Department of Electronic Engineering
N.E.D. University of Engineering & Technology

PRACTICAL WORK BOOK

For the course

INTEGRATED CIRCUITS (EL-333)
For TE (TC) and BS (AP)

Instructors name:____________________________
Student Name: ______________________________
Roll No.:________________ Batch: _____________
Semester :______________ Year:_______________
Department: _________________________________

LABORATORY WORKBOOK
For The Course
EL-333 Integrated Circuits

Prepared by:

Ayesha Akhtar (Lecturer)

Reviewed by: Dr. Sana Arshad

Integrated Circuits Laboratory
Contents

Lab No.1

OBJECTIVE:
To **DESIGN** and investigate the Inverting and Non-Inverting Amplifier i.e. To determine the phase shift between the input and output signals and gain

EQUIPM ENT REQUIRED:
Breadboard
Wires 741 IC Operational Amplifier
Resistance sheet
Dual Power Supply

THEORY:

Introduction
An operational amplifier, (or "op amp" as commonly known), has two inputs as shown in Fig.1

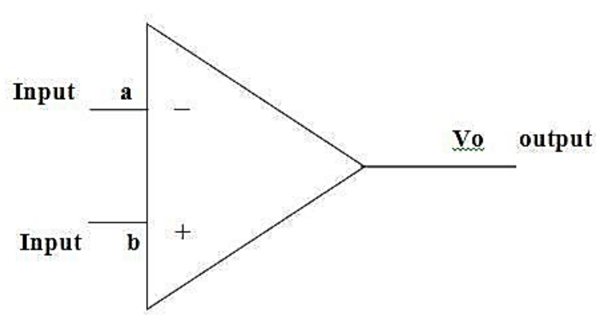

Fig. 1: Op-amp

The output voltage V_0 is proportional to the difference in voltage between the two inputs, and is given by:

$$V_0 = G_v.(V_b - V_a)$$

where G_v is a large number, possibly as high as 1,000,000. Ideally, op amps should have:

infinite input impedance
zero currents flowing into the inputs
zero output impedance.

NON-INVERTING OP-AMP:

Using the 741 op amp with power supplies connected assemble Circuit in Fig 2.

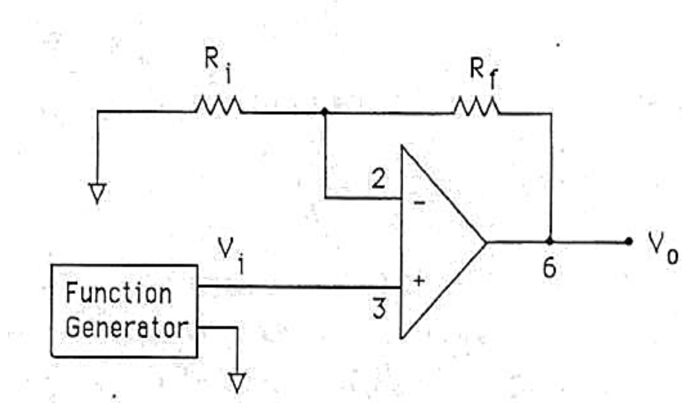

Fig.2 Non-inverting op-amp

The input- output relationship for this circuit is given by

$$V_o = \left(1 + \frac{R_F}{R_i}\right) V_i \qquad (1)$$

PROCEDURE 1:

- Start with Ri = 10 kΩ and Rf = 33 kΩ.
- Before inserting resistors Ri and Rf, record and measure their actual resistance using the DMM.
- Use the function generator to supply a 1 kHz 1V peak-to-peak sine wave to the input (Vi) to pin 3.
- Use oscilloscope CH1 to measure Vi and CH2 to measure Vo.
- Observe and record the input and output voltages using the oscilloscope noting the phase relationship, peak-to-peak voltages and period. Compare your measurements to those predicted by Equation 1.
- Repeat the above exercise for Rf = 0 Ohms, i.e., a short circuit.
- Next, choose values for Ri and Rf such that the closed-loop gain (Vo / Vi) is 2. Repeat your measurements.

INVERTING OP-AMP:

Assemble the circuit shown in Fig. 3, again measuring the actual resistance values first.
The input-output relationship for this circuit is given by :

$$V_o = \left(\frac{-R_F}{R_i}\right) V_i \qquad (2)$$

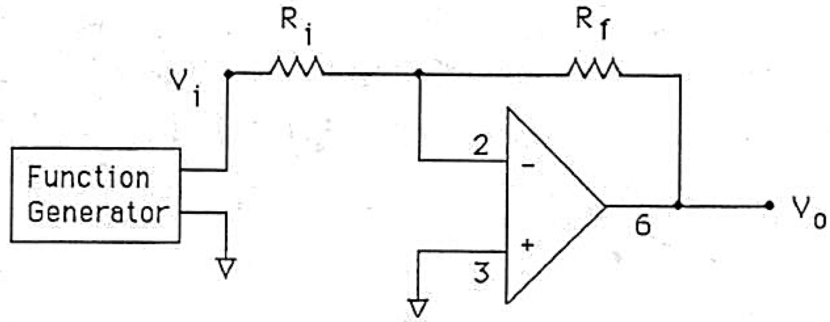

Fig. 3: Inverting op-amp

PROCEDURE 2:

1) Start with Ri = 1kΩ and Rf = 10kΩ . Use the function generator LOW OUTPUT to supply a 1 kHz 1 V peak-to-peak sine wave input as Vi. Observe and record the input and output voltages as before.
2) Choose values of Ri and Rf for gains of -2.2 and -1.
3) Note particularly the phase relationship between the function generator output (which is the amplifier input) and the amplifier output. Compare your measurements to those predicted by Equation 2 above.
4) Attach simulation results.

OBSERVATIONS:

NON-INVERTING CONFIGURATION:

Rf	Ri	Vo	Vin	Gain
33	10			
0	10			
				2

INVERTING CONFIGURATION:

Rf	Ri	Vo	Vin	Gain
10	1			
				-2.2
				-1

CALCULATIONS:

RESULT:

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Remarks	
Instructor's Signature with Date:	

Lab No.2

OBJECTIVE:
To **DESIGN** and investigate summing amplifier circuit

EQUIPMENT REQUIRED:
Breadboard
Wires 741 IC Operational Amplifier
Resistance sheet
Dual Power Supply
Digital Multimeter
Function Generator
Oscilloscope

THEORY:

The Summing Amplifier

The **Summing Amplifier** is another type of operational amplifier circuit configuration that is used to combine the voltages present on two or more inputs into a single output voltage. We know that the inverting amplifier has a single input voltage, (Vin) applied to the inverting input terminal. If we add more input resistors to the input, each equal in value to the original input resistor, (Rin) we end up with another operational amplifier circuit called a **Summing Amplifier**, "*summing inverter*" or even a "*voltage adder*" circuit as shown below in Fig.1.

Summing Amplifier Circuit:

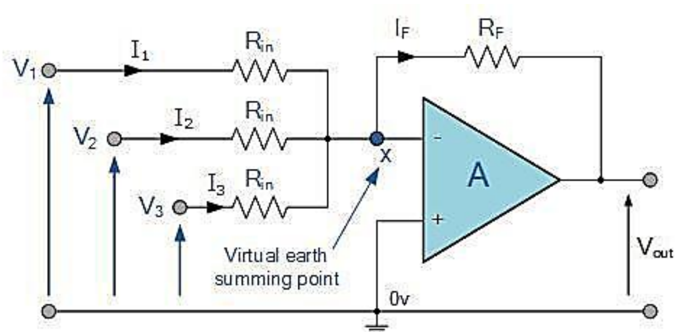

Fig.1Summing Amplifier

In this simple summing amplifier circuit, the output voltage, (Vout) now becomes proportional to the sum of the input voltages, V1, V2, V3, etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left(\frac{V_1}{R_{in}} + \frac{V_2}{R_{in}} + \frac{V_3}{R_{in}}\right)$$

Inverting Equation: $V_{out} = -\frac{R_F}{R_{in}} \times V_{in}$

Then, $-V_{out} = \left(\frac{R_F}{R_{in}} V_1 + \frac{R_F}{R_{in}} V_2 + \frac{R_F}{R_{in}} V_3\right)$

However, if all the input impedances, (Rin) are equal in value, we can simplify the above equation to give an output voltage of:

$$-V_{out} = -\frac{R_F}{R_{in}}(V_1 + V_2 + V_3)$$

We now have an operational amplifier circuit that will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic "SUM" of the three individual input voltages V1, V2 and V3. We can also add more inputs if required as each individual input "see's" its respective resistance, Rin as the only input impedance.

This is because the input signals are effectively isolated from each other by the "virtual earth" node at the inverting input of the op-amp. A direct voltage addition can also be obtained when all the resistances are of equal value and Rf is equal to Rin.

Note that when the summing point is connected to the inverting input of the op-amp, the circuit will produce the negative sum of any number of input voltages.

PROCEDURE:

- Implement the circuit as in Fig. 2 given below
- Set the supply as +/- 15 V dc.
- Also supply input voltages as given in the circuit.
- Determine the output voltage as measured by Multimeter.
- Attach simulation results.

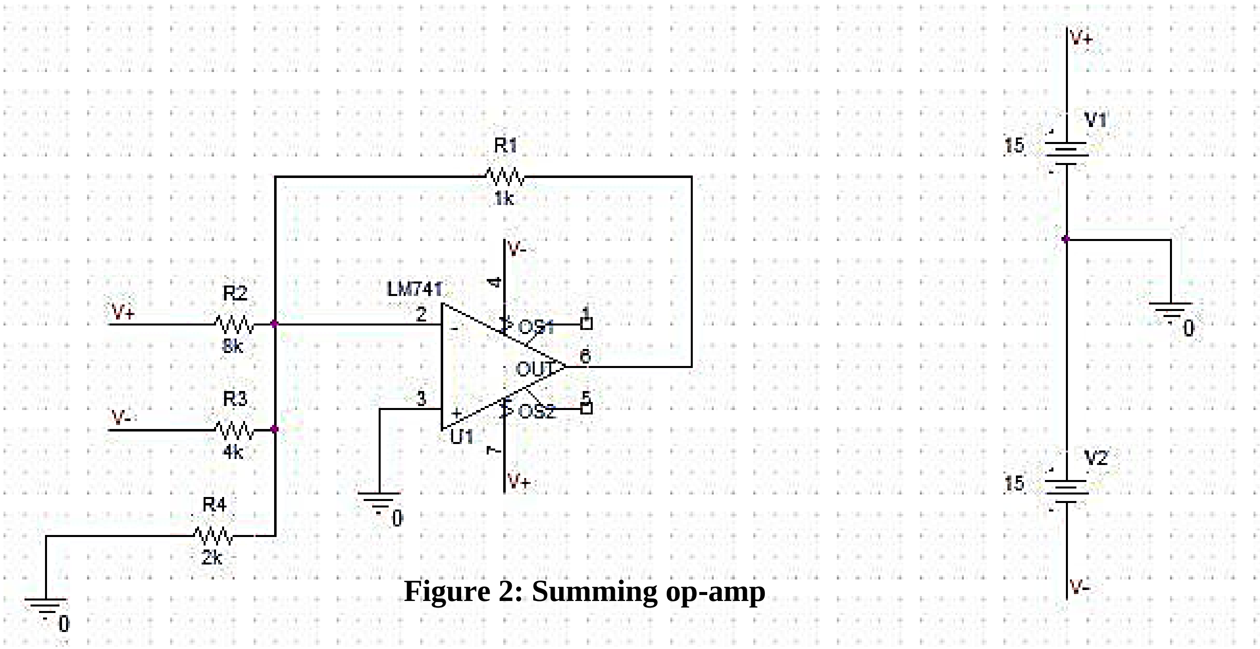

Figure 2: Summing op-amp

CALCULATIONS:

RESULT:

Output voltage as measured comes out to be: ____________

Output voltage as calculated comes out to be: _____________

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Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Lab No.3

OBJECTIVE:

To **DESIGN** and analyze an op-amp based circuit to measure its slew rate

EQUIPMENT REQUIRED:

Proto board
Function Generator
Digital Multi meter
Power Supply
Resistors
741op-amp

THEORY:

The slew rate is defined as the speed with which the amplifier can change its output voltage. This parameter is measured in volts/second (or volts/µs) and can be measured with the circuit shown in Fig.1.

$$SR = \left(\frac{dV_0(t)}{dt}\right)_{max}$$

To measure this parameter, apply a square wave signal to the amplifier input and measure the change in output voltage during a short time interval (e.g. in one µs)

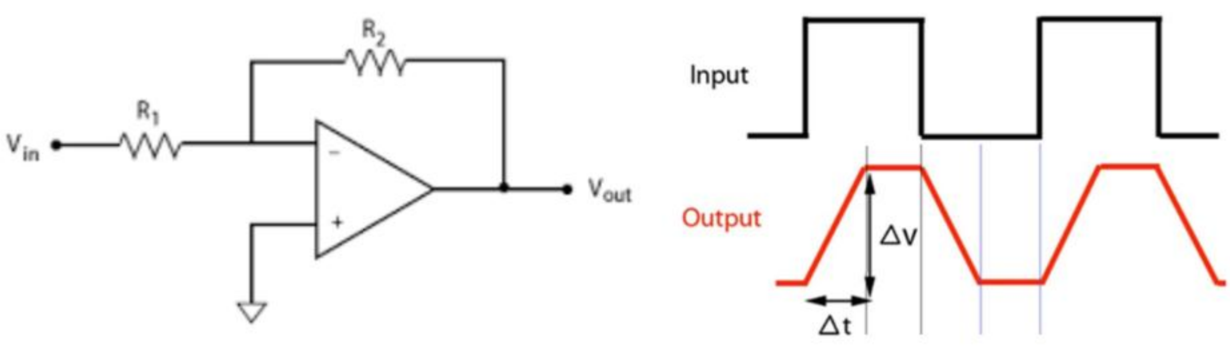

Fig. 1 Inverting Amplifier circuit with input and output waveform

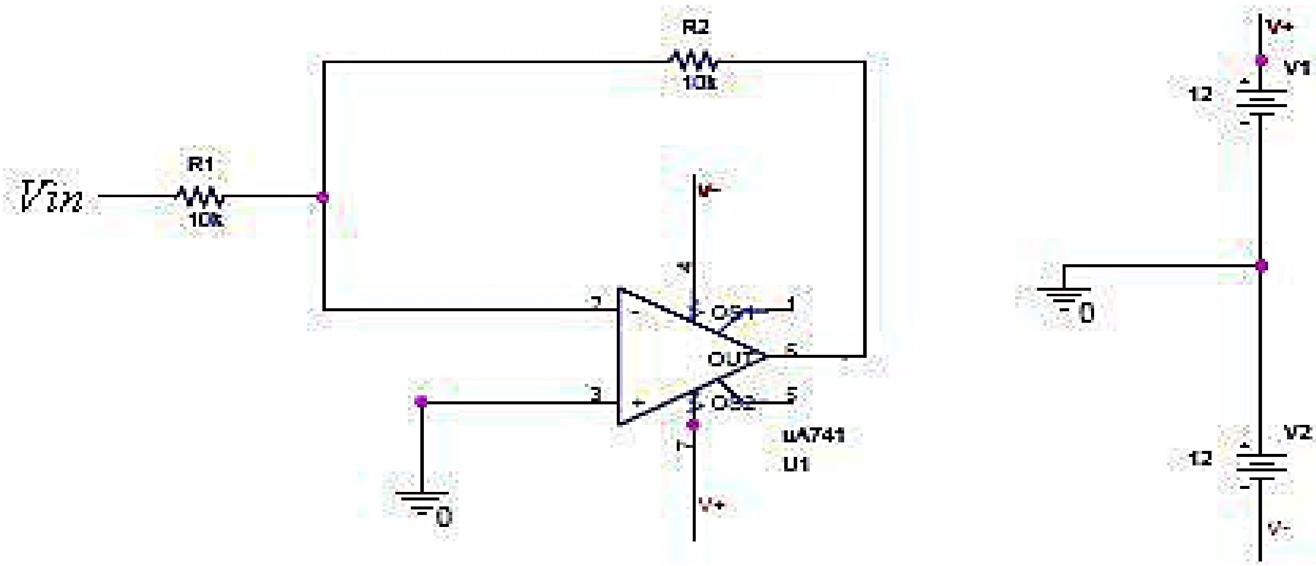

Fig. 2 Circuit to be implemented

SLEW RATE MEASUREMENT

- Implement the circuit in Fig. 2
- Apply a square-wave signal, 10 KHz, 3Vpp and zero average voltage value between terminal 2 and ground.
- Connect the first probe of the oscilloscope to the input of the circuit (terminal 2) and the second to the output of the amplifier.
- Measure the time taken for the output to raise from -1 V to + 1 V.
- Attach simulation results.

OBSERVATION:

Quantity	Observed Value
dVo	
D	
SR	

RESULT:

The slew rate of the op-amp comes out to be…………..

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Lab No.4

OBJECTIVE:

To **DESIGN** and analyze an op-amp based circuit to measure its bandwidth

EQUIPMENT REQUIRED:

- Proto board
- Function Generator
- Digital Multi meter
- Power Supply
- Resistors
- 741 op-amp

THEORY:

The bandwidth is defined as the difference between the upper and lower frequencies in a continuous set of frequencies as shown in Fig.1. It is typically measured in hertz.

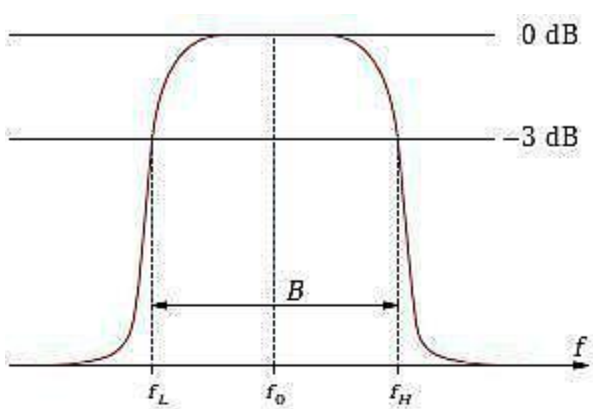

Fig. 1 Frequency response graph to study bandwidth

FORMULA:

$$BW = \frac{f_o}{Q}$$

Or

$$BW = f_2 - f_1$$

Where BW = bandwidth of a circuit in units of frequency
fo = center frequency

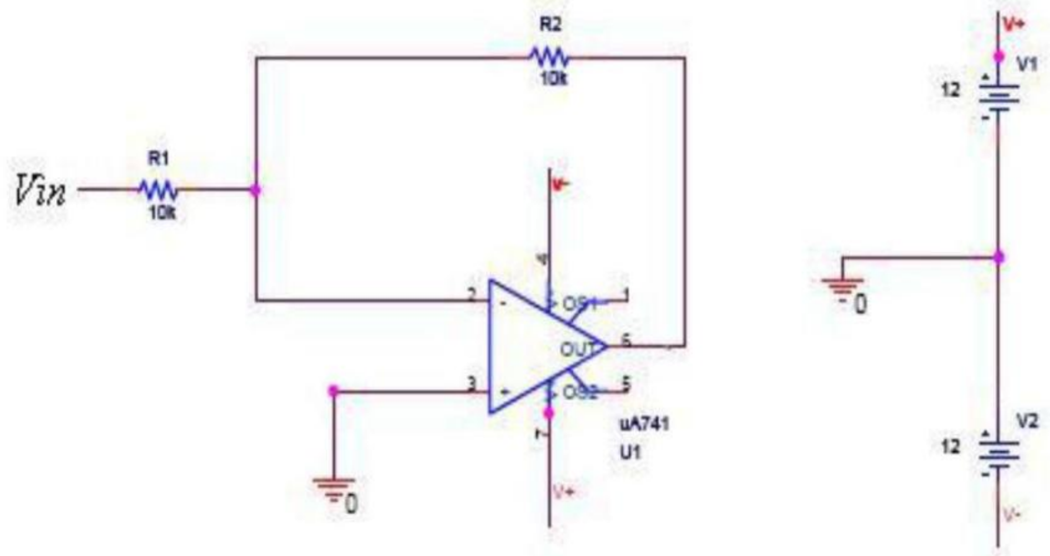

Fig. 2 Op-amp circuit to study its bandwidth

PROCEDURE:

- Implement the circuit as shown in Fig.2
- Apply a Sine wave, 100Hz, 1Vpp between input terminals.
- Note down the output voltage.
- Increase the frequency to all values shown in table and record the output voltage at each frequency
- Plot the graph of output voltage w.r.t frequency.
- Determine the frequency at which the output voltage drops to 0.707 of its maximum value.
- Measure the frequency for which the amplification is equal to 1.
- Attach simulation results.

OBSERVATION:

Input Frequency	Output Voltage
10Hz	
50 Hz	
100Hz	
500Hz	
1KHz	
10KHz	
20KHz	
50KHz	
100KHz	
200KHz	
500KHz	

RESULT:

- The bandwidth of the op-amp comes out to be………………

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Lab No.5

OBJECTIVE:
To **DESIGN** and understand the working of zero and non-zero level detector

THEORY:

ZERO LEVEL DETECTOR:
A zero level detector or comparator determines whether an input voltage is greater or less than a predetermined reference level as shown in Figs. 1 and 2. Since a comparator is operated in an open loop mode, the output voltage approaches either its positive or its negative supply value. Useful Formula:

1) Noninverting comparator output
   1. Vout = +VSAT when Vin > VREF
   2. Vout = -VSAT when Vin < VREF

2) Inverting comparator output
   1. Vout = +VSAT when Vin < VREF
   2. Vout = -VSAT when Vin > VREF

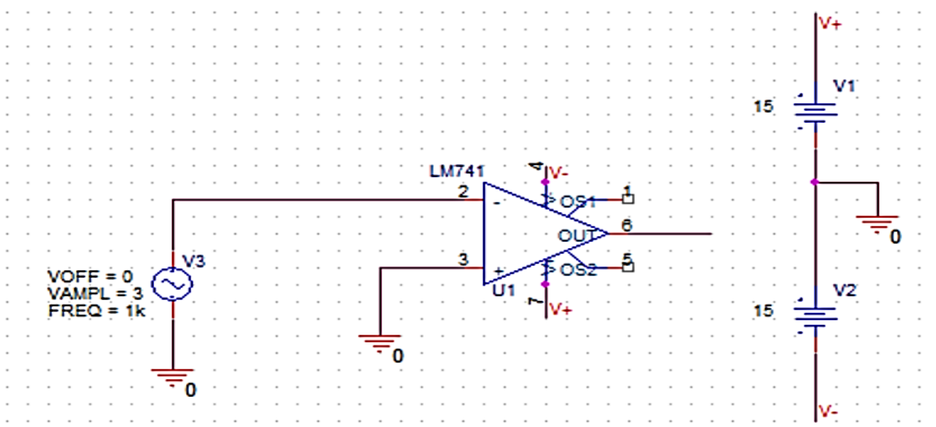

Fig.1 Inverting Comparator or Zero level Detector

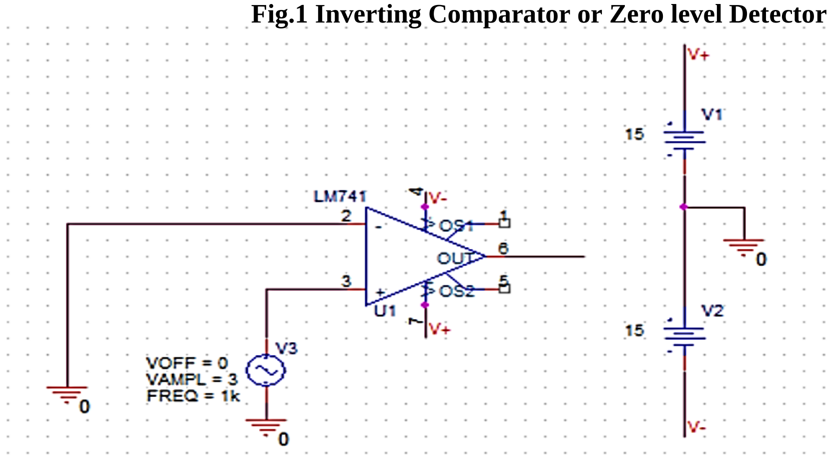

Fig.2 Non- Inverting Comparator or Zero Level Detector

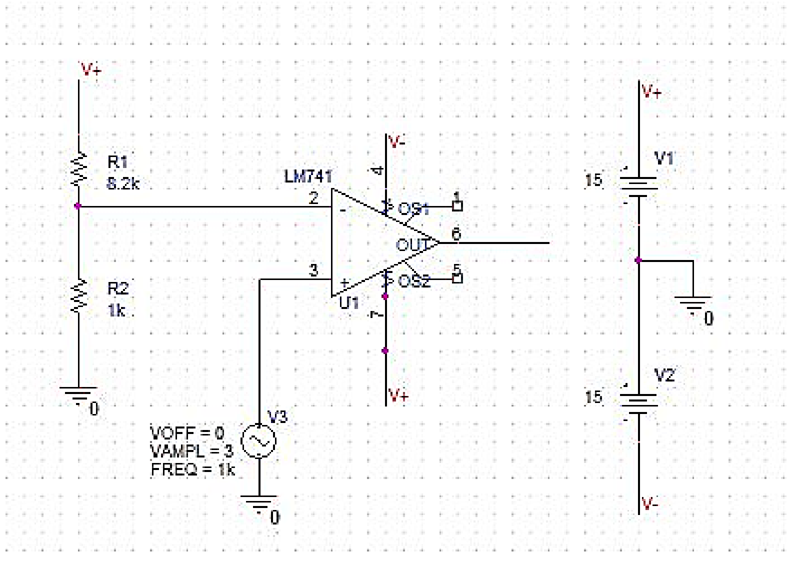

Fig.3 Comparator comparing given AC input with fixed DC value

PROCEDURE:

1) Implement the circuits of Fig.1, Fig. 2 and Fig.3 one by one.
2) Apply +15V and -15V supply voltage and

determine the output voltage waveform and peak to peak for each of them.

3) Attach simulation results as well.

CALCULATIONS:

WAVEFORM:

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Lab No.6

OBJECTIVE:

To **DESIGN** and demonstrate the ability of an integrator operational amplifier to supply the output with a signal corresponding to the integral function of the input

The typical circuit of an operational amplifier in integrator configuration is shown in Fig.1 below. The first thing to note is the presence of a capacitor in the feedback chain. Let's note the relations connecting the output to the input for an ideal amplifier, starting from the law governing the operation of the capacitor C. The relationship between the voltage *V*, and the current I for an ideal capacitor of capacitance C is:

$$I = C\frac{dV}{dt}$$

where dV / dt indicates the derivative of the variable V with respect to time t.

The inverting input can be considered as at zero voltage (virtual ground) in this configuration, too, as the infinite gain guarantees zero differential input voltage. So, the current through the resistor R is given by the ratio between the input voltage Vin and R. This current, as the input resistance is ideally infinite, will charge the capacitor which, having the left terminal (refer to Fig. 1) to ground, will present its voltage

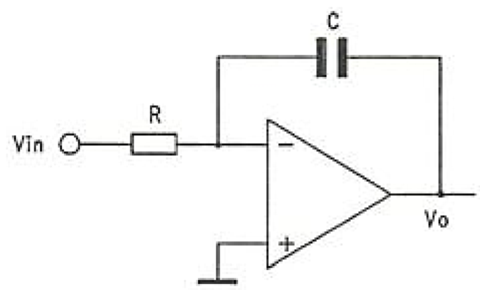

Fig. 1 Op-amp Integrator

Then we can write

$$\frac{Vin}{R} = C \frac{dV}{dt}$$

From which , as Vo = -V, we obtain

$$dVo = -\frac{1}{RC} V_{in}\, dt$$

And integrating both sides

$$Vo = -\frac{1}{RC} \int V_{in}\, dt$$

This formula says that the output voltage is the integral of the input voltage divided by the constant R·C .The variable C can be defined as the time necessary for the voltage Vo to reach an amplitude equal to the one across the input, from zero starting conditions and constant input voltage.

Replacing the ideal amplifier with a real one we must take account of the offset voltage, which appears as a dc voltage at the input, and when integrated, appears at the output as a voltage which increases linearly. Also a part of the bias current is integrated contributing to this output voltage variation.

These two causes of error will eventually take the amplifier to saturation. This is one of the limits of this circuit. The problems listed before can be partly removed by connecting a resistor between the no inverting input and ground with a value equal to R, to compensate for the effect of the bias current, and also by inserting a resistor in parallel with C to counteract the effect of the offset voltage as shown in Fig.2

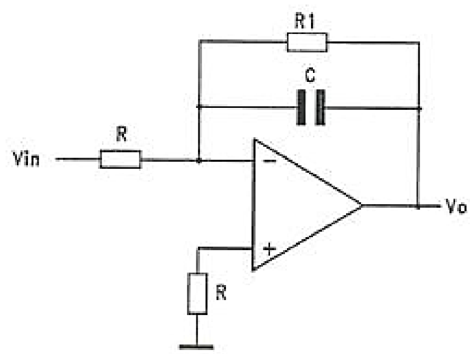

Fig.2 Op-amp Integrator with R in parallel to C to counteract the effect of the offset voltage

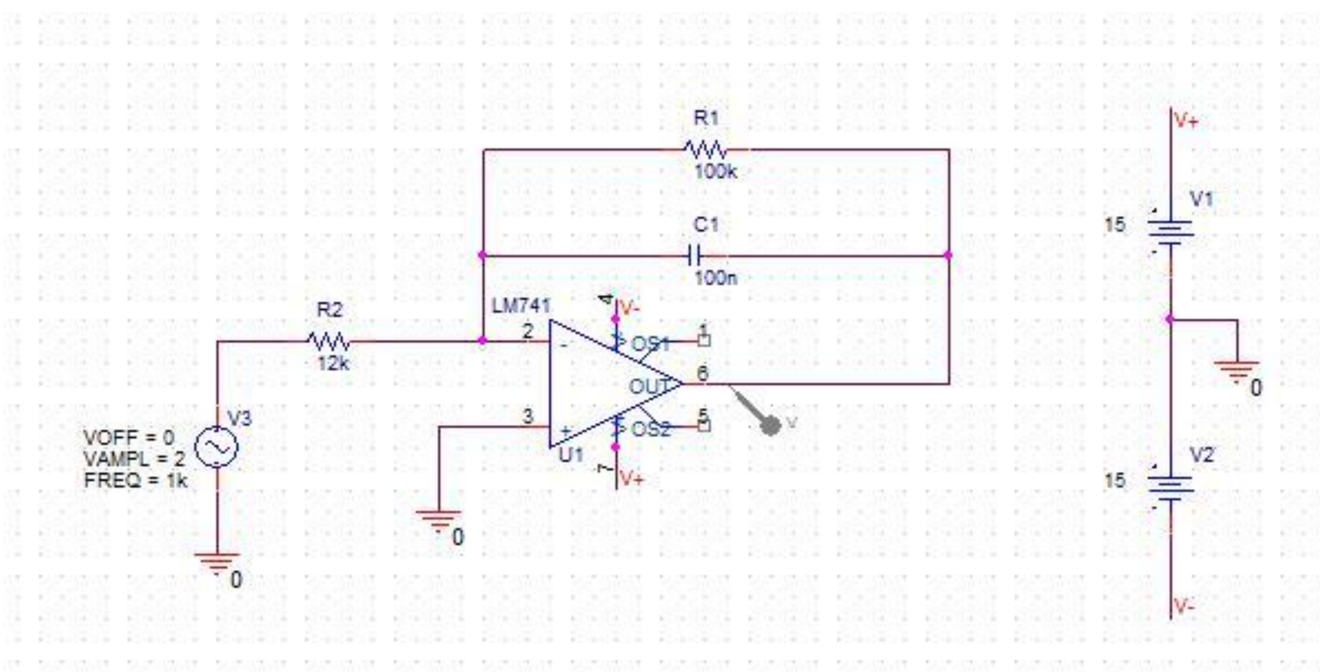

Fig. 3 Op-amp Integrator to be implemented

PROCEDURE:

1) Implement the circuit as given in Fig.3
2) Apply 2Vp-p sine wave input signal to the integrator circuit with frequency 50Hz, 100Hz and 200Hz.
3) For each input signal note down the shape, frequency and magnitude (peak to peak) of output voltage.
4) Attach simulation results as well.

OBSERVATION:

Vin = 2Vp-p

S.No.	Frequency	Output voltage
1	50Hz	
2	100Hz	
3	200Hz	

WAVEFORMS:

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Psychomotor Domain Assessment Rubric-Level P3					
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Laboratory Session No. ____________ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Lab No.7

OBJECTIVE:

To **DESIGN** and demonstrate the ability of a differentiator op amp to produce an output voltage Vo equal to the derivative of the input signal Vin and to determine the gain variation as the input frequency is changed.

The circuit diagram for a differentiator made using an operational amplifier is shown in Fig. 1. A resistor is inserted in the feedback branch, while a capacitor is connected to the input.

If the amplifier has an ideal behaviour (infinite bandwidth, amplification and input impedance) we can calculate the relation between the input and the output, starting from the fact that the inverting input is at zero voltage (virtual ground). So the current through R is given by:

$$i = \frac{V_0}{R}$$

As for the capacitor, the law governing its operation is:

$$i = C\frac{dV}{dt}$$

Since the input impedance is infinite, the current into the capacitor is equal to the one through resistor R. By substitution:

$$V_0 = -RC\frac{dV_{in}}{dt}$$

If we apply a sine wave v(t) = sin(wt) as input signal, the output voltage will be:

$$V_0 = -RC\omega\cos(\omega t)$$

For a zero frequency, (i.e. dc) it is clear that the output voltage is zero, as capacitors block DC. The gain of the amplifier is then zero for the DC component.

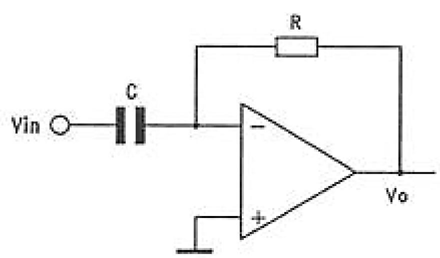

Fig.1 Op- Amp Differentiator

High amplifications make the circuit unstable. Besides, as the gain increases with frequency, interference noise (which typically has high frequencies) can be amplified so much that it swamps the original signal. To solve these problems a resistor Rl can be connected in series with the capacitor in order to limit the gain of the differentiator.

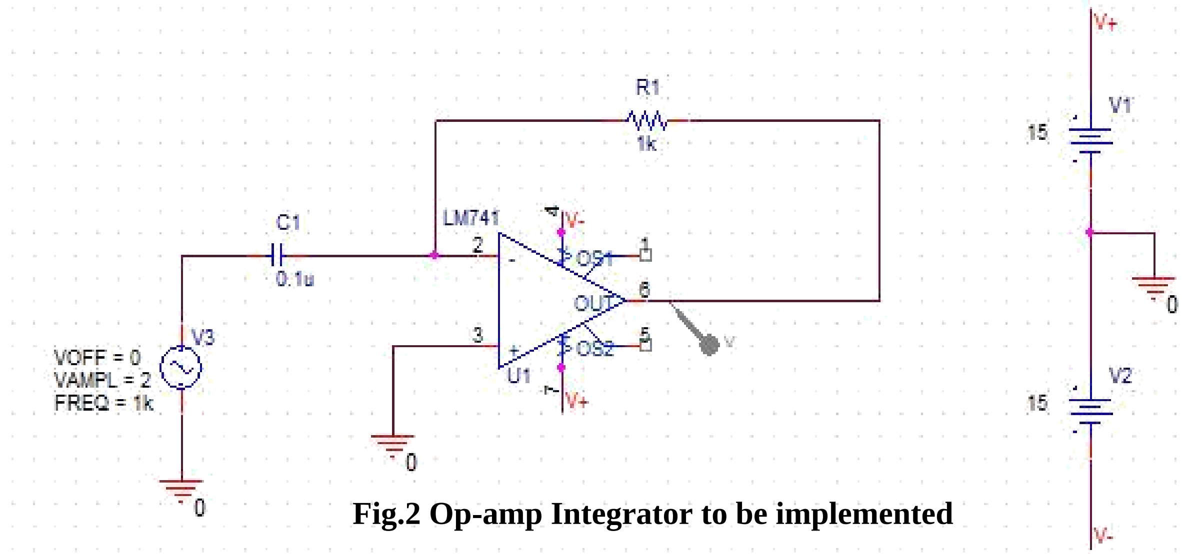

Fig.2 Op-amp Integrator to be implemented

PROCEDURE:

1. Implement the circuit as given in Fig.2
2. Apply 2Vp-p sine wave input signal to the Differentiator circuit with frequency 50Hz, 1 kHz and 2 kHz.
3. For each input signal note down the shape, frequency and magnitude (peak to peak) of the output voltage.
4. Attach simulation results as well.

OBSERVATION:

Vin = 2Vp-p

S.No.	Frequency	Output voltage
1	50Hz	
2	1 kHz	
3	2 kHz	

WAVEFORMS:

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Lab No.8

OBJECTIVE:

To **DESIGN** and investigate the operation of Common Emitter Amplifier. To describe the purpose of components present in Common Emitter Amplifier.

THEORY:

The CE Amplifier is one of the three basic transistor amplifier circuit used in electronic industry. In this configuration, input is applied at the base lead while its output is taken at collector, which is in 180^{o} phase shift.

CHARACTERISTICS:

Large voltage and current gain
Low input resistance
High output resistance

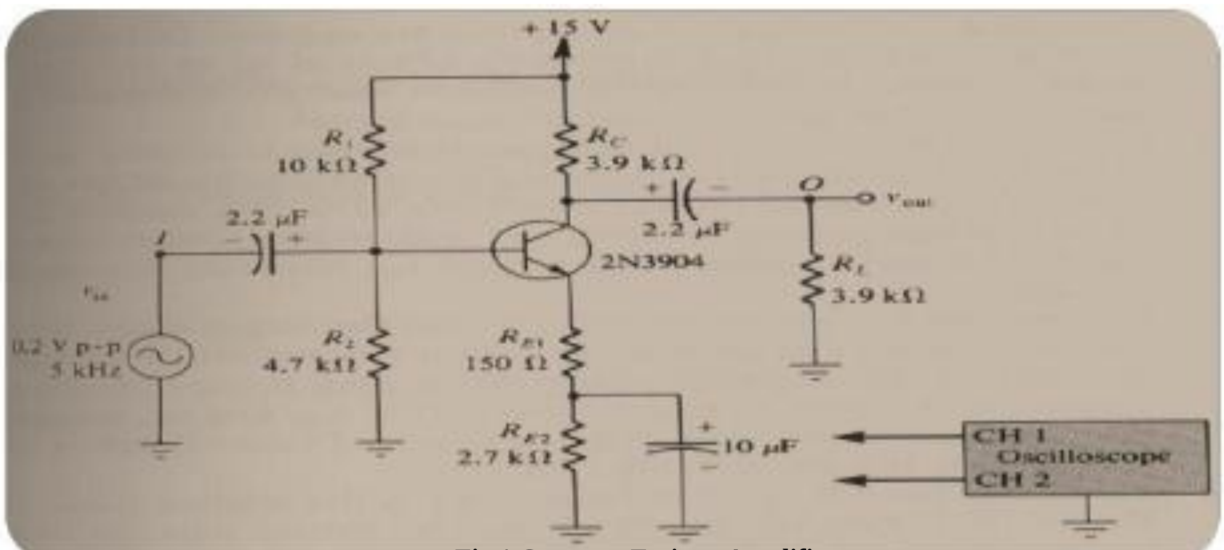

Fig.1 Common Emitter Amplifier

Fig. 1 above shows the biased BJT in CE configuration. Observe the capacitors are to act as open circuits for DC and as short circuits for AC signals. The purpose of 2.2 uF capacitor at input side is to make the DC operating point insensitive to the signal generator impedance. The bypass capacitor of 10uF is present to ground an emitter for AC signal and, hence, increase voltage gain of the amplifier. The Resistances R1 and R2 are used to mark the DC operating point for forward biasing the base emitter junction. Emitter degeneration resistance introduces negative feedback in the amplifier circuit.

PROCEDURE:

1. Implement the circuit given above in Fig.1.
2. Measure the DC operating points i.e. V_B,V_C,V_E .
3. After the confirmation of the transistor in active mode apply the AC voltage of 10mV , 1kHz sine wave to the base of the transistor through the coupling capacitor .
4. Check the amplified output waveform across the load resistor. Calculate the gain of the circuit. Attach simulation results as well.

OBSERVATION:

Parameters	Measured Value
V_C	
V_B	
V_E	

Gain:

RESULT:

The gain of the circuit comes out to be ……………..

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Remarks	
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Lab No.9

OBJECTIVE:
To **DESIGN** and analyze op-amp based Wien Bridge oscillator.

EQUIPMENT REQUIRED:
- Proto board
- Function Generator
- Digital Multi meter
- Power Supply
- Resistors
- Capacitors 2x1nF
- 741op-amp (8-pin mini DIP)

THEORY:

THE OSCILLATOR
Oscillators are electronic circuits that generate an output signal without the necessity of an input signal. It produces a periodic waveform on its output with only the DC supply voltage as an input. The output voltage can be either sinusoidal or non-sinusoidal, depending on the type of oscillator. Different types of oscillators produce various types of outputs including sine waves, square waves, triangular waves, and saw-tooth waves. A basic oscillator is shown in Fig. 1 below.

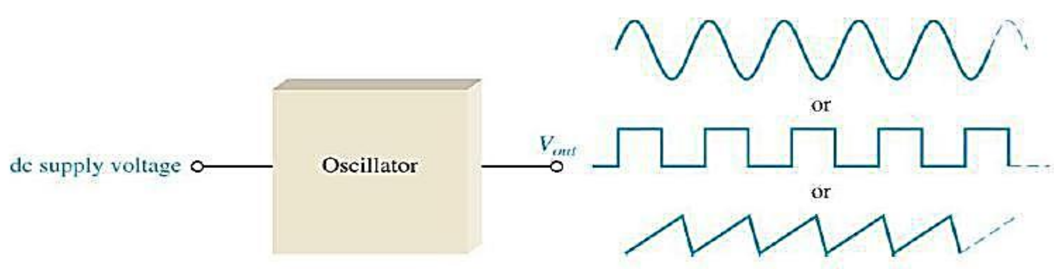


Fig. 1 The basic Oscillator concept showing three common types of output waveforms: sine wave, square wave and saw tooth.

TYPES OF OSCILLATOR:
Oscillators can be of 2 types.
1) Feedback Oscillators
2) Relaxation oscillators

FEEDBACK OSCILLATORS:
One type of oscillator is the feedback oscillator, which returns a fraction of the output signal to the input with no net phase shift, resulting in a reinforcement of the output signal. After oscillations are started, the loop gain is maintained at 1.0 to maintain oscillations.
A feedback oscillator consists of an amplifier for gain (either a discrete transistor or an op-amp) and a positive feedback circuit that produces phase shift and provides attenuation, as shown in Fig. 2.

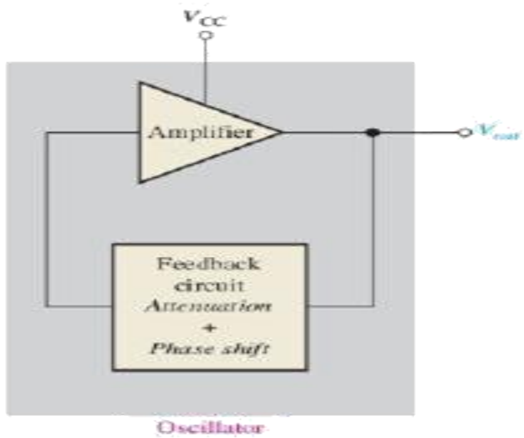


Fig. 2 Basic elements of a feedback oscillator

RELAXATION OSCILLATORS:

A second type of oscillator is the relaxation oscillator. Instead of feedback, a relaxation oscillator uses an RC timing circuit to generate a waveform that is generally a square wave or other non-sinusoidal waveform. Typically, a relaxation oscillator uses a Schmitt trigger or other device that changes states to alternately charge and discharge a capacitor through a resistor.

FEEDBACK OSCILLATORS:

Feedback oscillator operation is based on the principle of positive feedback. Feedback oscillators are widely used to generate sinusoidal waveforms.

POSITIVE FEEDBACK:

In positive feedback, a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a strengthening of the output signal. This basic idea is illustrated in Fig. 3(a).

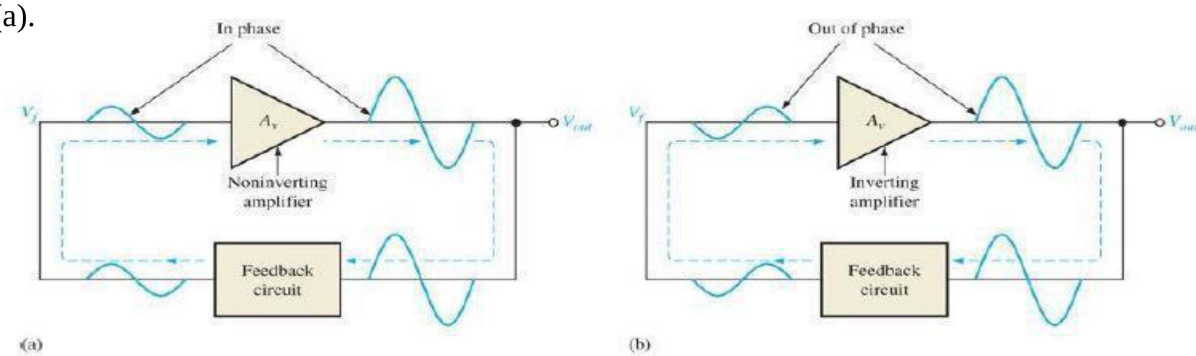


Fig. 3 Positive feedback produces oscillation

As you can see, the in-phase feedback voltage is amplified to produce the output voltage, which in turn produces the feedback voltage. That is, a loop is created in which the signal maintains itself and a continuous sinusoidal output is produced. This phenomenon is called oscillation.

In some types of amplifiers, the feedback circuit shifts the phase and an inverting amplifier is required to provide another phase shift so that there is no net phase shift. This is illustrated in Fig. 3(b).

CONDITIONS FOR OSCILLATION:

Two conditions, illustrated in Fig. 4, are required for a sustained state of oscillation:

1. The phase shift around the feedback loop must be effectively zero.
2. The voltage gain, A_{cl}, around the closed feedback loop (loop gain) must equal 1 (unity).

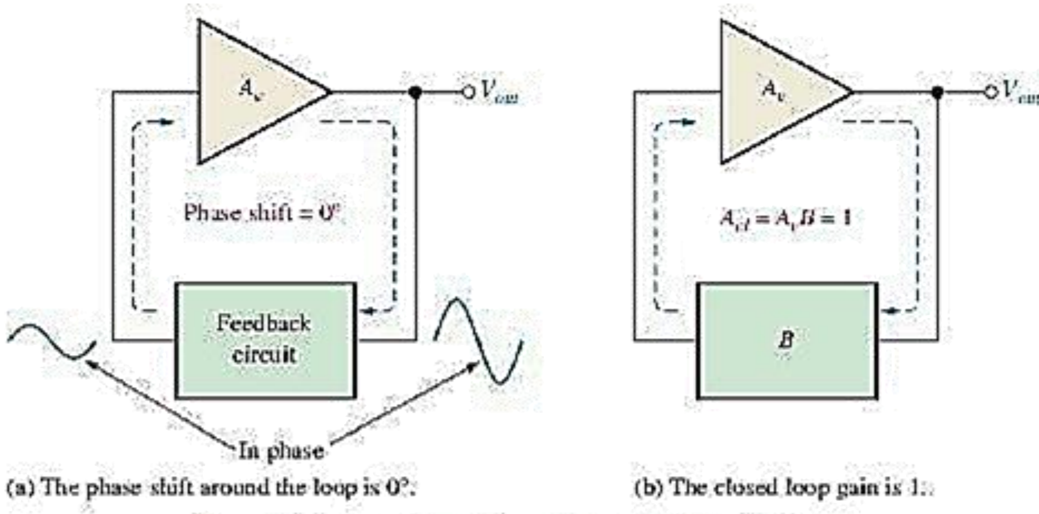


Fig. 4 General conditions to sustain oscillation

The voltage gain around the closed feedback loop, A_{cl}, is the product of the amplifier gain, A_v, and the attenuation B, of the feedback circuit.

$$A_{cl} = A_v \, x \, B$$

If a sinusoidal wave is the desired output, a loop gain greater than 1 will rapidly cause the output to saturate at both peaks of the waveform, producing unacceptable distortion. To avoid this, some form of gain control must be used to keep the loop gain at exactly 1 once oscillations have started. For example, if the attenuation of the feedback circuit is 0.01, the amplifier must have a gain of exactly 100 to overcome this attenuation and not create unacceptable distortion(100 x0.01=1). An amplifier gain of greater than 100 will cause the oscillator to limit both peaks of the waveform.

START-UP CONDITIONS:

The unity-gain condition must be met for oscillation to be maintained.

For oscillation to begin, the voltage gain around the positive feedback loop must be greater than 1 so that the amplitude of the output can build up to a desired level. The gain must then decrease to 1 so that the output stays at the desired level and oscillation is sustained. The voltage gain conditions for both starting and sustaining oscillation are illustrated in Fig. 5.

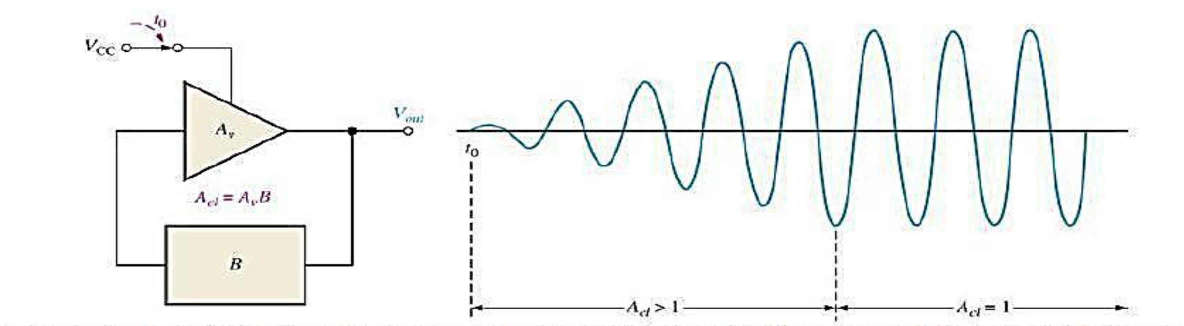


Fig. 5 When oscillation starts at to, the condition Acl > 1 causes the sinusoidal output voltage amplitude to build up to a desired level. Then Acl decreases to 1 and maintains the desired amplitude.

OSCILLATION WITH *RC* FEEDBACK CIRCUITS:

Three types of feedback oscillators that use RC circuits to produce sinusoidal outputs are the

- Wien-bridge oscillator
- Phase-shift oscillator
- Twin-T oscillator

Generally, RC feedback oscillators are used for frequencies up to about 1 MHz. The Wien-bridge is by far the most widely used type of RC feedback oscillator for this range of frequencies.

WIEN-BRIDGE OSCILLATOR

One type of sinusoidal feedback oscillator is the Wien-bridge oscillator. A fundamental part of the Wien-bridge oscillator is a lead-lag circuit like that shown in Fig. 6(a). R_1 and C_1 together form the lag portion of the circuit; R_2 and C_2 form the lead portion.

The operation of this lead-lag circuit is as follows.

- At lower frequencies, the lead circuit takes over due to the high reactance of C_2.
- As the frequency increases, X_{C2} decreases, thus allowing the output voltage to increase.
- At some specified frequency, the response of the lag circuit takes over, and the decreasing value of X_{C1}causes the output voltage to decrease,

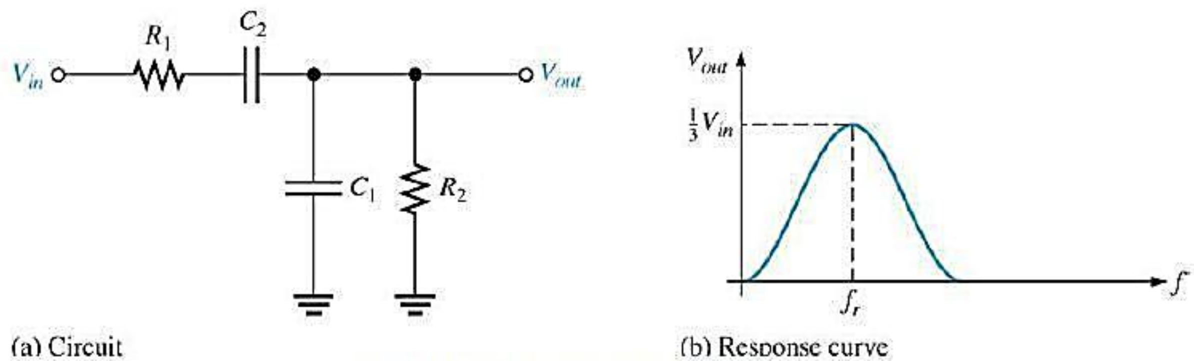


Fig. 6 lead-lag circuit and its response curve

The response curve for the lead-lag circuit shown in Fig. 6(b) indicates that the output voltage peaks at a frequency called the resonant frequency, f_r. At this point, the attenuation (V_{out}/V_{in}) of the circuit is 1/3 if R_1=R_2 and X_{C1} =X_{C2} as stated by the following equation

$$\frac{V_{out}}{V_{in}} = \frac{1}{3}$$

The formula for the resonant frequency is

$$f_{r=} \frac{1}{2\pi RC}$$

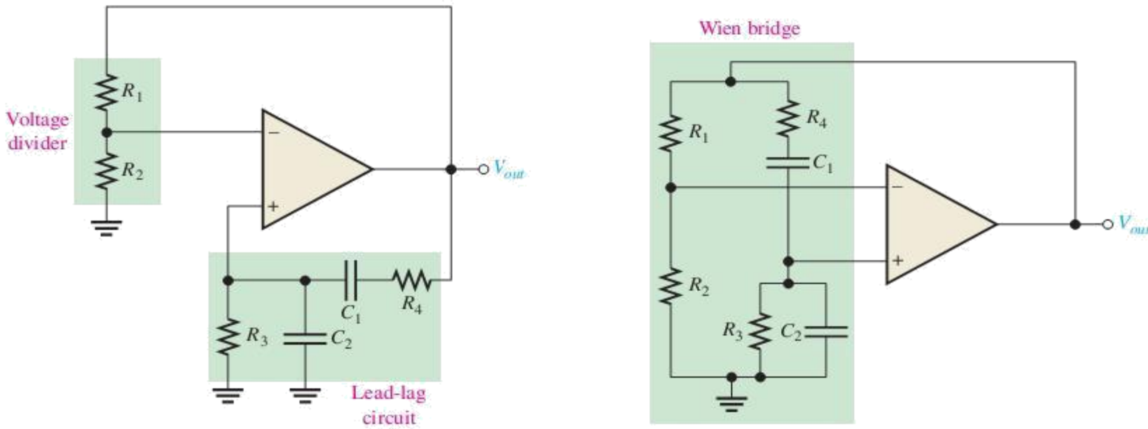
To summarize, the lead-lag circuit in the Wien-bridge oscillator has a resonant frequency, at which the phase shift through the circuit is and the attenuation is 1/3.Below, f_r the lead circuit dominates and the output leads the input. Above, f_r the lag circuit dominates and the output lags the input.

THE BASIC CIRCUIT:

The lead-lag circuit is used in the positive feedback loop of an op-amp, as shown in Fig. 7(a). A voltage divider is used in the negative feedback loop. The Wien-bridge oscillator circuit can be viewed as a non-inverting amplifier configuration with the input signal fed back from the output through the lead-lag circuit. Recall that the voltage divider determines the closed-loop gain of the amplifier.

$$A_{cl} = \frac{1}{\beta} = \frac{1}{\frac{R_2}{R_1 + R_2}} = \frac{R_1 + R_2}{R_2}$$

The circuit is redrawn in Fig. 7(b) to show that the op-amp is connected across the bridge circuit. One leg of the bridge is the lead-lag circuit, and the other is the voltage divider.



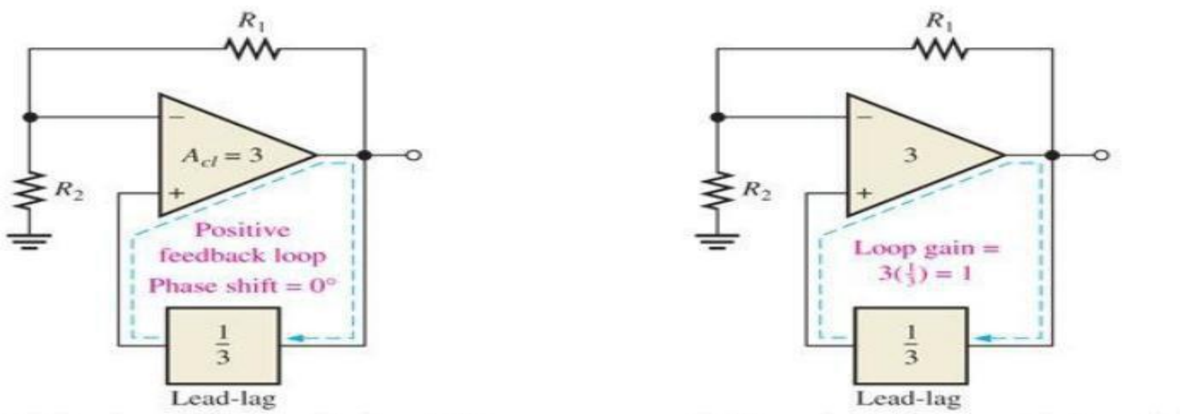
(a)

(b) Wien bridge circuit combines a voltage divider and a lead-lag circuit.

Fig. 7 The Wein-Bridge oscillator schematic drawn in two different but equivalent ways

POSITIVE FEEDBACK CONDITIONS FOR OSCILLATION:

As you know, for the circuit output to oscillate, the phase shift around the positive feedback loop must be 0° and the gain around the loop must equal unity (1). The 0° phase-shift condition is met when the frequency is f_r because the phase shift through the lead -lag circuit is 0° and there is no inversion from the non-inverting input of the op-amp to the output. This is shown in Fig. 8(a).



(a) The phase shift around the loop is 0°. (b) The voltage gain around the loop is 1.

Fig. 8 Conditions for sustained oscillations

The unity-gain condition in the feedback loop is met when

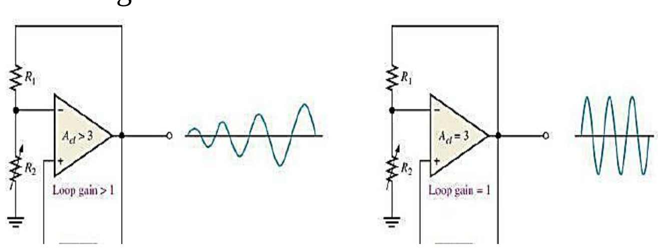
$$A_{CL} = 3$$

This offsets the 1/3 attenuation of the lead-lag circuit, thus making the total gain around the positive feedback loop equal to 1, as shown in Fig. 8(b). - To achieve a closed-loop gain of 3,

$$R_1 = 2\,R_2$$

START-UP CONDITIONS

Initially, the closed-loop gain of the amplifier itself must be more than 3 ($A_{cl} > 3$) until the output signal builds up to a desired level. Ideally, the gain of the amplifier must then decrease to 3 so that the total gain around the loop is 1 and the output signal stays at the desired level, thus sustaining oscillation. This is illustrated in Fig. 9 below.



Initially, a small positive feedback signal develops from noise. The lead-lag circuit permits only a signal with a frequency equal to appear in phase on the non-inverting input. This feedback signal is amplified and continually strengthened, resulting in a buildup of the output voltage. When the output signal reaches the zener breakdown voltage, the zeners conduct and effectively short out. This lowers the amplifier‟s closed-loop gain to 3. At this point, the total loop gain is 1 and the output signal levels off and the oscillation is sustained.

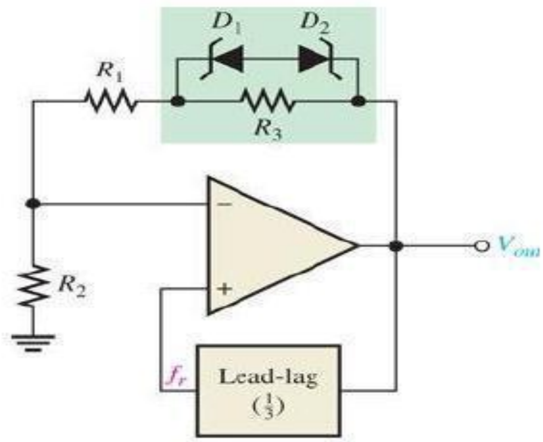
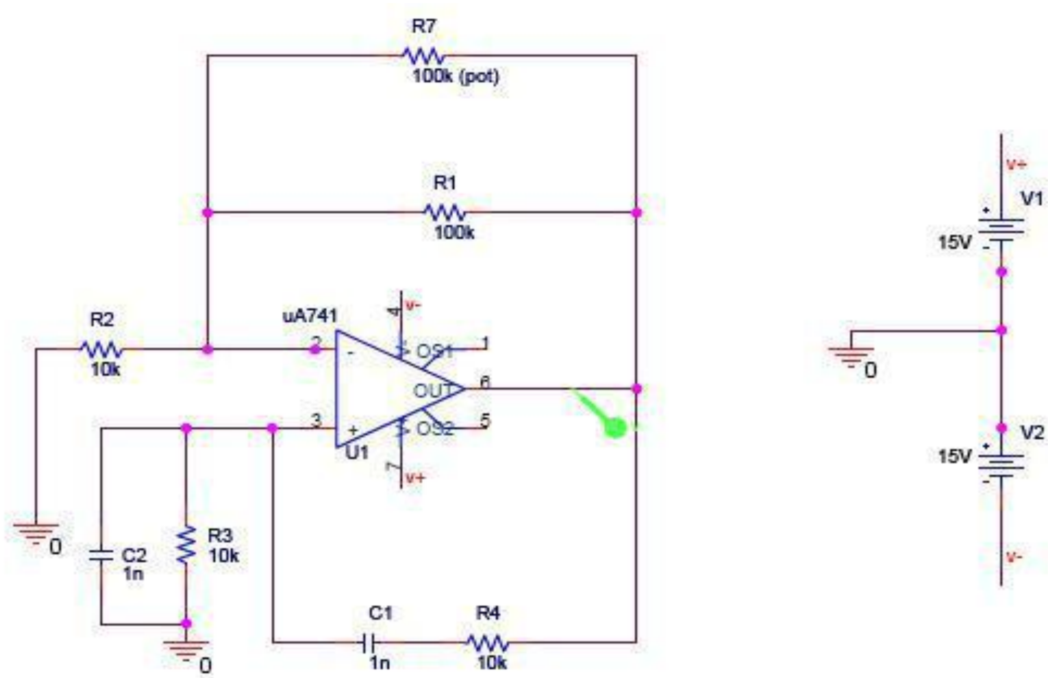


Fig. 10 Self-starting Wein-Bridge oscillator using back-to-back Zener diodes

Fig. 11 Circuit to be implemented



PROCEDURE:

1. Wire the circuit as shown in Fig.11.
2. Apply $\pm$ 15V supply connections to the bread board.
3. Turn 100kΩ potentiometer completely clock-wise
4. Connect one probe of the oscilloscope to the output of the circuit and the second probe to the positive pin of op-amp.
5. Adjust the potentiometer to obtain a sine wave across the output.
6. Calculate the theoretical value of the frequency at which the circuit should oscillate as given by the formula.
7. Measure the oscillation frequency with an oscilloscope.

USEFUL FORMULA:

$$R_1 = 2\ R_2$$

$$f_r = \frac{1}{2\pi RC}$$

OBSERVATION:

Parameter	Measured	Expected	% error
R2			
fr			

CALCULATIONS:

RESULT:

The resonant frequency as measured comes out to be: ___________
The resonant frequency as calculated comes out to be: ____________
R_2 as measured comes out to be: ______________
R_2 as calculated comes out to be: ______________

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Laboratory Session No. ___________ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Lab No.10

OBJECTIVE:

To **DESIGN** and analyze an Astable-Multivibrator with symmetrical square wave output

EQUIPMENT REQUIRED:

- Bread Board
- Resistors (1/4 Watt)
- Capacitor
- Oscilloscope

THEORY:

With an astable multivibrator, the op amp operates only in the non-linear region. So its output has only two voltage levels, Vmin and Vmax. The astable continually switches from one state to the other, staying in each state for a fixed length of time. The circuit of an astable multivibrator is shown in Fig. 1. Note that this circuit does not need an input signal. To find out the relations governing the operation of the astable, we start with the usual hypothesis that the operational amplifier has an ideal behavior. Suppose the output is in the state Vo = Vmax. When Vo takes this value the voltage V_{A1} of the non-inverting input is:

$$V_{A1} = V_{max}\, R_1/(R_1 + R_2)$$

The capacitor C starts charging through resistor R towards the value Vmax. This charging continues until the voltage V_B of the inverting input reaches the value V_{A1}. At this point, as the inverting input voltage is more than the non-inverting input, the output switches low, to Vmin. The voltage V_{A2} is now given by:

$$V_{A2} = V_{min}\, R_1/(R_1 + R_2)$$

At this point, the capacitor C starts discharging through R towards the voltage Vmin until it reaches the value V_{A2}, at which point the output switches to Vmax .The cycle then starts again.We have seen that the voltage across the capacitor C can vary from V_{A1} to V_{A2}, so in the period of time when the output is low, at Vmin, the voltage on the capacitor is given by:

$$V_B(t) = V_{min} - (V_{min} - V_{max}\, R_1/(R_1 + R_2))\, e^{-t/RC}$$

While in the period of time when the output is at *Vmax*, the capacitor voltage is:

$$V_B(t) = V_{max} - (V_{max} - V_{min}\, R_1/(R_1 + R_2))\, e^{-t/RC}$$

The period T1 for which the output voltage is at *Vmax* can be found by calculating the time the capacitor voltage takes to equal V_{A1}. So:

$$V_{max}/(R_1 + R_2) = (V_{min}/(R_1 + R_2) - V_{max})e^{-T1/RC} + V_{max}$$

From which:

$$T_1 = RC \ln \frac{V_{max} - R_1/(R_1 + R_2)x\, V_{min}}{V_{max} - R_1/(R_1 + R_2)xV_{max}}$$

Similarly we can find the period T2 for which the output stays at *Vmin:*

$$T_2 = RC \ln \frac{V_{max}\, x\, R_1/(R_1 + R_2) - V_{min}}{V_{min} x\, R_1/(R_1 + R_2) - V_{min}}$$

Supposing that *Vmin* = -*Vmax* we obtain:

$$T_1 = T_2 = 2RC \ln \frac{1 + R_1/R_1 + R_2}{1 - R_1/R_1 + R_2}$$

The total period T of the square-wave is given by the sum of $T1$ and $T2$. We can see that the square-wave period and so the frequency can be varied by varying the values of R1, R2, R and C. To obtain an asymmetrical square-wave (duty cycle not 50%) we can make the capacitor charge and discharge through resistors of different values.

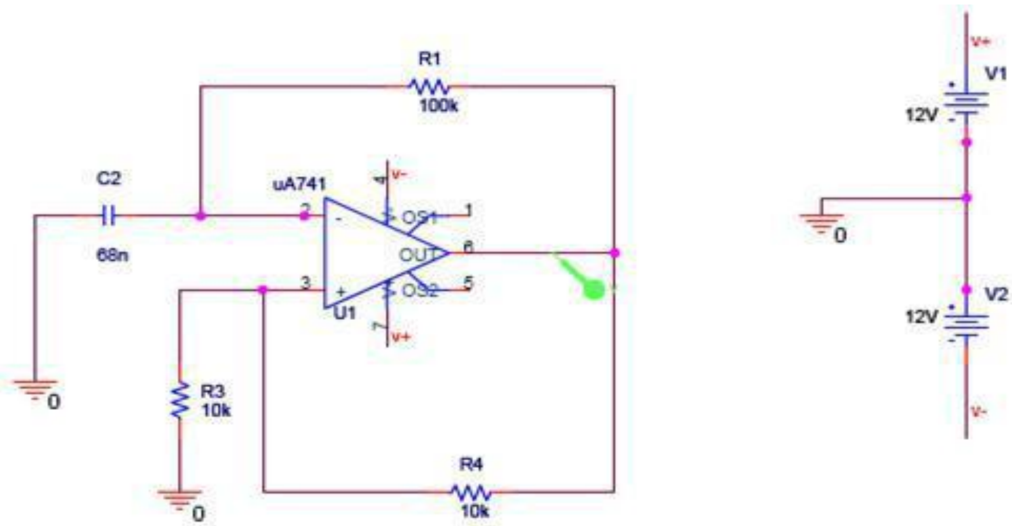

Fig. 1 Astable Multivibrator circuit

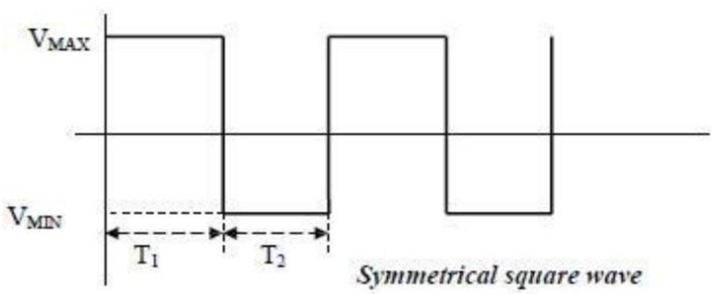

Fig. 2 Output of Astable Multivibrator circuit

PROCEDURE:

- Implement the circuit of Fig. 1.
- Calculate the output frequency with the formulae.
- Connect the first probe of the oscilloscope to the output V_o of the amplifier and the second probe to the inverting input V_B.
- Measure the frequency with the oscilloscope, and compare it with the theoretical result
- Calculate the capacitor voltages at which output switching occurs, according to the formulae
- Measure the capacitor voltages at which output switching occurs and compare the results with those calculated from theory.
- Calculate the values of T1 and T2 as given by the formulae.
- Measure the values of T1 and T2 with the oscilloscope.

OBSERVATION(SYMMETRICAL SQUARE WAVE):

S.NO.	Quantity	Observed Value	Calculated Value
1	VB (P-P)		
2	VO(P-P)		
3	Frequency		
4	Vmax		
5	Vmin		
6	Capacitor charging time		
7	Capacitor discharging time		

OUTCOME:

The approximate frequency of the oscillation of the astable multivibrator (Symmetrical square wave), when R1=R2=10k and R=100K, C = 68nf and Vmin = -Vmax comes out to be: $\frac{1}{T_1+T_2}$=

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Remarks	
Instructor's Signature with Date:	

Lab No.11

OBJECTIVE:

To **DESIGN** and analyze a class B push-pull power amplifier.

EQUIPMENT REQUIRED:

- Proto board
- Function Generator
- Digital Multi meter
- Power Supply
- Resistors
- Capacitors 2x10µF, 220uF
- Diodes: 2x 1N914 or 1N4148
- Transistors: 1xQ2N3904, 1xQ2N3906

INTRODUCTION:

POWER AMPLIFIER:

Power Amplifiers are large signal amplifiers .This generally means that a much larger portion of the load line is used during signal operation than in a small signal amplifier.

Power amplifiers are normally used as the final stage of a communications receiver or transmitter to provide signal power to speakers or to transmitting antenna.

CLASS B PUSH-PULL AMPLIFIERS:

When an amplifier is biased at cut-off so that it operates in the linear region for 180^{o} of the input cycle and is in cutoff for 180^{o}, it is a class B amplifier. The primary advantage of a class B amplifier over a class A amplifier is that either one is more efficient than a class A amplifier; you can get more output power for a given amount of input power. A disadvantage of class B is that it is more difficult to implement the circuit in order to get a linear reproduction of the input waveform.

CLASS B OPERATION:

The class B operation is illustrated in Fig.1. Where the output is shown relative to the input in terms of time (t)

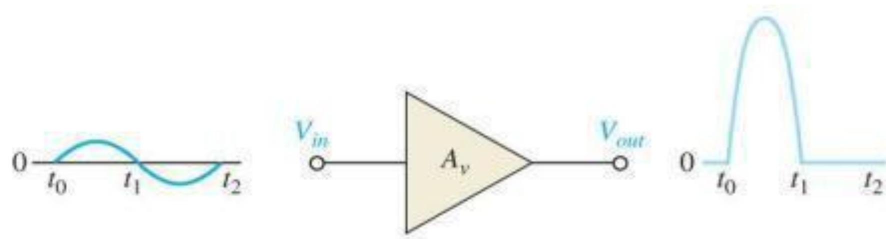

Fig. 1 Basic Class B Amplifier operation

THE Q-POINT IS AT CUTOFF:

The class B amplifier is biased at the cutoff point so that $I_{CQ} = 0$ and $V_{CEQ} = V_{CE\,(cutoff)}$. It is brought out of cutoff and operates in its linear region when the input signal drives the transistor into conduction. This is illustrated in Fig.2 with an emitter-follower circuit where, the output is not replica of the input.

CLASS B PUSH-PULL OPERATION:

The circuit in Fig.2 only conducts for the positive half cycle of the cycle. To amplify the entire cycle, it is necessary to add a second class B amplifier that operates on the negative half of the cycle. The combination of two class B amplifiers working together is called push-pull operation.

There are two common approaches for using for using push-pull amplifiers to reproduce the entire waveform. The first approach uses transformer coupling. The second uses two complementary symmetry transistors; these are a matching pair of npn/pnp BJTs or a matching pair of n-channel/p-channel FETs.

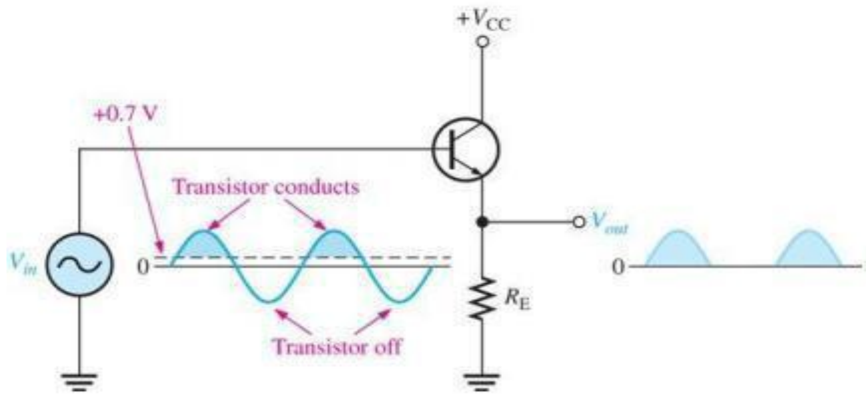

Fig.2 Common collector class B amplifier

TRANSFORMER COUPLING:

Transformer coupling is illustrated in Fig.3.The input transformer is center-tapped secondary that is connected to ground, producing phase inversion of one side with respect to the other. The input transformer thus converts the input signal of two out-of-phase signals for the transistors. Notice that both transistors are npn types. Because of the signal inversion, Q_1 will conduct on the positive part of the cycle and Q_2 will conduct on the negative part. The output transformer combines the signals by permitting current in both the directions, even though one transistor is always cut-off. The positive power supply signal is connected to the center tap of the output transformer.

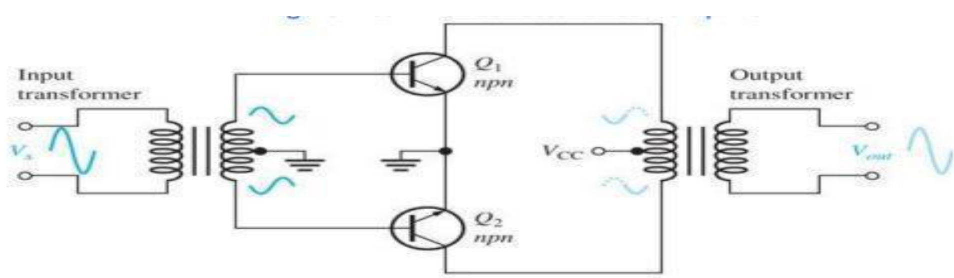

Fig.3 Transformer coupled push-pull amplifiers

COMPLEMENTARY SYMMETRY TRANSISTORS:

Fig.4 shows a push-pull class B amplifier using two emitter-followers and both positive and negative power supplies. This is a complementary amplifier because one emitter-follower uses an npn transistor and the other a pnp, which conduct on opposite alterations of the input cycle. In this circuit there is no DC base bias voltage (V_B=0) .Thus, only the signal voltage drives the transistors into conduction. Transistor Q_1conducts during the positive half of the input cycle, and Q_2 conduct during the negative half.

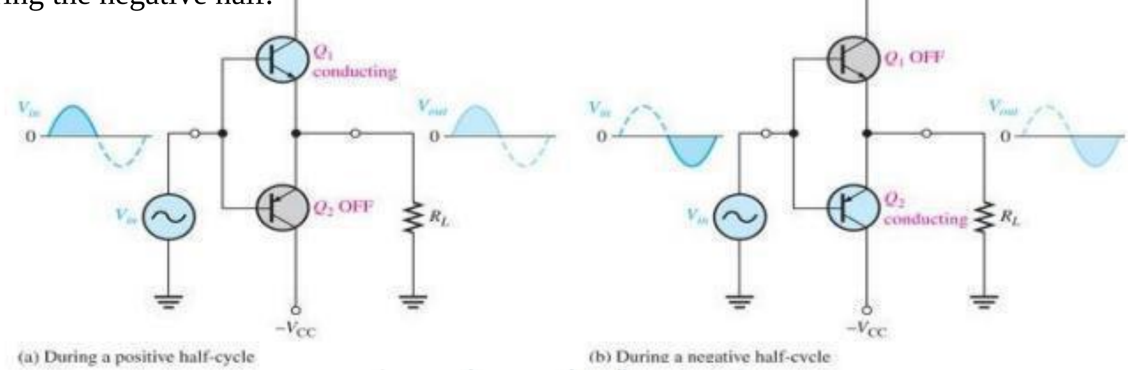

Fig.4: Class B push-pull ac operation

CROSSOVER DISTORTION:

When the DC base voltage is zero, both transistors are off and the input signal voltage must exceed V_{BE} before a transistor conducts. Because of there is a time interval between the positive and negative alternations of the input when neither transistor is conducting as shown in Fig.5. The resulting distortion in the output waveform is called crossover distortion.

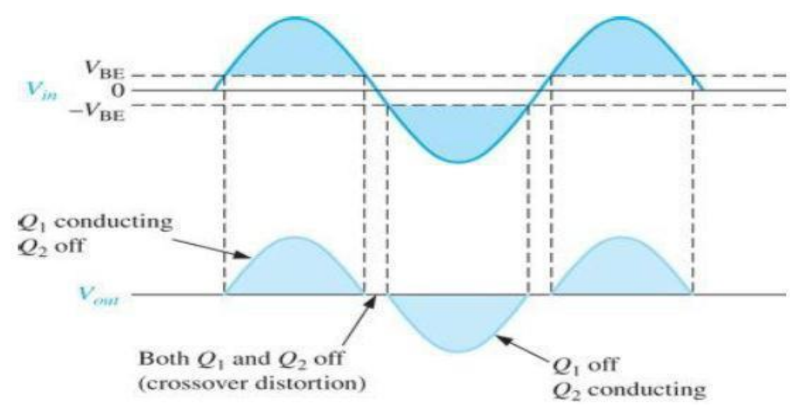

Fig.5: Crossover distortion in a class B push-pull amplifier

EFFICIENCY:

Efficiency is defined as the ratio of AC output power to DC input power .So

$$\eta = \frac{\pi \ x \ V_{outpk}}{4 \ x \ V_{cc}}$$

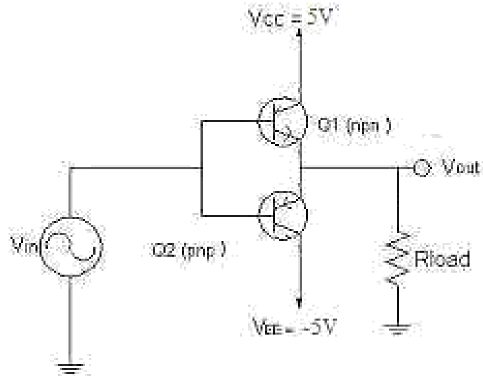

Fig. 6: Class B push-pull Power amplifier circuit to be implemented

PROCEDURE:

1. Wire the circuit shown in Fig. 6.
2. Connect channel 1 of your oscilloscope at the input and channel 2 at the output.
3. Apply power to the bread board and adjust the sine the wave output level of the generator at 6 V peak-to-peaks at a frequency of 1 kHz.
4. Now carefully increase the peak-to-peak input signal so that the output peaks just clip off. Measure the peak to peak voltage across the 1kΩ load resistor .Record the observations in table 1.
5. Finally, compute the percent efficiency (%η) of your amplifier.
6. Attach simulation results.

USEFUL FORMULA:

$$\eta = \frac{\pi \ x \ V_{outpk}}{4 \ x \ V_{cc}}$$

OBSERVATION:

Class B Amplifier Efficiency

Parameter	Measured Value
Vo(peak)	
Vcc	

CALCULATION:

RESULT:

The efficiency of class B amplifier is found to be:____________

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Laboratory Session No. ___________ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Lab No.12

OBJECTIVE:
To **DESIGN** and analyze a class AB push-pull emitter-follower amplifier.

EQUIPMENT REQUIRED:
- Proto board
- Function Generator
- Digital Multi meter
- Power Supply
- Resistors
- Capacitors 2x10μF, 220uF
- Diodes: 2x 1N914 or 1N4148
- Transistors: 1xQ2N3904, 1xQ2N3906

INTRODUCTION:
POWER AMPLIFIER:
Power Amplifiers are large signal amplifiers .This generally means that a much larger portion of the load line is used during signal operation than in a small signal amplifier.

Power amplifiers are normally used as the final stage of a communications receiver or transmitter to provide signal power to speakers or to transmitting antenna.

CLASS AB PUSH-PULL AMPLIFIERS:
When an amplifier is biased at cut-off so that it operates in the linear region for 180^o of the input cycle and is in cutoff for 180^o, it is a class B amplifier. Class AB amplifiers are biased to conduct for slightly more than 180^o .The primary advantage of a class B or class AB amplifier over a class A amplifier is that either one is more efficient than a class A amplifier; you can get more output power for a given amount of input power. A disadvantage of class B or class AB is that it is more difficult to implement the circuit in order to get a linear reproduction of the input waveform.

CLASS B OPERATION:
The class B operation is illustrated in Fig.1. Where the output is shown relative to the input in terms of time (t)

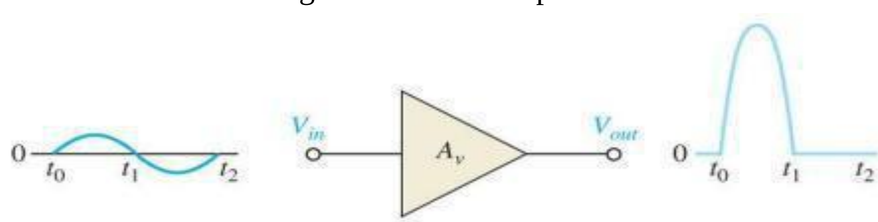

Fig. 1 Basic Class B Amplifier operation

THE Q-POINT IS AT CUTOFF:

The class B amplifier is biased at the cutoff point so that $I_{CQ}= 0$ and $V_{CEQ} = V_{CE\ (cutoff)}$. It is brought out of cutoff and operates in its linear region when the input signal drives the transistor into conduction. This is illustrated in Fig.2 with an emitter-follower circuit where, the output is not replica of the input.

CROSSOVER DISTORTION:

When the dc base voltage is zero, both transistors are off and the input signal voltage must exceed V_{BE} before a transistor conducts. Because of there is a time interval between the positive and negative alternations of the input when neither transistor is conducting as shown in Fig.2. The resulting distortion in the output waveform is called crossover distortion.

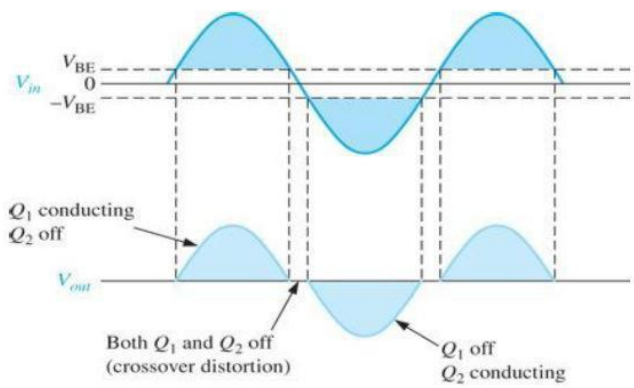

Fig.2 Crossover distortion in a class B push-pull amplifier

BIASING THE PUSH-PULL AMPLIFIER FOR CLASS AB OPERATION:

To overcome crossover distortion, the biasing is adjusted to overcome the V_{BE} of the transistors; this result in a modified form of operation called class AB. In class AB operation, the push-pull stages are biased into slight conduction, even when no input signal is present. This can be done with a voltage-divider and diode arrangement, as shown in Fig.3.When the diode characteristics of both diodes are closely matched to the characteristics of the transistor emitter-base junctions, the current in the diodes and the current in the transistors are the same; this is a current mirror. In the bias path both the resistors are also of equal value.

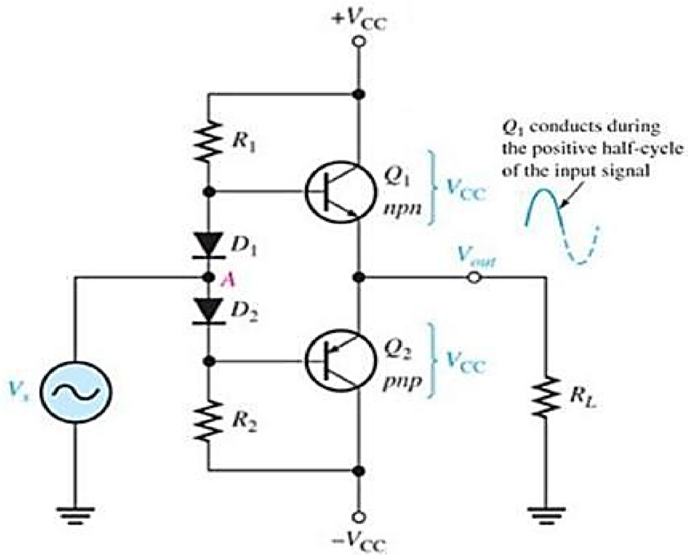

Fig.3 Biasing the push-pull amplifier to eliminate crossover distortion

The AC load line for the class AB amplifier is shown in Fig.4

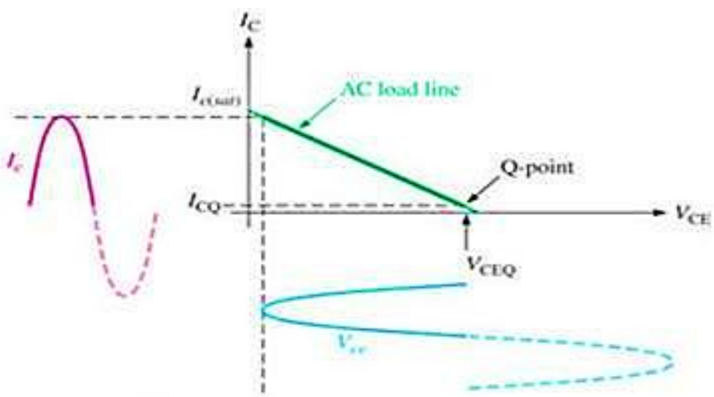

Fig.4 Load lines for a complementary symmetry push-pull amplifier. Only the load lines for the npn transistor are shown

Under maximum condition, $Q_1$and Q_2 are alternatively driven from near cutoff to near saturation that is for Q_1 from 0V to +V_{CC} and for Q2 from 0V and to –V_{CC}. The main advantage of class B/AB amplifier over the class A is that there is very little current in the transistor when there is no input signal .This results in low power dissipation when there is no signal.

SINGLE-SUPPLY PUSH-PULL AMPLIFIER:

Push-Pull amplifiers using complementary symmetry transistors can be operated from a single voltage source as shown in Fig.5.The circuit operation is the same as described previously, except the bias is set to force the output emitter voltage to be $V_{CC}/2$ instead of 0v used with two supplies. Because the output is not biased at 0V capacitive coupling for the input and output is necessary to block the bias voltage from the source and the load resistor .Ideally the output voltage can swing from zero to V_{CC}, but in practice it does not quite reach these ideal values.

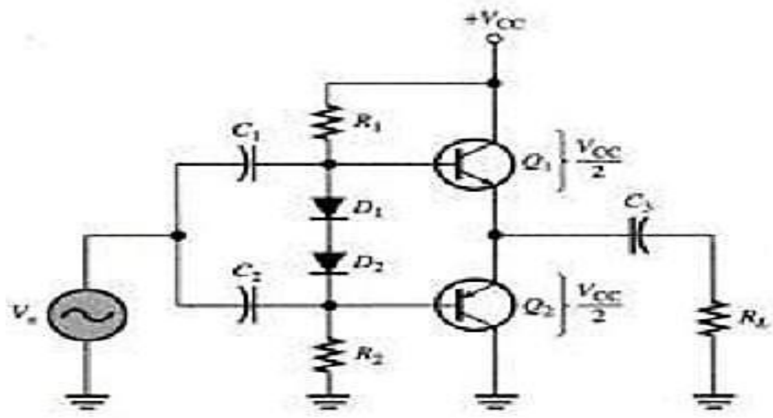

Fig.5 Single-ended push-pull amplifier

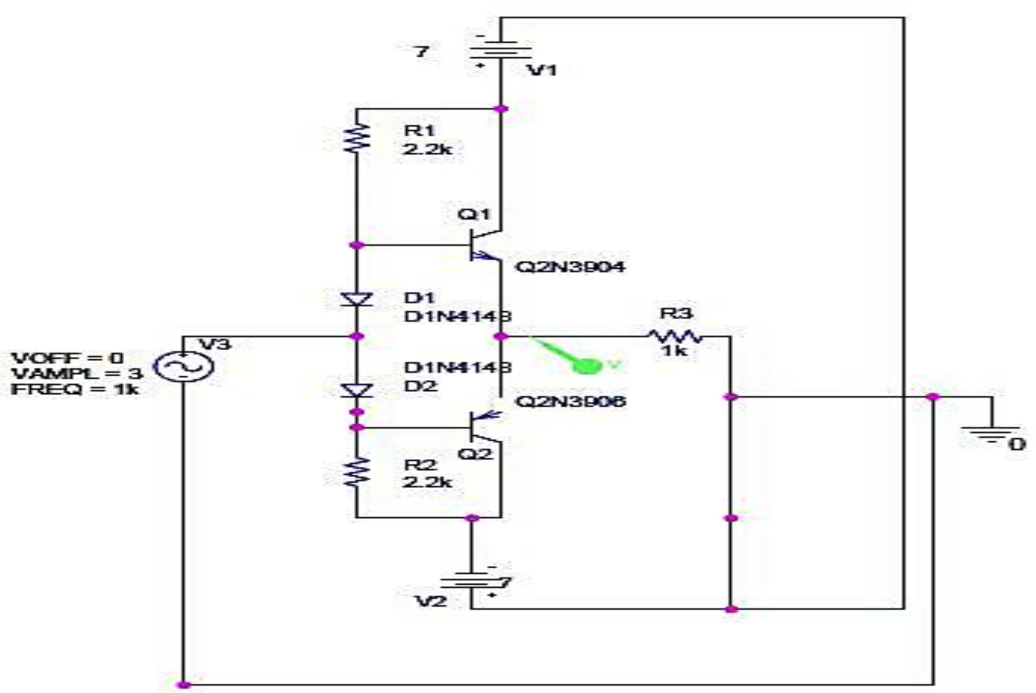

Fig. 6 Class B push-pull Power amplifier circuit

PROCEDURE

1. Wire the circuit shown in Fig. 6(a).
2. Connect channel 1 of your oscilloscope at the input and channel 2 at the output.
3. Apply power to the bread board and adjust the sine wave output level of the generator at 6 V peak-to-peaks at a frequency of 1 kHz. Observe amplifier's input and output waveform.
   Measure the base-to-emitter voltages required for both transistor to become forward biased, recording these values in table .
4. Now carefully increase the peak-to-peak input signal so that the output peaks just clip off. Measure the peak output voltage just before the output clips off.
5. Finally, compute the percent efficiency (%η) of your amplifier, and compare it with the theoretical efficiency slightly less than 78.5% of a class B amplifier. If a value greater than 78.5% is calculated, then repeat the steps trying to determine the source of your error.
6. Attach simulation results.

USEFUL FORMULA:

$$\eta = \frac{\pi \ x\, V_{outpk}}{4\ x\, V_{cc}}$$

OBSERVATION:

Table : Voltage Divider Bias with no crossover distortion

Parameter	Measured Value
V_{BE1}	
V_{BE2}	

CALCULATIONS:

RESULT:

The efficiency of class AB amplifier is found to be: ____________

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Laboratory Session No. ___________ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Lab :13 Open Ended Task

OBJECTIVE:

To **DESIGN** an Operational Amplifier based signal conditioning unit that can convert an input signal ranging from -1 to +1 to an output signal value compatible with TTL logic level i.e. 0 to 5 V.

You are expected to

1. Present the simulation work showing all states of the circuit clearly showing all outputs or voltages and current appearing at different terminals to prove the correctness of your circuit.

2. Hand calculations of all results as simulated above.

3. Operational Hardware proving above results.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____ELECTRONIC__ Engineering
Course Code and Title: ____EL-333 INTEGRATED CIRCUITS_____

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ___________ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	