97
	3.08	1.98	0.87	
	3.2	0	-9.78	-9.78+10.98
47	0	2	10.98	= 1.2
	3.08	1.98	-3.31	
	3.2	0	-9.81	-9.81+11
100	0	2	11	= 1.19
	3.08	1.98	-9.26	

Thus, it does not hold for R_f = 47KΩ or 100KΩ.

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b) Differential Amplifier :

$$V_{out} = V_2 \times \left[\frac{R_3}{R_2+R_3}\right]\left(1+\frac{R_f}{R_i}\right) - V_1\left(\frac{R_f}{R_i}\right) \quad \dots \text{(i)}$$

Also given, $R_1 = 10K\Omega$, $R_2 = 10k\Omega$, $R_3 = 47k\Omega$.

$\therefore$, $R_1 = R_2$ and $R_3 = R_f$. $\therefore$, from eqn (i), we have :

$$V_{out} = \frac{R_f}{R_i}(V_2 - V_1)$$

$R_f = 27K\Omega$:

OBSERVED VALUES : $V_1 = 2.08V$ $V_2 = 3.28V$ $V_{out} = 4.32V$

THEORITICAL : $V_{out} = 3.28\left(\frac{47}{57}\right)\left(1+2.7\right) - 2.08\,(2.7)$

$= 4.39V$

$R_f = 47k\Omega$:

OBSERVED VALUES : $V_1 = 2.06V$ $V_2 = 3.28V$ $V_3 = 5.6V$.

THEORITICAL : $V_{out} = (3.28 - 2.06) \times \frac{R_f}{R_i}$

$= 5.734V$

VII Integrator : sine wave :

5KHz sine-wave of 1V p-p is applied and it is traced from CRO.

$V_{out} = -(RC)^{-1} \int V_{in}dt + \text{const.}$

$= -\left(\frac{1}{100\times10^3 \times 47\times10^{-8}}\right) \frac{0.5\times 1}{5\times10^3} =$

$\therefore$, ~~Theoretical gain~~ =

~~Observed gain~~ =

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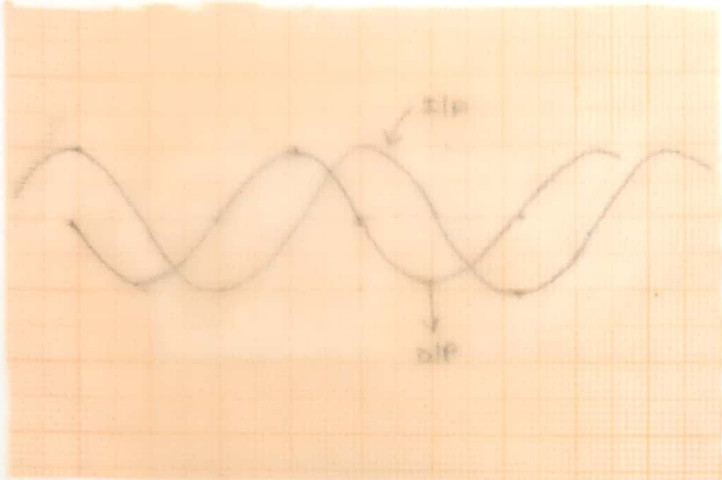


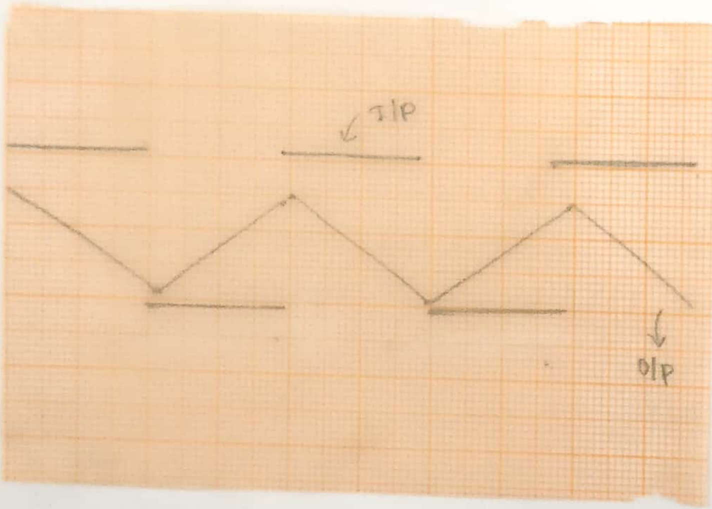
Sinewave:

T/div = 50µs/div

I/P = 0.5 V/div

O/P = 5mV/div

f = 5KHz.



Squarewave:

Time/div = 50µs/div

I/P = 0.5 V/div

O/P = 20mV/div

f = 5kHz

✓

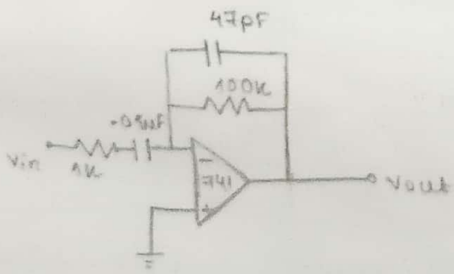


Figure-8

Square wave :

5KHZ square wave of 1Vp-p is applied.

V_{out} (Theoritical) = $-\left(\frac{1}{100\times10^3\times47\times10^{-9}}\right)\frac{0.5\times1}{5\times10^3} = 21mV$.

observed V_{out} = 52mV

V_{in} = 1Vp-p.

SL.NO.	Sine wave :		Square wave :	
	Frequency (KHZ)	V_{out} (mV)	Frequency(KHZ)	V_{out} (mV)
1	1.01	50	1	52
2	20.	30	1.5	38
3	3.5	15	2.31	24
4	4.19	9	2.87	20
5	5.82	9	3.9	15
6	7.5	7	5.23	12
7	8.91	6	7.28	8
8.	10.13	~~80~~ ~~8~~ 5	10.13	5

VIII Differentiator :

a) Square wave :

0.2V_{p-p}, 1KHZ square wave is applied.

V_{out} = $-RC \times (dV_{in}/dt)$.

cannot be calculated (dV_{in}/dt) is not defined at edges.

V_{out}(observed) = 6.4V (overshoot)

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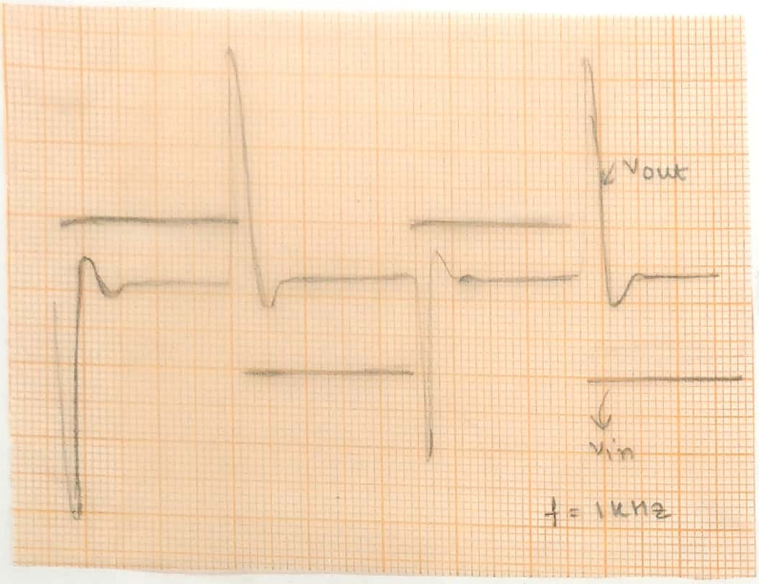
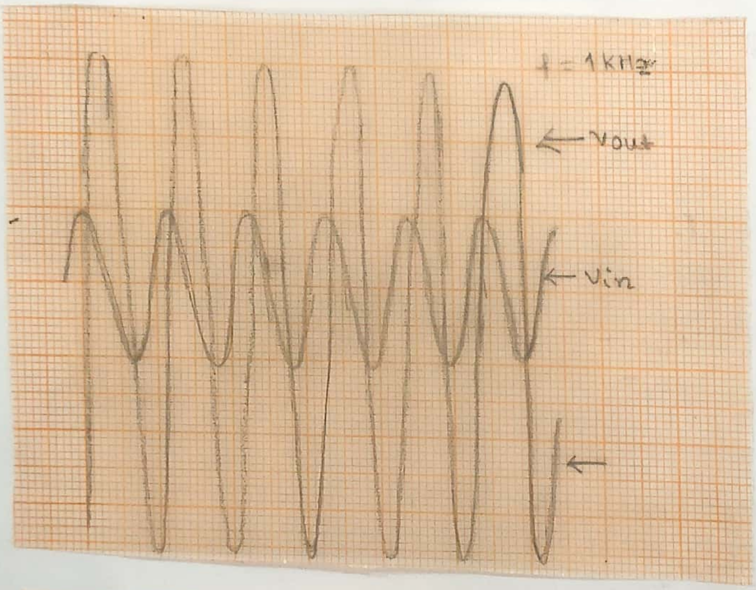


square wave :

Time /div = 0.2ms/div

I/P = 0.1 V/div

O/P = 2V/div.



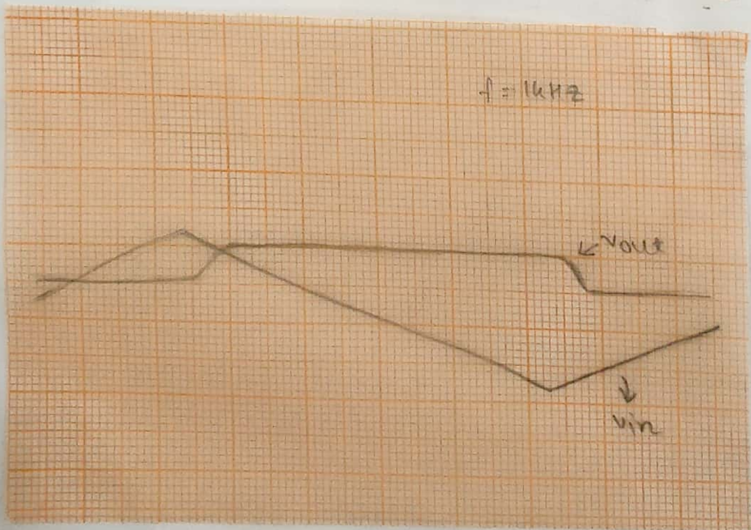
sine wave :

Time / div = 1ms/div.

I/P = 0.1V/div

O/P = 0.1V/div

(90° phase difference observed.)



Triangular wave :

Time/div = 0.1ms/div.

I/P = 0.1V/div

O/P = 1V/div.

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sine wave :

0.2 V_{p-p} is applied at 1KHz.

Vout (calculated) = 1.663V

Vout (observed) = ~~0~~ 1.32V

Triangular wave :

0.2Vp-p is applied at 1KHz.

Vout (calculated) = vary from max ~~M~~ to min ~~F~~ with change at max / min of triangular wave and constant otherwise.

Vout (observed) = 0.8V

Frequency Response :

Sl.No.	Sine wave Frequency (KHz)	Sine wave Vout (V)	Square wave: Frequency (KHz)	Square wave: Vout (V)	Triangular wave: Frequency (KHz)	Triangular wave: Vout (V)
1	1KHz	1.32	1.02	6.4	1.017	0.8
2	2.	2.65	2.34	6.4	2.06	2
3	3	3.2	3.15	6.4	3.02	3
4	4	5.3	4.48	7	5.01	5
5	5	7.7	6.65	7.2	6.97	7
6	6	8.2	8.34	7.4	8.95	9
7	7	9.2	10.0	6.6	10.74	9.2
8	8	10.4			13.01	8.2
9	9	11				
10	10	11.2				

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DISCUSSION :

Swastika Dutta
(16CS10060)

Firstly a voltage divider was configured on the board. Then the opamp was set up in inverting configuration and V_{out} (observed) was compared with V_{out} (calculated) $= -\frac{R_f}{R_i} V_i$. The point of saturation of opamp was noted and graph was drawn. The effect of change of R_f and V_{in} was also observed.

Then the amplifier was set up in non-inverting configuration. The V_{out} (expected) $= \left(1+\frac{R_f}{R_i}\right) V_i$ was calculated and compared to V_{out} (observed). Higher current gain tends to 'roll-off' sooner since gain × bandwidth remains constant for given setup and varying R_f. A_0 was measured using observed value of A_f.

Voltage follower is used as a buffer amplifier to connect high-impedance source to low impedance load. We also observed that $V_{in} \approx V_{out}$ and ground conditions of pin 2.

In adder, $V_2 = V_{offset}$, and we used formula:

$$V_0 = R_f \left[\Sigma \frac{V_i}{R_i} \right]$$

to calculate theoretical V_0 and compare with observed V_0.

We then observed the applicability of superposition theorem on the circuit. It ceases to be valid for higher values of R_f when amplifier gets in saturation mode.

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In differential amplifier, we calculated V_{out} using simplified formula : $\left(\frac{R_f}{R_1}\right)(V_2 - V_1)$ and compared it with observed V_0.

In integrator circuit, we traced the waveforms of corresponding I/P O/P signals for square wave and sine wave.

$$V_{out} = -\frac{1}{RC} V_{in} dt + const.$$

This was compared to observed values. Also frequency response of both square wave and sine waves were recorded.

Again for differential circuit, we supply 0.2 Vpp input to sine wave, square waves and triangular waves respectively.

$$V_{out} = -RC \frac{dV_{in}}{dt}.$$

Square waves and triangular waves are not differentiable at points and that has been observed in corresponding O/P waveforms in CRO. Also, we noticed 90° phase shift between I/P and O/P waveforms for sine waves in both integrator and differentiator circuits.

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Discussion:- By Chelsi Raheja 16CS10013

- An operational amplifier is a DC coupled high gain electronic voltage amplifier with a differential input and usually a single ended output.

- In voltage divider circuit, we observed slighly lesser value when it is connected to required load due to loading effect.

- In inverting part we got values close to theoritical values and when $R_1 = 10k\Omega$, $R_f = 100k\Omega$ we observed that voltage at inverting pin2 to be 0, i.e, virtual ground condition.

- As we increased power supply values, we observed saturation voltage level has increased.

- At high frequency, capacitor acted as short circuit
- In adder circuit, the result we obtained on addition was slighly different from ~~observed~~ estimated value.

- While ~~increasing~~ studying frequency, higher current gain ~~g~~ begins to roll of sooner and for higher values of R_f, higher gain was observed. Thus bandwidth decreases with increasing R_f & A_0 increases with increasing R_f.

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- Superposition theorem was found only True for small R_f. For larger R_f, linear approx is not valid as amplifier come in saturation mode.

- In differential amplification part we observed Vout was directly proportional to difference of inputs.

9.5/10

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