



**FEDERAL UNIVERSITY OYE EKITI**

**FACULTY OF ENGINEERING**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICS  
ENGINEERING.**

**PRACTICAL MANUAL**

*for*

**EEE 311- Electrical Engineering Practical – I**

**Coordinated By: *Dr. Engr. A.M Zungeru***

## INTRODUCTION

The place of laboratory work in Electrical and Electronic Engineering is very important. Laboratory course work enables students to do experiments on the fundamental laws and principles encountered in the theoretical work. In these formative years the student is made to identify a wide range of electrical components, measure their values thereby learning to handle instruments and equipments and to appreciate their limitations. Students are also made to learn how to bread board, connect simple circuits and verify the simple laws of Ohms' Kirchhoff 's Current and Voltage Laws, Thevenin's, Norton's, and others who have contributed immensely on the formulation of laws and theories. Other aspect of Electrical and Electronic practical were all dealt with.

It may also be observed that the background information to every experiment is the 'theory' aspect and it is quit lengthy in many cases. It is aimed at ensuring that the students are sufficiently familiar with the theoretical aspect of the experiment and consequently sharpen their focus on the results expected.

The laboratory exercises in this manual are designed to provide a working knowledge of some of the more fundamental principles of Electrical, Electronic and Computer Engineering. All the experiments on this handbook were simulated to get the response of each circuit, and were all found working properly as expected. While working through the manual the student will become more familiarize with the manual and the basic theories in Electrical and Electronic Engineering.

In order to fully understand the principle being investigated, the student is advised to read extensively in the related topics before entering the laboratory. At the end of each laboratory, questions and exercises should be completed and returned to the Examiner for proper grading as scheduled.

## **GENERAL LABORATORY SAFETY**

Safety is an important factor in any laboratory work. It should be understood that any use of electricity inherently involves some degree of safety hazard. The best way to achieve safety in the use of electrical equipment is to adhere to all the safety rules which include;

1. Understanding equipment you are proposing to use and its rating,
2. Understanding the application to which the equipment is to be use for,
3. Ensuring that all reasonable safety measures are followed,
4. Taking no chance, nor short cut, in safety procedures.

## **GENERAL ENGINEERING LABORATORY RECORDS AND REPORTS**

The formats for the experimental records and reports of the experiments to be conducted are expected to be outlined as.

1. Experiment number, Title and Date: These should be stated clearly at the beginning of the report;
2. Objective of Experiment: The aim for which the experiment is taken;
3. Theory: This include the laws related to the experiment;
4. Apparatus: Description of apparatus, where applicable, the serial number of the apparatus and any special features of the apparatus must be stated;
5. Procedure (method): These should include the description of the connections made, the nature and range of inputs, how readings are taken, any adjustment made, etc.;
6. Circuit Diagram: The circuit diagram must be clearly labeled;
7. Results: Readings obtained should be clearly tabulated, calculations should be clearly outlined, graphs where necessary must be drawn neatly.
8. Observation: Difficulties encountered, precaution taken etc should be clearly stated;
9. Conclusion: Comment on the result obtained, whether the result confirms the theory. If theory is not confirmed, give possible reasons

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**INSTITUTION:**-----

**DEPARTMENT:**-----

**STUDENTS'S NAME:** -----**REG/MAT NO:** -----

**GROUP NO:** -----**DATE:** -----

**INSTRUCTOR'S NAME:** -----**SIGNATURE:** -----

## EXPERIMENT ONE: THE BIPOLAR TRANSISTOR CHARACTERISTICS

### 1.0 OBJECTIVES:

- (1) The bipolar transistor.
- (2) The bipolar transistor characteristics.
- (3) Operating line and operating point.

### 1.1 EQUIPMENT REQUIRED

TPS-3321  
Power supply  
A multimeter  
Banana wires  
Transistor 1N2222  
Resistors:  $100\Omega$ ,  $1k\Omega$ ,  $10k\Omega$ ,  $91k\Omega$

### 1.2 PROCEDURE

**Step 1:** Connect TPS-3321 trainer to the power supply and connect the power supply to the Mains.

**Step 2:** Implement the following circuit on the main plug in board.

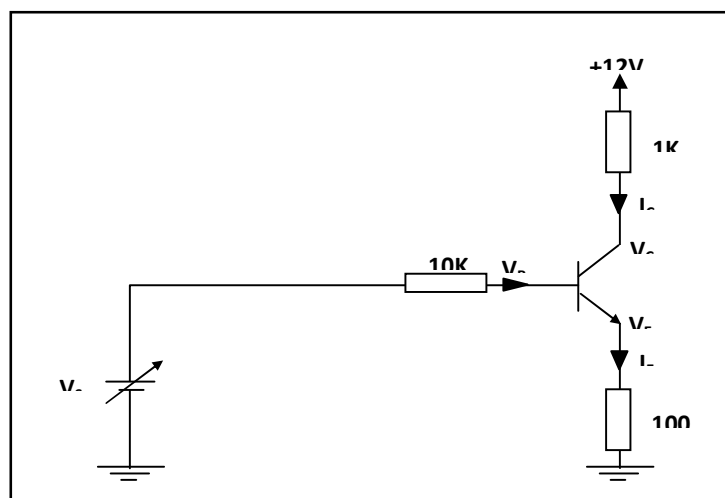


Fig 1.0

**Step 3:** Turn ON the power supply.

**Step 4:** Change  $V_{BB}$  according to the following table and register the measured values of  $V_B$ ,  $V_C$  and  $V_{CE}$ .

**Table 1.0**

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
$V_S$ [V]	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6
$V_B$ [V]													
$V_C$ [V]													
$V_E$ [V]													
$V_{BE}$ [V]													
$V_{CE}$ [V]													
$I_E$ [mA]													
$I_C$ [mA]													
$I_B$ [mA]													
$h_{FE}$													

**Step 5:** Calculate  $V_{CE}$  for every column according to the following formula:

$$V_{CE} = V_C - V_E \quad (1.1)$$

**Step 6:** Calculate  $V_{BE}$  for every column according to the following formula:



$$V_{BE} = V_B - V_E \quad (1.2)$$

**Step 7:** Calculate  $I_E$  for every column according to the following formula:

$$I_E = \frac{V_E}{R_E} \quad (1.2)$$

**Step 8:** Calculate  $I_C$  for every value of  $V_C$  according to the following formula:

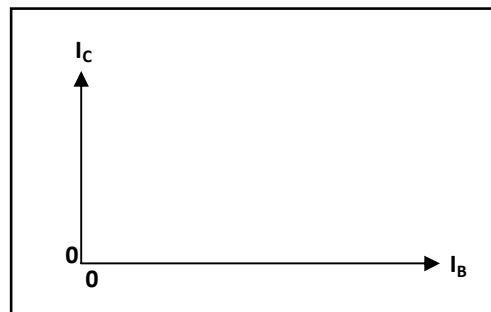
$$I_C = (V_{CC} - V_C) / R_C \quad (1.3)$$

**Step 9:** Calculate  $I_B$  for every column according to the following formula:

$$I_B = \frac{V_B}{R_B} \quad (1.4)$$

**Step 10:** Calculate  $h_{FE} = I_C / I_B$  for each column in the table.

**Step 11:** Plot your results on the following graph.

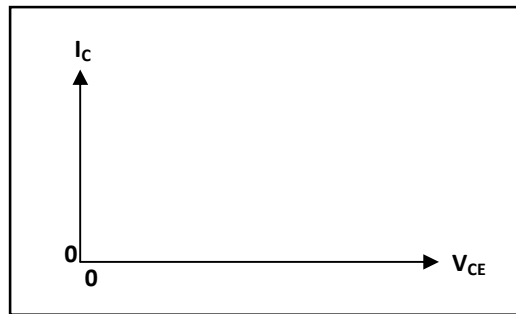


**Fig 1.1**

**Step 12:** Mark the three region on the graph:

- The cutoff region.
- The linear region.
- The saturation region.

**Step 13:** Plot your results on the following graph.

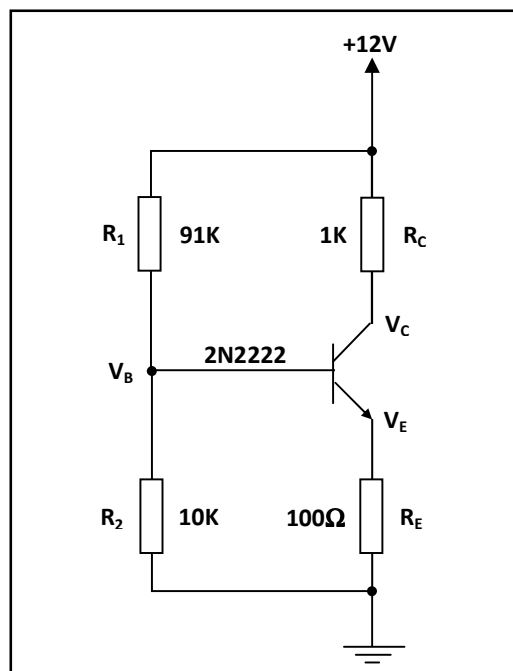


**Fig 1.2**

**Step 14:** Mark the three regions on the graph:

- The cutoff region.
- The linear region.
- The saturation region.

**Step 15:** Implement the following circuit on the main plug in board.



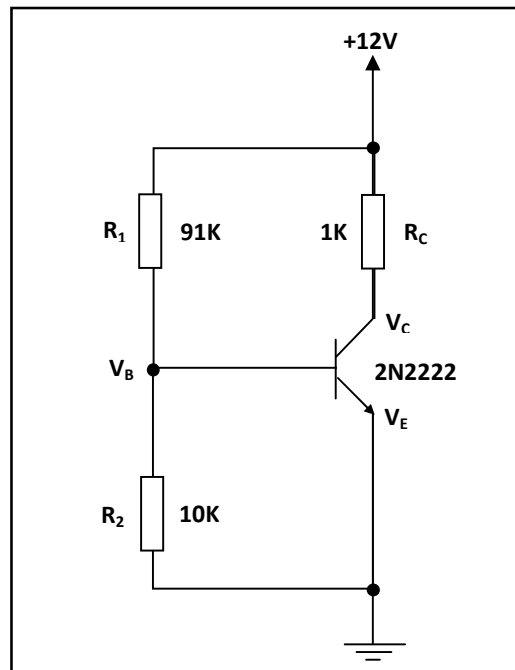
**Fig 1.3**

**Step 16:** Measure  $V_B$ ,  $V_C$  and  $V_{CE}$ .

**Step 17:** Calculate  $I_C = (V_{CC} - V_C) / R_C$  (1.5)

**Step 18:** Mark the operating point on the graph that you plotted in step 13.

**Step 19:** Implement the following circuit on the main plug in board.



**Fig 1.4**

**Step 20:** Measure  $V_B$ ,  $V_C$  and  $V_{CE}$ .

**Step 21:** Calculate  $I_C = (V_{CC} - V_C) / R_C$ .

**Step 22:** Mark the operating point on the graph that you plotted in step 13.

## **EXPERIMENT REPORT:**

- 1) Write the name of each experiment and draw below the electronic circuit.

For each circuit include the experiment measurements, results and graphs.

- 2) Compare between the preliminary questions and the examples with the measurement results.

## **EXPERIMENT TWO: THE BIPOLAR TRANSISTOR AMPLIFIER**

### **1.0 OBJECTIVES**

1. Amplifier gain measurement.
2. Input impedance measurement.
3. Output impedance measurement.
4. Phase shift measurement.

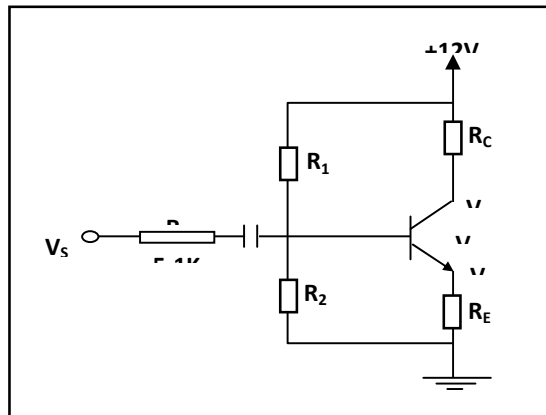
### **1.1 EQUIPMENT REQUIRED**

- TPS-3321
- Power supply
- A Multimeter
- An oscilloscope
- Banana wires
- A transistor 2N2222
- Resistors: 100 $\Omega$ , 1k $\Omega$ , 5.1k $\Omega$ , 10k $\Omega$ , 91k $\Omega$
- Capacitor: 10 $\mu$ F

### **1.2 PROCEDURE**

**Step 1:** Connect TPS-3321 trainer to the power supply and connect the power supply to the Mains.

**Step 2:** Implement the following circuit on the main plug in board.



**Fig 2.0**

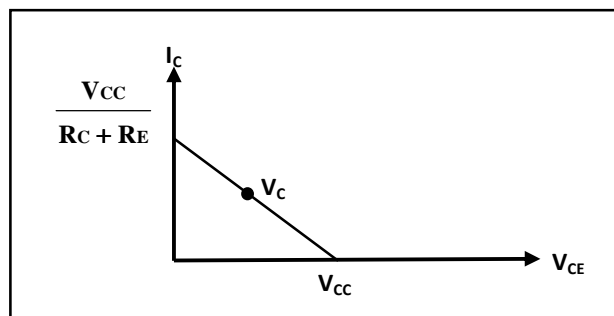
**Step 3:** Turn ON the power supply.

**Step 4:** Measure  $V_B$ ,  $V_C$ ,  $V_{CE}$  and  $V_E$ .

**Step 5:** Calculate  $I_C$ :

$$I_C = \frac{(V_{CC} - V_C)}{R_C} = \frac{(12 - V_C)}{1000} \quad (2.1)$$

**Step 6:** Plot the operating line and the operating point on the graph.



**Fig 2.1**

**Step 7:** Connect the function generator output probe to the  $V_S$  point.

**Step 8:** Connect the scope probe CH1 to the function generator output. To calculate the amplifier's parameters, it does not matter if we use  $V_{peak}$  or  $V_{p-p}$  or an effective voltage as long as we are consistent.

*Note:* To annotate AC parameters we use small letters.

We use the  $1\text{k}\Omega$  resistor as the  $R_S$  resistance.

Use the following h parameter values for your calculations:

$$H_{fe} = 100, \quad h_{ie} = 2\text{K}\Omega, \quad \frac{1}{h_{oe}} = 40\text{K}\Omega$$

### **CE Amplifier:**

- Step 9:** Connect a by-pass capacitor of  $10\ \mu\text{F}$  parallel to  $R_E$  thus short circuiting the AC voltages  $R_E$ . We do not short circuit  $R_E$  in order not to change its DC operating point.
- Step 10:** Adjust the function generator to generate a  $1\ \text{V}_{\text{p-p}}$  1KHz sine wave.
- Step 11:** Connect the CH<sub>2</sub> probe to the  $V_C$  point.
- Step 12:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$ ,  $R_o$  according to  $h$  parameter model.
- Step 13:** Measure the voltages  $V_C$  ( $V_o$ ),  $V_{RS}$  and  $V_i$ .
- Step 14:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$  according to your measurements.
- Step 15:** Check the phase shift between the output and the input.
- Step 16:** Compare the amplifier calculation characteristics and the measurement characteristics.

### **CE Amplifier with $R_E$ :**

- Step 17:** Disconnect the by-pass capacitor of  $R_E$ .
- Step 18:** Adjust the function generator to generate a  $1\ \text{V}_{\text{p-p}}$  1KHz sine wave.
- Step 19:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$  according to h parameter model.
- Step 20:** Measure the voltages  $V_C$  ( $V_o$ ),  $V_{RS}$  and  $V_i$ .
- Step 21:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$  according to your measurements.

**Step 22:** Check the phase shift between the output and the input.

**Step 23:** Compare the amplifier calculation characteristics and the measurement characteristics.

**Emitter Follower Amplifier:**

**Step 24:** Connect the CH2 probe to point  $V_E$ .

**Step 25:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$  according to h parameter model.

**Step 26:** Measure the voltages  $V_E$  ( $V_o$ ),  $V_{RS}$  and  $V_i$ .

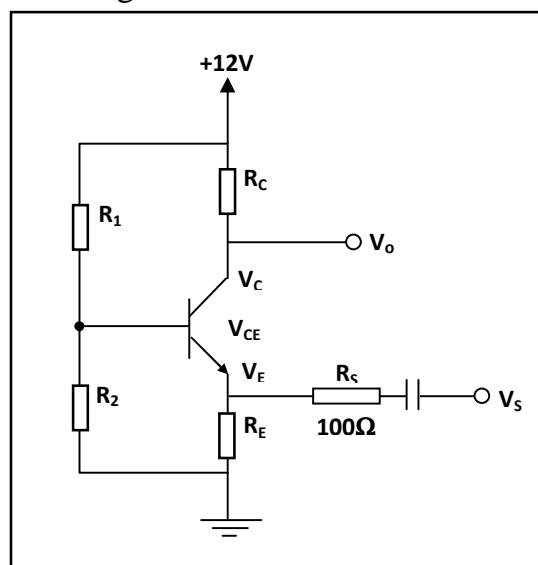
**Step 27:** Calculate and record the  $A_V$ ,  $A_I$ ,  $R_i$  according to your measurements.

**Step 28:** Check the phase shift between the output and the input.

**Step 29:** Compare the amplifier calculation characteristics and the measurement characteristics.

**CB Amplifier:**

**Step 30:** Implement the following circuit.



**Fig 2.2**



**Step 31:** Adjust the function generator to generate a 1 V<sub>p-p</sub> 1KHz sine wave.

**Step 32:** Connect the CH<sub>2</sub> probe to point V<sub>C</sub>.

**Step 33:** Calculate and record the A<sub>V</sub>, A<sub>I</sub>, R<sub>i</sub> according to h parameter model.

**Step 34:** Measure the voltages V<sub>C</sub> (V<sub>o</sub>), V<sub>RS</sub> and V<sub>i</sub>.

**Step 35:** Calculate and record the A<sub>V</sub>, A<sub>I</sub>, R<sub>i</sub> according to your measurements.

**Step 36:** Check the phase shift between the output and the input.

**Step 37:** Compare the amplifier calculation characteristics and the measurement characteristics.

### **EXPERIMENT REPORT:**

1) Write the name of each experiment and draw below the electronic circuit.

For each circuit include the experiment measurements, results and graphs.

2) Compare between the preliminary questions and the examples with the measurement results.

## **EXPERIMENT THREE: INVERTING AND NON INVERTING OP-AMP CIRCUITS**

### **3.0 OBJECTIVE**

To demonstrate the operation of both inverting and non-inverting amplifier circuits, using a 741 operational amplifier. Both circuits operate in the closed-loop mode.

### **3.1 MATERIALS**

Resistors (1/2 W): 1k; 4.7k; (2) 10k; 22k; 47k; 100k

741 op-amp (8-pin mini-DIP)

Two 0-15 v dc power supplies

Signal generator

Dual trace oscilloscope

Breadboard.

### **3.2 PREPARATION**

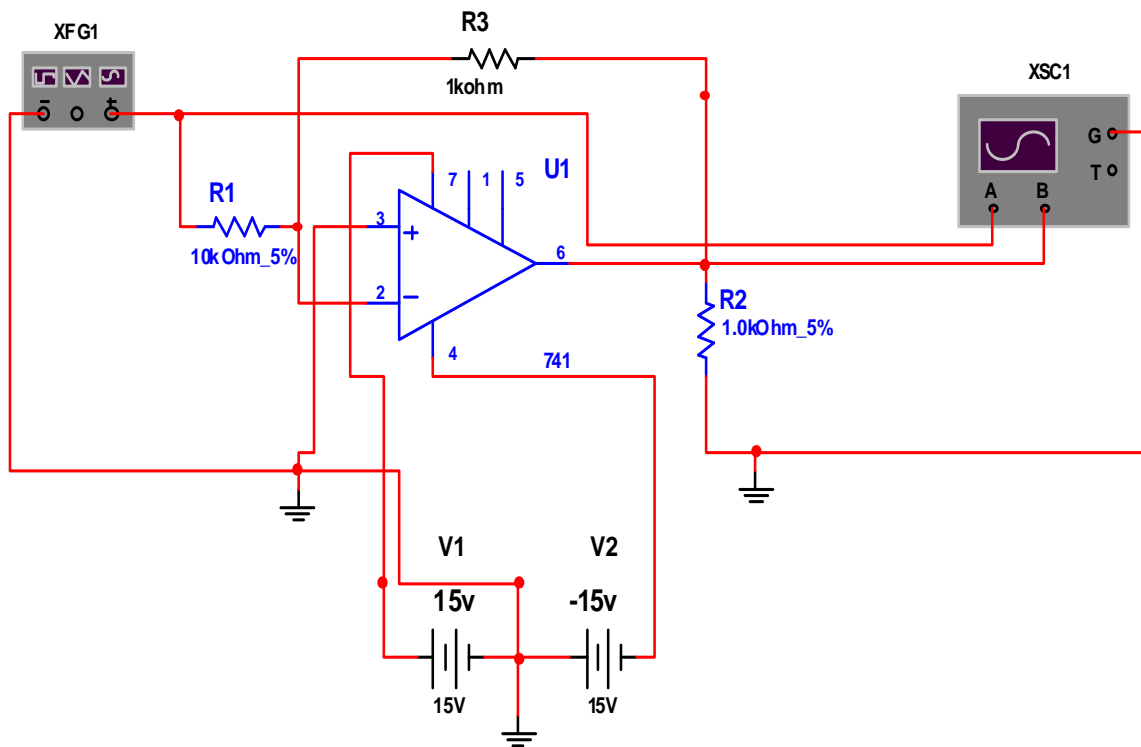
The inverting amplifier's closed-loop (voltage) gain can be less than, equal to, or greater than 1. As its name implies, its output signal is always inverted with respect to its input signal. On the other hand, the non-inverting closed-loop (voltage) gain is always greater than 1; while the input and output signal are always in-phase.

Inverting amplifier closed-loop voltage gain

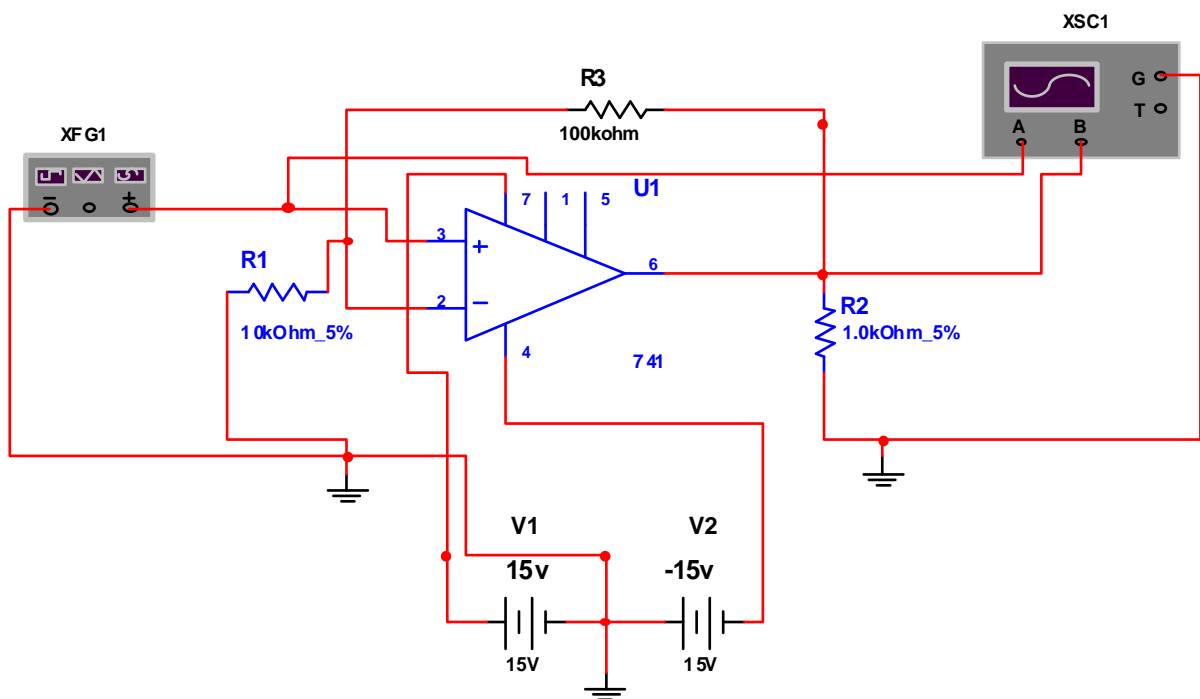
$$\mathbf{A_v = \frac{-R_f}{R_i}} \quad (3.1)$$

Non-inverting amplifier closed-loop voltage gain

$$\mathbf{A_v = 1 + R_f/R_i} \quad (3.2)$$



**Fig. 3.0: Inverting Amplifier Circuit**



**Fig. 3.1: Non inverting Amplifier Circuit**

### 3.3 PROCEDURE

- STEP 1:** Wire the inverting amplifier circuit shown in the schematic diagram of fig 3.0, and set your oscilloscope for the following settings: Channels 1 and 2: 5 v/ division, ac coupling Time base: 1 ms/division
- STEP 2:** Apply power to the breadboard, and adjust the input voltage to 1v peak-to-peak and the frequency at 500 Hz. Position the input voltage above the output voltage on the oscilloscope display. What is the difference between the two signals? Notice that the output signal is of opposite form, or is inverted, compare to the input signal. The output voltage is then said to be inverted from, or  $180^\circ$  out-of-phase with, the input, since the positive peak of the output signal occurs when the inputs peak is negative.
- STEP 3:** Measure the peak-to-peak output voltage. Then determine the voltage gain and compare it to the expected value, recording your results in table 3.0 The peak-to-peak output voltage should be the same as the input (1v), so that the voltage gain is -1. The minus sign indicates that the output is inverted with respect to the input.
- STEP 4:** Keeping the input signal at 1v peak-to-peak, change resistor  $R_f$  according to table 3.0, recording your results as in step 3. Each time, disconnect the power supplies and signal generator before you change the resistor. Do your results agree with those obtained from the equation for the inverting amplifier voltage gain? As the results of table 3.0 indicate, the voltage gain of an inverting amplifier can be made to be less than 1, equal to 1, or greater than 1.
- STEP 5:** Wire the non-inverting amplifier circuit shown in the schematic diagram of fig 3.1. Apply power to the breadboard and adjust the input voltage to 1v peak-to-peak and the frequency at 500Hz. Again position the

input voltage above the output voltage on the oscilloscope's display. What is the difference between the two signals? The only difference is that the output signal is larger than the input signal. Both signals are said to be in-phase, since the output signal goes positive exactly when the input does.

**STEP 6:** Measure the peak-to-peak output voltage. Then determine the voltage gain and compare it to the expected value, recording your results in table 3.1. The peak-to-peak output voltage should be approximately 2V, so that the voltage gain is 2.

**STEP 7:** Keeping the input signal at 1v peak-to-peak, change resistor  $R_f$  according to table 3.1, recording your results as in step 6. Each time, disconnect the power supplies and signal generator before you change the resistor. Do your results agree with those obtained from the equation for the non-inverting amplifier voltage gain? As the results of table 3.1 indicate, the voltage gain of a non-inverting amplifier can never be less than 1 or equal to 1. It will always be greater than 1.

**TABLE 3.0 INVERTING AMPLIFIER**

$R_f$	Measured $V_o$	Measured Gain	Expected Gain	% Error
10k				
22k				
47k				
100k				
4.7k				
1k				

**TABLE 3.1 NON-INVERTING AMPLIFIERS**

Rf	Measured Vo	Measured Gain	Expected Gain	% Error
10k				
22k				
47k				
100k				
4.7k				
1k				

## EXPERIMENT FOUR: OP-AMP COMPARATORS

### 4.0 OBJECTIVE

To demonstrate the operation of non-inverting and inverting comparator circuits using a 741 operational amplifier. A comparator determines whether an input voltage is greater than a predetermined reference level. Since a comparator operates in an open-loop mode, the output voltage approaches either its positive or its negative supply voltage.

### 4.1 MATERIALS

Resistors (1/2 W): (2) 1k; 4.7k; (2) 10k; 47k; 100k; 100k potentiometer

741 op-amp (8-pin mini-DIP)

1N914 (or 1N4148) diode

LED

2N3904 NPN transistor

Two 0-15v dc power supplies

Signal generator

Dual trace oscilloscope

Breadboarding socket

### 4.2 PREPARATION

Non-inverting comparator output

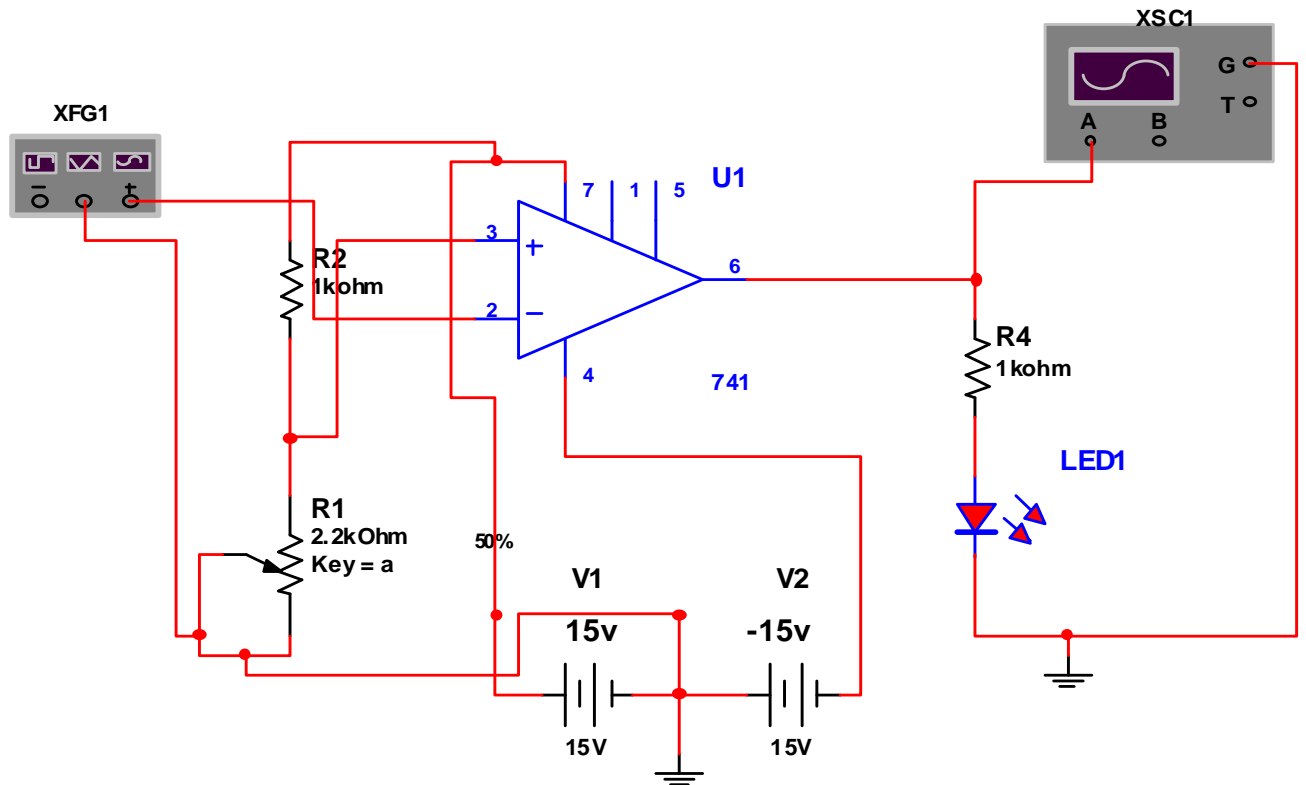
$$V_o = + V_{sat} \quad \text{when } V_i > V_{REF}$$

$$V_o = - V_{sat} \quad \text{when } V_i < V_{REF}$$

Inverting comparator output

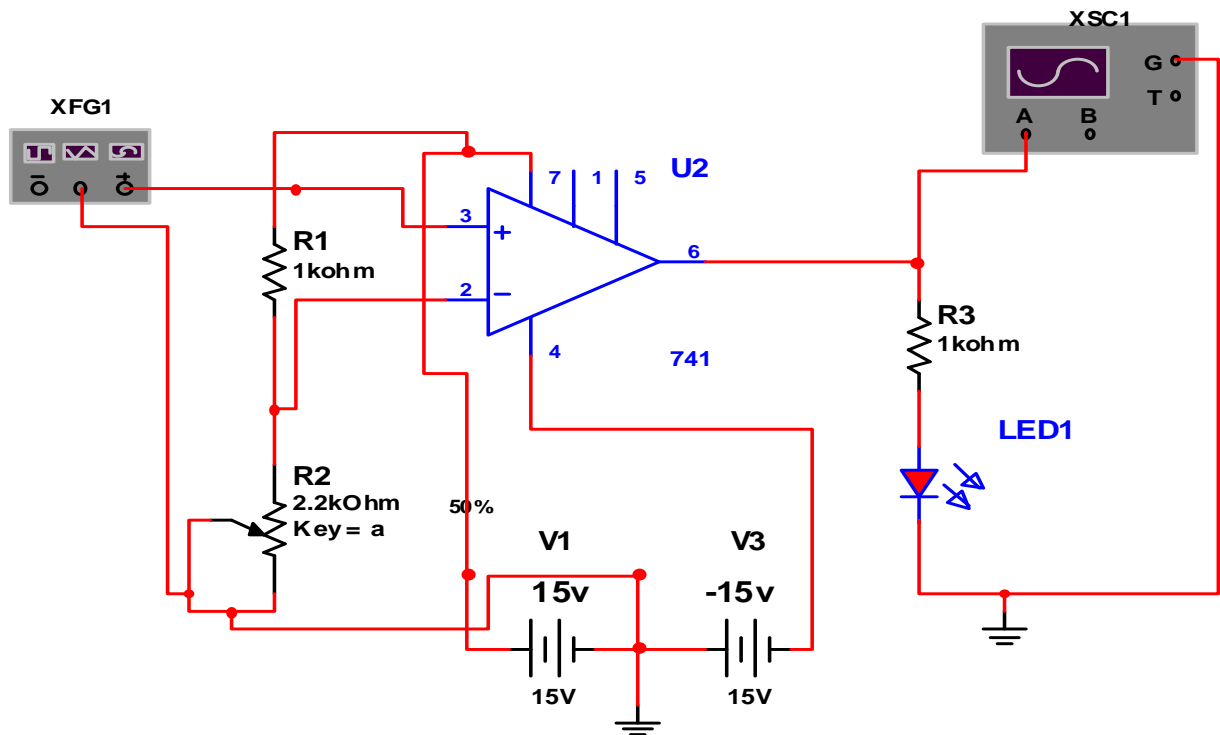
$$V_O = +V_{\text{sat}} \quad \text{when } V_i < V_{\text{REF}}$$

$$V_O = -V_{\text{sat}} \quad \text{when } V_i > V_{\text{REF}}$$



**Fig. 4.1: Inverting Operational Amplifier Comparator Circuit**





**Fig 4.2 Non Inverting Amplifier Comparator Circuit**

### 4.3 PROCEDURE

**STEP 1:** Wire the circuit shown in the schematic diagram of fig 4.1, and set your oscilloscope for the following settings:

Channel 1: 1v / division. Dc coupling

Channel 2: 10v / division, Dc coupling

Time base: 1ms/ division

**STEP 2:** Apply power to the breadboard, and adjust the input voltage at 3v peak-to-peak and the frequency at 300 Hz. What the polarity of the output voltage when the input signal goes positive? When the input goes negative? When the input signal  $V_i$  is applied to the op-amp's non-inverting input, the output signal polarity will be the same as that of the input, so that this circuit is a non-inverting comparator. In this case, the reference voltage  $V_{REF}$  is zero (the inverting input is

grounded). Because of high open loop gain of the op-amp, the output immediately goes positive when  $V_i$  is greater than zero volt ( $V_{REF}$ ), and vice versa. This circuit is also referred to as a non-inverting zero-level detector since it detects the polarity of the input signal. The maximum output (saturation) voltage  $V_{SAT}$ , for the 741 op-amp is typically 12V to 14V when using a 15V supply.

**STEP 3:** Disconnect the power and signal leads to the breadboard, and reverse the input connections to the op-amp so that the input signal is now connected to the inverting input while the non-inverting input is grounded, as shown in fig 4.1.

**STEP 4:** Again apply both the power and signal leads to the breadboard. Now what is the difference between the operation of this circuit and that of the circuit used earlier? Notice that the output of this comparator circuit has a polarity that is inverted with respect to the input signal. Such a circuit is called inverting comparator. Furthermore, since the reference voltage (the voltage at the non-inverting input) is zero, this circuit is also referred to as inverting zero-level detector. When the polarity of the input signal is positive, the output voltage equals  $-V_{SAT}$ , and vice versa. As can be seen, both circuits are useful in converting sine waves into square waves.

**STEP 5:** Disconnect the power and signal leads from the breadboard, and wire the circuit shown in fig 4.1. Make sure that you have the 1N914 and LED diodes, as well as the NPN transistors, wire correctly.

**STEP 6:** Apply power to the breadboard. Depending on the setting of the potentiometer, the LED may or may not be ON when you connect the power. If the LED is on, turn the potentiometer past the point at which the LED is off.

**STEP 7:** With your oscilloscope, measure the voltage at the op-amp's inverting terminal (pin 2), which is the reference voltage  $V_{REF}$  for the comparator, and record the value in table 4.0

**STEP 8:** Now connect the oscilloscope to the op-amp's non-inverting input (pin 3). While watching the LED, vary the potentiometer just until the LED lights up. Measure this voltage at pin 3,  $V_i$  (on), and record your result in table 4.0. How does this value compare with the one you determined in step 7? These two values should be nearly the same. When the input voltage  $V_i$  at the non-inverting input exceeds the comparator's reference voltage at the inverting input, the op-amp comparator's output switches from its negative saturation voltage to its positive saturation voltage. This circuit is a non-inverting comparator whose nonzero reference voltage is set by the  $10k\Omega$  and  $1k\Omega$  resistors connected as a simple voltage divider. The transistor-LED circuit connected to the output of the comparator allows you to determine visually whether the input voltage is greater or less than the reference voltage. If the input voltage exceeds the reference, the LED is lit.

**STEP 9:** Disconnect the power to the breadboard. Verify the operation of this non-inverting comparator by varying voltage-divider resistor  $R_1$  and repeating step 6, 7 and 8, according to table 4.1

**TABLE 4.0 INVERTING COMPARATOR**

R1	Measured $V_{REF}$	Measured $V_i$ (on)
1k		
10k		
47k		

**TABLE 4.1: NON-INVERTING COMPARATOR**

R1	Measured $V_{REF}$	Measured $V_i$ (on)
1k		
10k		
47k		

## **EXPERIMENT FIVE: FIELD –EFFECT TRANSISTORS (FETS)**

### **5.0 OBJECTIVES**

To examine the characteristics of a field-effect Transistor.

### **5.1 MATERIALS**

1 FET Transistor 2N3819 or equivalent

One PSU 20V variable D.C. metered output

One 8.2k $\Omega$  resistor

One PSU 0—5V D.C. metered output

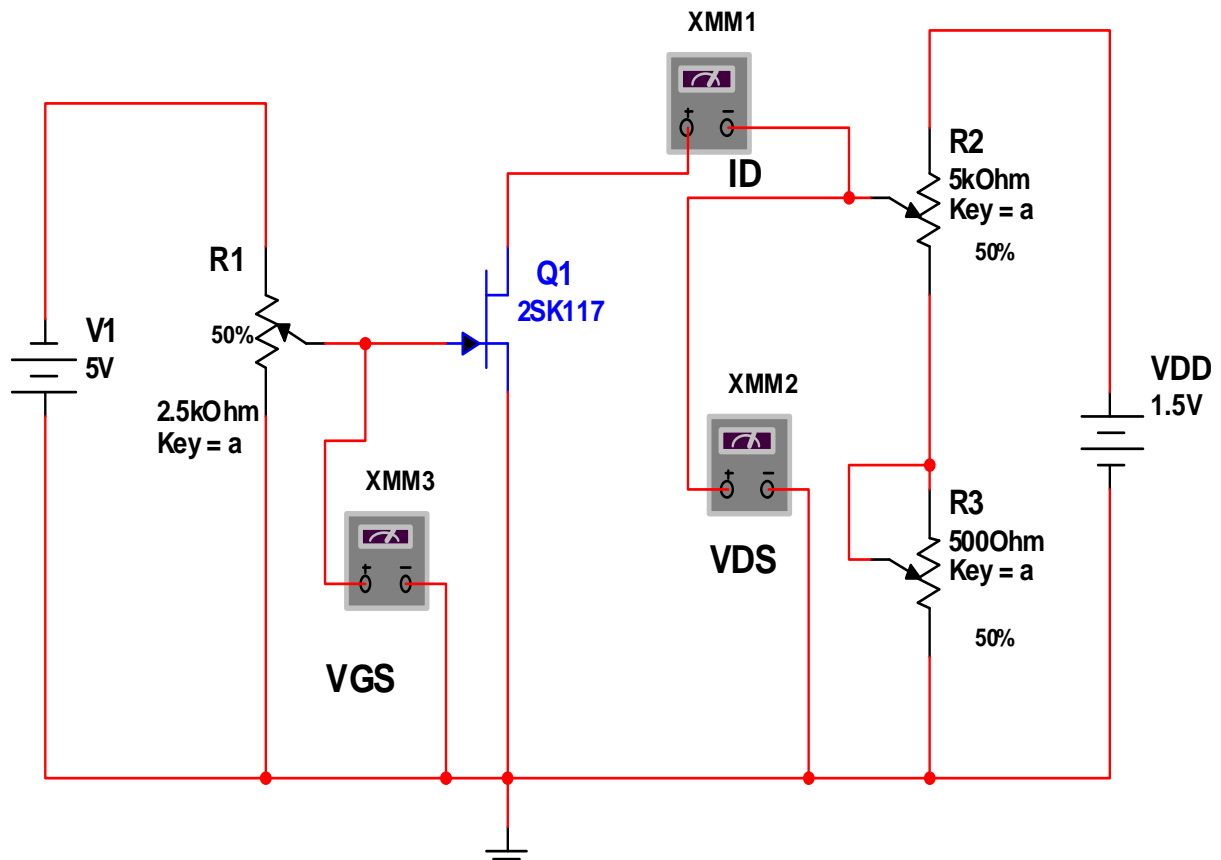
One voltmeter 0-5V D.C.

One voltmeter 0-20V D.C.

One milliammeter 0-10mA D.C.

### **5.2 PREPARATION**

The field effect transistor (FET) is a three – terminal semiconductor device having characteristics similar to that of a pentode vacuum tube. Unlike the bipolar Transistor, the FET is a **voltage operated device** (i.e. instead of being biased by current, the FET is biased by a voltage. There are two kinds of field –effect devices: The Junction FET (JFET) and the metal –oxide semi-conductor FET (MOSFET). The FET has an extremely high input resistance and has no offset voltage when used as a switch (or chopp)



**Fig. 5.0: JFET Characteristics Circuit**

### 5.3 PROCEDURE:

Connect the circuit in fig 5.0 Ensure the power supply units (psu) control is set to minimum. With the values of  $V_{GS} = 0$ , switch on the power and note  $V_{DS}$  and  $I_D$ ; Increase  $V_{GS}$  in steps of -1V until -4V is reached noting  $I_D$  for  $V_{DS} = 1, 2, 3, 4, 8V$  and 12V for each increment of  $V_{GS}$ . Tabulate your values.

Now set  $V_{DS}$  to +1V and repeat the full set of readings as above. Finally take more readings for  $V_{DS} = + 2V, 3V, 5V, 10V$  and 12V.

### Using The Table Of Values Obtained Above

**STEP 1:** Plot a graph of  $I_D$  against  $V_{GS}$  (called Transistor characteristics).

**STEP 2:** Plot  $I_D$  against  $V_{DS}$  (called drain characteristics).

**STEP 5:** Locate the knee on the forward drain characteristics  $V_{DS}$  max and plot  $\log I_D$  Versus  $\log 10V_{DS}$  max and comment on the slope. Comment on the shape of your graphs.

## EXPERIMENT SIX: ACTIVE LOW- PASS AND HIGH – PASS FILTERS

### 6.0 OBJECTIVES

1. Plot the gain-frequency response and determine the cut-off frequency of a second-order (two-pole) low-pass active filter.
2. Plot the gain-frequency response and determine the cut-off frequency of a second-order (two-pole) high pass active filter.
3. Determine the roll-off in dB per decade for a second-order (two-pole) filter.
4. Plot the phase-frequency response of a second (two-pole) filter.

### 6.1 MATERIALS

One function generator

One dual-trace oscilloscope

One LM741 op-amp

Capacitors: two .001  $\mu\text{F}$ , one pF

Resistors: one 1 k $\Omega$ , one 5.86k $\Omega$ , two 10 k $\Omega$ , two 30 K $\Omega$

### 6.2 PREPARATION

In electronic communication system, it is often necessary to separate a specific range of frequencies from the total frequency spectrum. This is normally accomplished with filters. A **filter** is a circuit that passes a specific range of frequencies while rejecting other frequencies. **Active filters** use active devices



such as op-amps combined with passive elements. Active filters have several advantages over passive filters. The passive elements provide frequency selectivity and active device provide voltage gain, high input impedance, and low output impedance. The voltage gain reduces attenuation of the signal by the filter, the high input impedance prevents excessive loading of the source, and the low output impedance prevents the filter from being affected by the load. Active filters are also easy to adjust over a wide frequency range without altering the required response. The weakness of the active filters is the upper-frequency limit due to the limited open-loop bandwidth ( $f_{\text{unity}}$ ) of op-amps. The filter cut-off frequency cannot exceed the unity-gain frequency ( $f_{\text{unity}}$ ) of the op-amp. Ideally, a high-pass filter should pass all frequencies above the cut-off frequency ( $f_c$ ). Because op-amps have a limited open-loop bandwidth (unity-gain frequency,  $f_{\text{unity}}$ ), high-pass active filter have an upper-frequency limit on the high-pass response, making it appear as a band-pass filter with a very wide bandwidth. Therefore, active filters must be used in applications where the unity-gain frequency ( $f_{\text{unity}}$ ) of the op-amp is high enough so that it does not fall within the frequency range of the application. For this reason, active filters are mostly used in low-frequency applications.

The four basic types of filters are low-pass, high-pass, band-pass and band-stop.

**A low-pass filter** is designed to pass all frequencies below the cut-off frequency and reject all frequencies above the cut-off frequency. **A high-pass filter** is designed to pass all frequencies above the cut-off frequency and rejects all the frequencies below the cut-off frequency. **A band-pass filter** passes frequencies within a band of frequencies and rejects all other frequencies outside the band. **A band-stop filter** rejects all frequencies within a band of frequencies and passes all other frequencies outside the band. A band-stop filter is often referred to as **notch filter**. In this experiment, you will study **active low-pass** and **high-pass** filter.

The most common way to describe the frequency response characteristics of a filter is to plot the filter voltage gain ( $V_0/V_m$ ) in dB as a function of frequency ( $f$ ). The frequency at which the output power gain drops to 50% of the maximum value is called the **cut-off frequency ( $f_c$ )**. When the output power gain drops to 50%, the voltage gain drops 3 dB (0.707 of the maximum value). When the filter dB voltage gain is plotted as a function of frequency using straight lines to approximate the actual frequency response, it is called a **Bode plot**. A Bode plot is an ideal plot of filter frequency response because it assumes that the voltage gain remains constant in the passband until the cut-off frequency is reached, and then drops in a straight line. The filter network gain in dB is calculated from the actual voltage gain ( $A$ ) using the equation

$$A_{dB} = 20 \log A \quad (6.1)$$

$$\text{Where } A = V_0/V_{in} \quad (6.2)$$

An ideal filter has an instantaneous roll-off at the cut-off frequency ( $f_c$ ), with full signal level on one side of the cut-off frequency and no signal level on the other side of the cut-off frequency. Although the ideal is not achievable, actual filters roll off at 20- dB/decade or higher, depending on the type of filter. The -20-dB/decade roll-off is obtained with **one-pole filter** (one R-C circuit). A **two-pole filter** has two R-C circuits tuned to the same cut-off frequency and rolls off at -40 dB/decade. Each additional pole (R-C circuit) will cause the filter to roll off an additional -20dB/decade. In a **one-pole filter**, the phase between the input and the output will change by 90 degrees over the frequency range and 45 degrees at the cut-off frequency. In a **two-pole filter**, the phase will change by 180 degrees over the frequency range and by 90 degrees at the cut-off frequency.

The three basic types of response characteristics that can be realized with most **active filters** are Butterworth, Chebychev, and Bessel, depending on the selection of certain filter component values. The **Butterworth filter** provides a flat amplitude response in the pass-band and roll-off of -20 dB/decade/pole with a non-linear phase response. Because of the non-linear phase response, a pulse wave shape applied to the input of a Butterworth filter will have an overshoot on the output. Filters with a Butterworth response are normally used in applications where all frequencies in the pass-band must have the same gain. The **Chebychev filter** provides ripple amplitude response in the pass-band and roll-off better than -20 dB/decade/pole with a less linear phase response than the Butterworth filter. Filters with a Chebychev response are most useful when a rapid roll-off is required. The **Bessel filter** provides a flat amplitude response in a pass-band and a roll-off less than -20 dB/decade/pole with linear phase response. Because of its linear phase response, the Bessel filter produces almost no overshoot on the output with pulse waveforms without distorting the wave shape. Because of its maximally flat response in the pass-band, the Butterworth is the most widely used active filter.

**A second-order (two-pole) active low-pass Butterworth filter** is shown in

Fig 6.0

Because it is a two-pole (two R-C circuits) low-pass filter, the output will roll-off -40/dB per decade at frequencies above the cut-off frequency. **A second-order (two-pole) active high-pass Butterworth filter** is shown in Fig 6.1. Because it is two-pole (two R-C circuits) high-pass filter, the output will roll-off -40/dB per decade at frequencies below the cut-off frequency. These two-pole Sallen-Key Butterworth filters require a pass-band voltage gain of 1.586 to produce the Butterworth response. Therefore,

$$A_v = 1 + (R_1/R_2) = 1.586 \quad (6.3)$$

And

$$(R_1/R_2) = 0.586 \quad (6.4)$$

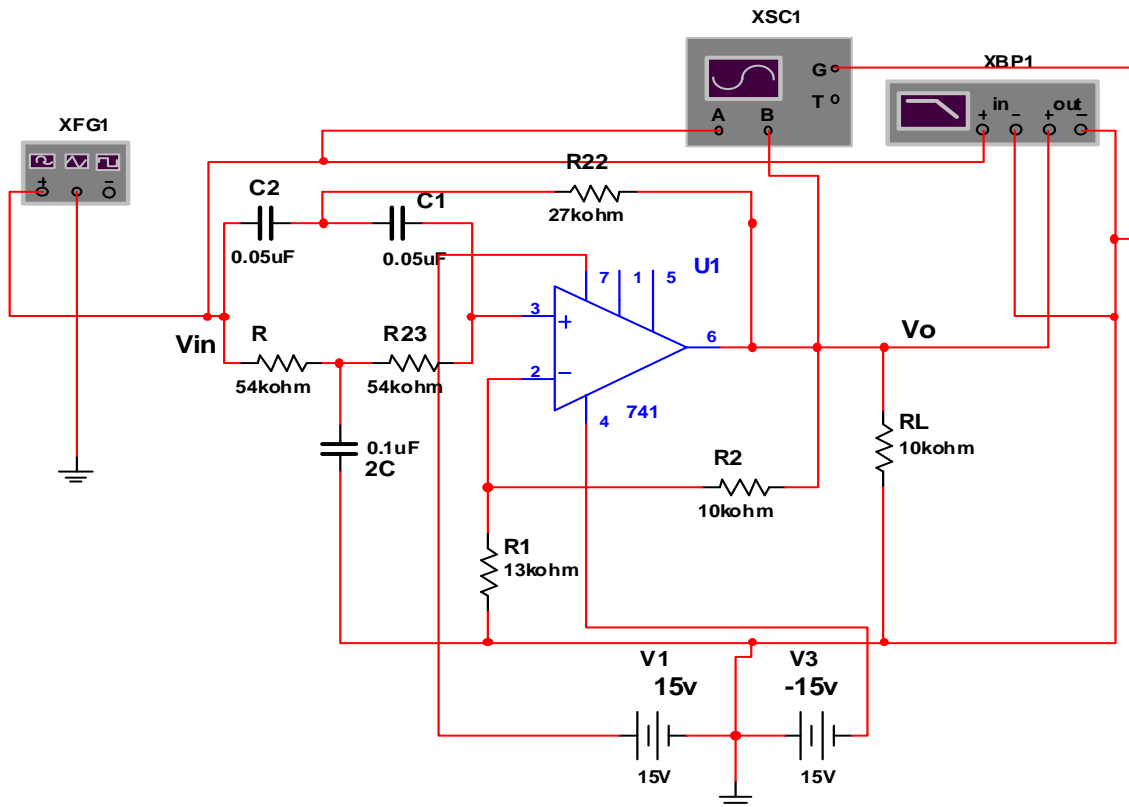
At the cut-off frequency of both filters, the capacitive reactance of each capacitor (C) is equal to the resistance of each resistor (R), causing the output voltage to be 0.707 times the input voltage (-3 dB). The expected cut-off frequency ( $f_c$ ), based on the circuit component values, can be calculated from

$$X_c = R \quad (6.5)$$

$$\frac{1}{2\pi f_c C} = R \quad (6.6)$$

Solving the  $f_c$  produces the equation

$$f_c = \frac{1}{2\pi RC} \quad (6.7)$$



**Fig. 6.0: Second-Order (Two-Pole) Sallen-Key Notch Filter**

## 6.3 PROCEDURE

### *Low-Pass Active Filter*

**Step 1:** Connect the circuit in Fig 6.0. Run the circuit. Plot the response curves by taking measurements at different frequencies between 100HZ and 100KHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 100Hz and 100KHz.

### Question 6.0

- Is the frequency responses curve that of a low-pass filter? **Explain why.**

**Step 2** Calculate the actual voltage Gain (A) from the measured Db gain

**Step 3** Based on the circuit component values in fig 6.0, calculate the Expected voltage gain (A) on the flat part of the curve for the low-pass Butterworth filter

**Question 6.1:**

- a. How did the measured voltage gain in step 2 compare with the Calculated voltage gain in step 3?

**Step 4:** Record the decibel gain and the frequency (cut-off frequency,  $f_c$ ) on the curve plot.

**Step 5:** Calculate the expected cut-off frequency ( $f_c$ ) based on the circuit component values.

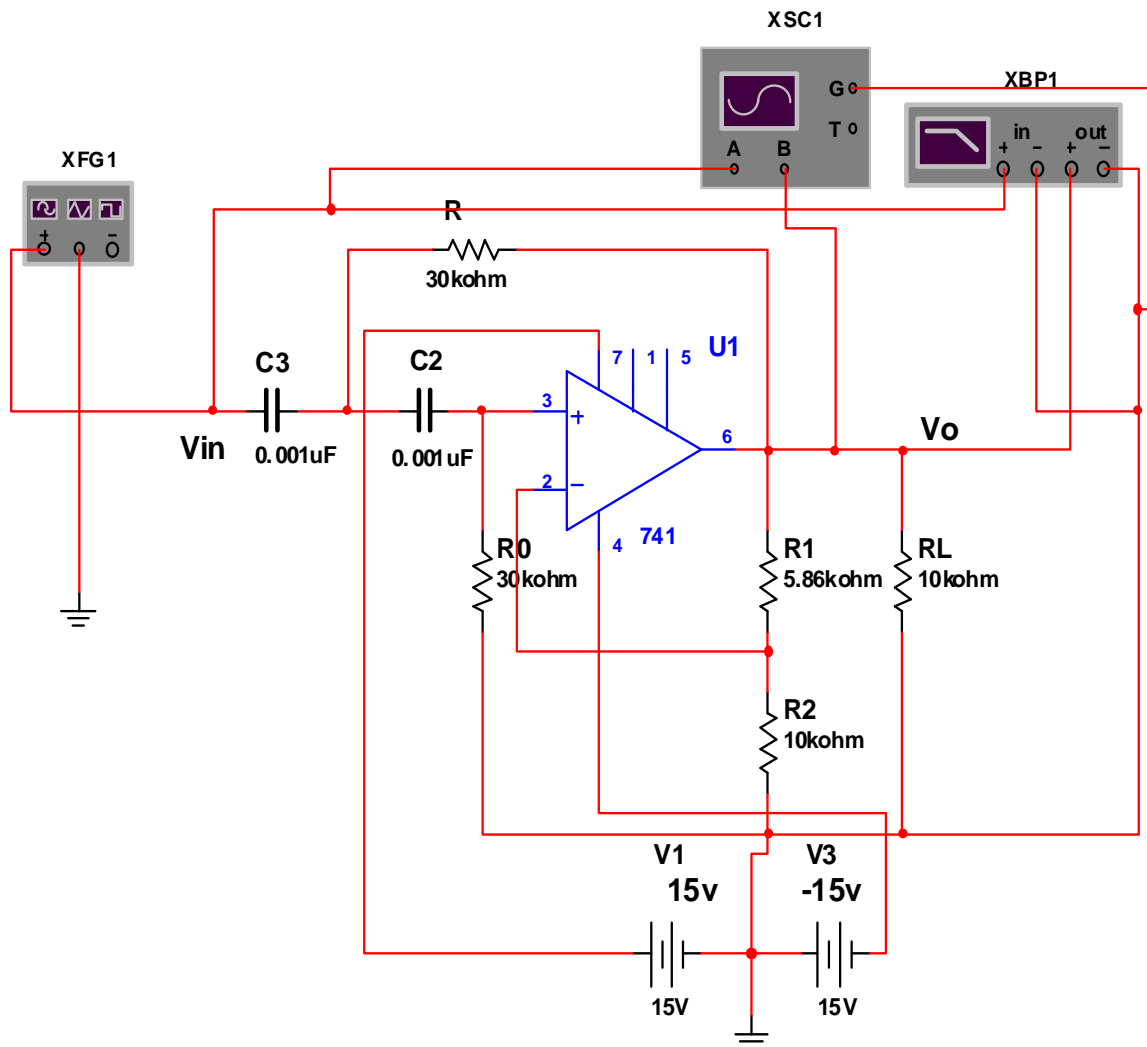
**Question 6.2:**

- a. How did the calculated value for the cut-off frequency compare with the measured value recorded on the curve plot for the two-pole low-pass active filter?

**Step 6:** Record the dB gain frequency ( $f_2$ ) on the curve plot.

**Questions 6.3:**

- a. Approximately how much did the dB gain decrease for a one-decade increase in frequency? Was this what you expected for a two-pole filter?



**Fig. 6.1: Second-order (2-pole) High-pass Butterworth Filter**

### *High-Pass Active Filter*

**Step 7:** Connect the circuit in Fig 6.1. Run the circuit. Plot the response curves by taking measurements at different frequencies between 100HZ and 100KHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 100Hz and 100KHz.

**Question 6.4:**

Is the frequency response curve that of a high-pass filter? **Explain why.**

**Step 8:** Calculate the actual voltage gain (A) from the dB gain.

**Step 9:** Based on the circuit component values in Fig 6.1, calculate the expected voltage gain (A) on the flat part of the curve for the high-pass Butterworth filter

**Question 6.5:**

- a. How did the measured voltage gain in Step 8 compare with the calculated voltage gain in Step 9?

**Step 10:** Record the dB gain and the frequency (cut-off frequency,  $f_c$ ) on the curve plot.

**Step 11:** Calculate the expected cut-off frequency ( $f_c$ ) based on the circuit component values.

**Question 6.6:**

- a. How did the calculated value of the cut-off frequency compare with the measured value recorded on the curve plot for the two-pole high-pass active filter?

**Step 12:** Record the dB gain and frequency ( $f_2$ ) on the curve plot

**Question 6.7:**

- a. Approximately how much did the dB gain decrease for a one-decade decrease in frequency? Was this what you expected for a two-pole filter?



## **EXPERIMENT SEVEN: ACTIVE BAND PASS AND BAND STOP FILTERS**

### **7.0 OBJECTIVES**

1. Plot the gain-frequency response curve and determine the centre frequency for an active band-pass filter.
2. Determine the quality factor (Q) and bandwidth of an active band-pass filter.
3. Plot the phase shift between the input and output for a two-pole active band-pass filter.
4. Plot the gain-frequency response curve and determine the centre frequency for an active band-stop (notch) filter.
5. Determine the quality factor (Q) and bandwidth of an active notch filter.

### **7.1 MATERIALS**

One function generator

One oscilloscope

Two LM741 op-amps

Capacitors: two 0.01  $\mu\text{F}$ , two 0.05  $\mu\text{F}$ , and 0.1  $\mu\text{F}$

Resistors one 1 k  $\Omega$ , two 10 k  $\Omega$ , one 13 k  $\Omega$ , one 27 k  $\Omega$ , two 54 k  $\Omega$ , and

One 100 k  $\Omega$

## 7.2 PREPARATION

In electronic communications systems, it is often necessary to separate a specific range of frequencies from the total frequency spectrum. This is normally accomplished with filters. A **filter** is a circuit that passes a specific range of frequencies while rejecting other frequencies. **Active filters** use active devices such as op-amps combined with passive elements. Active filters have several advantages over passive filters. The passive elements provide frequency selectivity and active device provide voltage gain, high input impedance, and low output impedance. The voltage gain reduces attenuation of the signal by the filter, the high input impedance prevents excessive loading of the source, and the low output impedance prevents the filter from being affected by the load. Active filters are also easy to adjust over a wide frequency range without altering the required response. The weakness of the active filters is the upper-frequency limit due to the limited open-loop bandwidth ( $f_{\text{unity}}$ ) of op-amps. The filter cut-off frequency cannot exceed the unity-gain frequency ( $f_{\text{unity}}$ ) of the op-amp. Therefore, active filters must be used in applications where the unity-gain frequency ( $f_{\text{unity}}$ ) of the op-amp is high enough so that it does not fall within the frequency range of the application. For this reason, active filters are mostly used in low-frequency applications

A **band-pass filter** passes all the frequencies lying within a band of frequencies and rejects all other frequencies outside the band. The low-cut-off frequency ( $f_{c1}$ ) and the high-cut-off frequency ( $f_{c2}$ ) on the gain-frequency plot are the frequencies where the voltage gain has dropped by dB (0.707) from the maximum gain. A **band-stop** filter rejects a band of frequencies and passes all other frequencies outside the band and the high-cut-off frequency ( $f_{c2}$ ) on the gain-frequency plot are

the frequencies where the voltage gain has dropped by 3 dB (0.707) from the pass-band dB gain.

The bandwidth (BW) of a band-pass or a band-stop filter is the difference between the high-cut-off frequency and the low cut-off frequency. Therefore,

$$BW = f_{C_2} - f_{C_1} \quad (7.1)$$

The centre frequency ( $f_0$ ) of a band-pass or band-stop filter is the geometric mean of the low-cut-off frequency ( $f_{c1}$ ) and the high-cut-off frequency ( $f_{c2}$ ). Therefore,

$$f_0 = \sqrt{f_{C_1} f_{C_2}} \quad (7.2)$$

The quality factor (Q) of a band-pass or a band-stop filter is the ratio of the centre frequency ( $f_0$ ) and the bandwidth (BW), and is an indication of the selectivity of the filter. Therefore,

$$Q = \frac{f_0}{BW} \quad (7.3)$$

A higher value of Q means a narrower bandwidth and a more selective filter. A filter with a Q less than one is considered to be a wide-band filter with a Q greater than ten is considered to be a narrow-band filter.

One way to implement a band-pass filter is to cascade a low-pass and a high-pass filter. As long as the cut-off frequencies are sufficiently separated, the low-pass filter cut off frequency will determine the low-cut-off frequency of the band-pass filter and the high-pass filter cut-off frequency will determine the high-cut-off frequency of the band-pass filter. Normally this arrangement is used for a wide-band filter ( $Q < 1$ ) because the cut-off frequencies need to be sufficiently separated.

A multiple-feedback active band-pass filter is shown in Fig 7.0. Components  $R_1$  and  $C_1$  determine the low-cut-off frequency, and  $R_2$  and  $C_2$  determine the high-cut-off frequency. The centre frequency ( $f_o$ ) can be calculated from the component values using the equation

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = \frac{1}{2\pi C \sqrt{R_1 R_2}} \quad (7.4)$$

Where  $C = C_1 = C_2$ .

The voltage gain ( $A_v$ ) at the centre frequency is calculated from

$$A_v = \frac{R_2}{2 R_1} \quad (7.5)$$

And the quality factor ( $Q$ ) is calculated

$$Q = 0.5 \sqrt{\frac{R_2}{R_1}} \quad (7.6)$$

Fig 7.0 shows a second-order (two-pole) Sallen-Key notch filter. The expected centre frequency ( $f_o$ ), can be calculated from

$$f_o = \frac{1}{2\pi RC} \quad (7.7)$$

At this frequency ( $f_o$ ), the feedback signal returns with the correct amplitude and phase to attenuate the input. This causes the output to be attenuated at the centre frequency.

The notch filter in Fig 7.1 has a pass-band voltage gain

$$A_v = \frac{R_2}{R_1} + 1 \quad (7.8)$$

and a quality factor

$$Q = \frac{0.5}{2 - A_v} \quad (7.9)$$

The voltage gain of a Sallen-Key notch filter must be less than 2 and the circuit Q must be less than 10 to avoid oscillation.

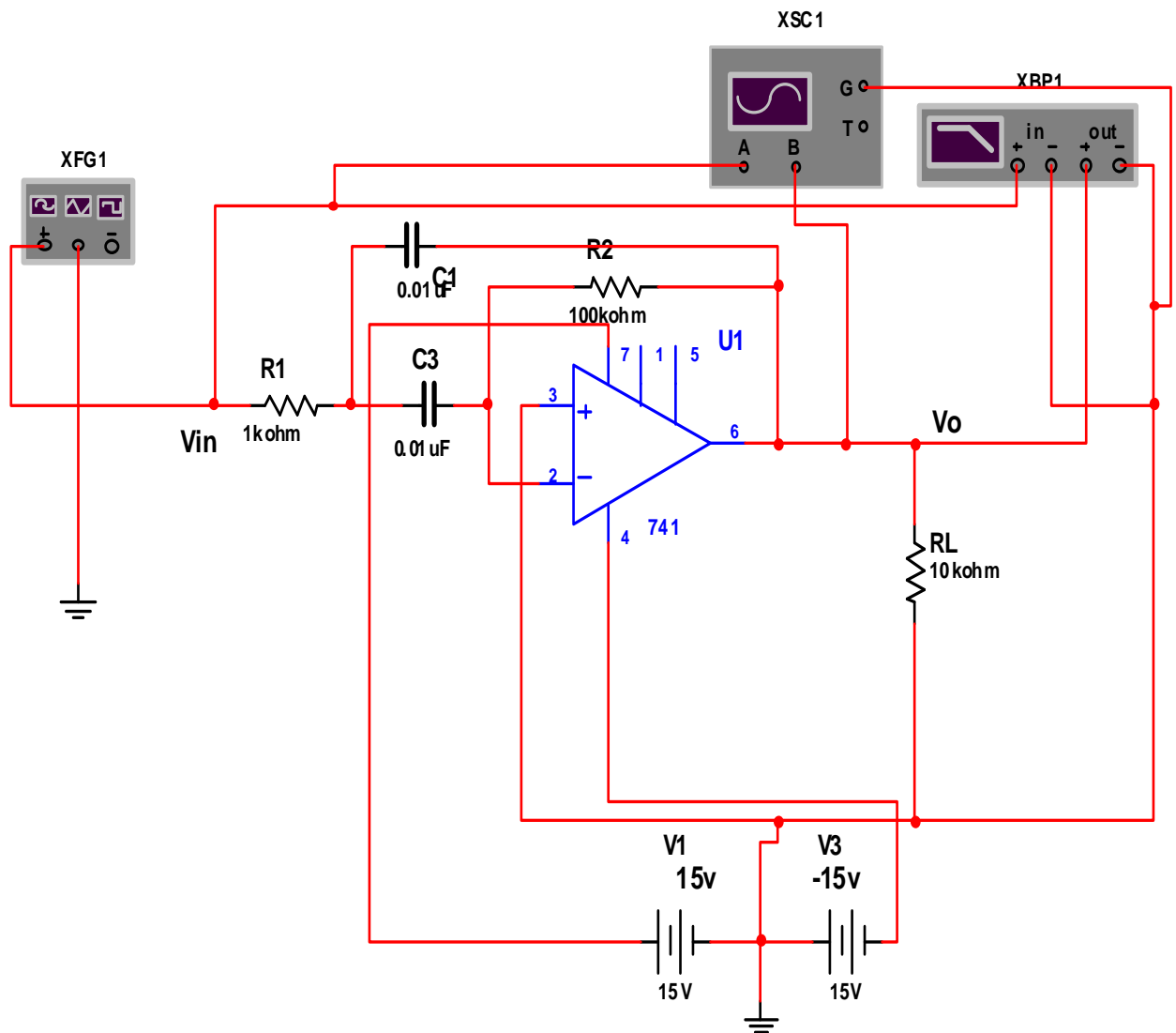


Fig 7.0: Multiple-Feedback Active Band-pass Filter

## 7.3 PROCEDURE

### Active Band –Pass Filter

**Step 1:** Connect the circuit in Fig 7.0.

**Step 2:** Run the circuit. Plot the response curves by taking measurements at different frequencies between 100HZ and 10KHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 100Hz and 10KHz.

#### **Question 7.0:**

- a. Is the frequency response curves that of a band-pass filter? **Explain why.**

**Step 3:** Based on the dB voltage gain at the centre frequency, calculate the actual voltage gain ( $A_v$ )

**Step 4:** Based on the circuit component values, calculate the expected voltage gain ( $A_v$ ) at the centre frequency ( $f_0$ ).

#### **Question 7.1:**

- a. How did the measured voltage gain at the centre frequency compare with voltage gain calculated from the circuit values?

**Step 5:** Record the frequency (low-cut-off frequency,  $f_{c1}$ ) on the curve plot.

Record the frequency (high-cut-off frequency,  $f_{c2}$ ) on the curve plot.

**Step 6:** Based on the measured values of  $f_{c1}$  and  $f_{c2}$ , calculate the bandwidth (BW) of the band-pass filter.

**Step 7:** Based on the circuit components values, calculate the expected centre frequency ( $f_0$ ).

**Question 7.2:**

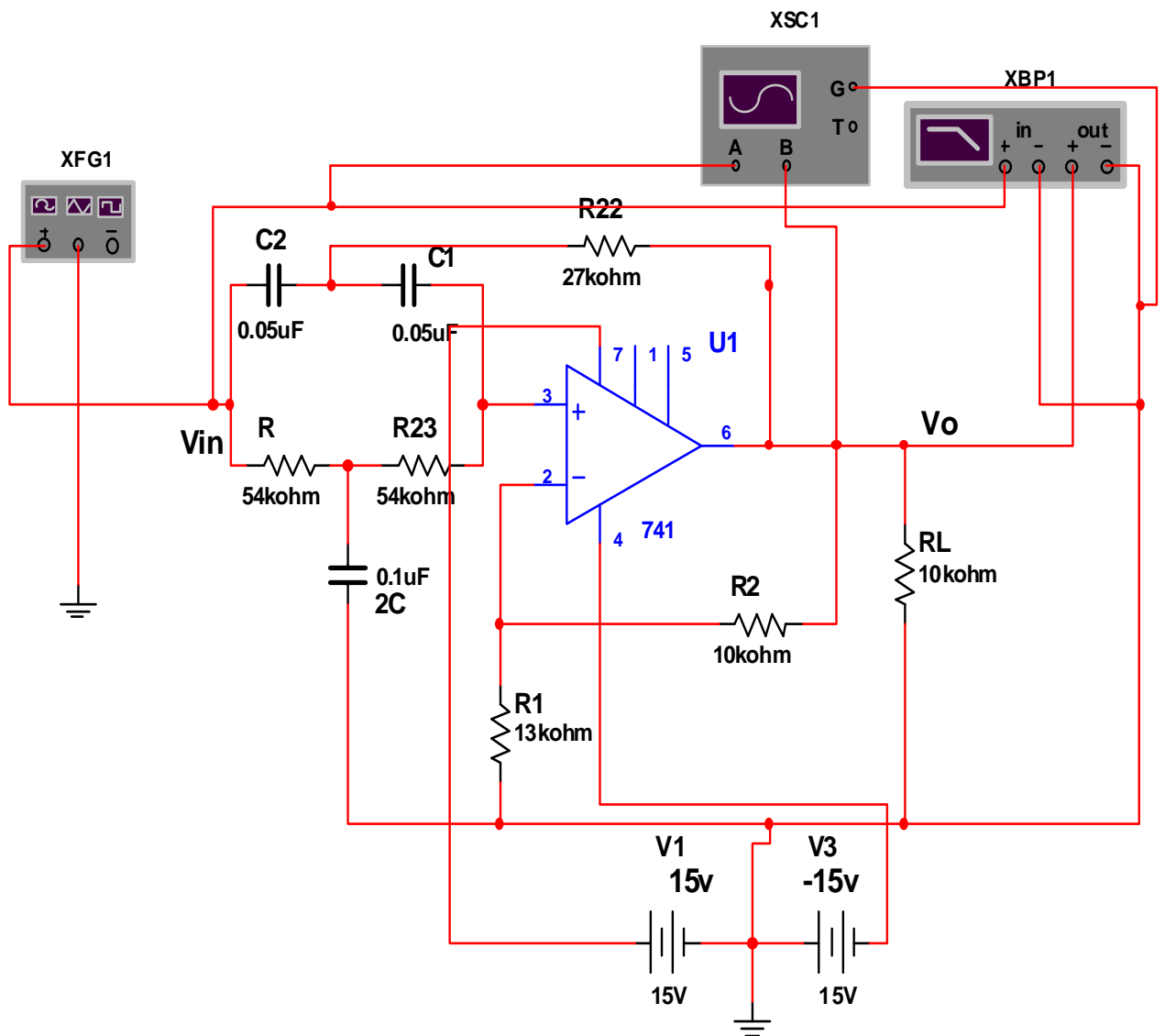
- a. How did the calculated value of the centre frequency compare with the measured value?

**Step 8:** Based on the measured centre frequency ( $f_0$ ) and bandwidth (BW), calculate the quality factor (Q) of the band-pass filter.

**Step 9:** Based on the component values, calculate the expected quality factor (Q) of the band-pass filter.

**Question 7.3:**

- a. How did your calculated value of Q based on the component values compare with the value of Q determined from the measured  $f_0$  and BW?



**Fig. 7.1: Second-order (two-pole) sallen-key notch Filter**



## **EXPERIMENT EIGHT: PASSIVE LOW- PASS AND HIGH –PASS FILTERS.**

### **8.0 OBJECTIVES**

1. Plot the gain-frequency response of a first order (one-pole) R-C low pass filter.
2. Determine the cut-off frequency and roll-off of an R-C first order (one-pole) low pass filter.
3. Plot the phase frequency response of a first order (one-pole) low pass filter.
4. Determine how the value of R and C affects the cut off frequency of an R-C low pass filter.
5. Plot the gain-frequency response of a first order (one-pole) R-C high pass filter.
6. Determine the cut off frequency and roll-off of a first order (one-pole) R-C high-pass filter.
7. Plot the phase-frequency response of a first order (one-pole) high pass filter.
8. Determine how the value of R and C affects the cut off frequency of an R-C high –pass filter.

### **8.1 MATERIALS**

One function generator

One dual-trace oscilloscope

Capacitors: .02 $\mu$ f, .04 $\mu$ f

Resistor: 1k, 2k

## 8.2 PREPARATION

In electronics communications system, it is often necessary to separate a specific range of frequencies types of filter from the total frequency spectrum. This is normally accomplished with filters. A filter is a circuit that passes a specific range of frequencies while rejecting other frequencies .A passive filter consists of passive circuit elements such as capacitors, inductors, and resistors. There are four basic types of filter, low-pass, high-pass, band-pass, and band-stop. A low- pass filter is designed to pass all frequencies below the cut-off frequency and reject all frequencies above the cut-off frequency. A high-pass all frequencies above the cut-off frequency and reject all frequencies below the cut-off frequency. A band-pass filter passes all frequencies within a band of frequencies and rejects all other frequencies outside the band. A band stop filter rejects all frequencies within a band of frequencies and passes all other frequencies outside the band. A band stop filter is often referred to as a notch filter. In this experiment, you will study low pass and high pass filters.

The most common way to describe the frequency response characteristics of a filter is to plot the filter voltage gain ( $V_O/V_I$ ) in dB as a function of frequency (f). The frequency at which the output gain drops to 50% of the maximum value is called the cut off frequency (FC). When the out put power gain drops to 50 %, the voltage gain drops 3dB (0.707 of the maximum value). When the filter dB voltage gain is plotted as a function frequency on a semi log graph using straight lines to approximate the action frequency response, it is called a Bode plot. A Bode plot is an ideal plot of filter frequency response because it assumes that voltage gain remains constant in the pass-band until the cut off frequency is reached and then

drops in a straight line. The filter network voltage gain in dB is calculated from the actual voltage gain (A) using the equation

$$A(\text{db}) = 20\log A \quad (8.1)$$

$$\text{Where } A = \frac{V_o}{V_{in}} \quad (8.2)$$

A low pass RC filter is shown in fig 8.0 At frequencies well below the cut off frequency, the capacitive reactance of a capacitor C is much higher than the resistance of the resistor R, causing the output voltage to be practically equal to the input voltage ( $A=1$ ) and constant with variations in frequency. At frequencies well above the cut off frequencies, the capacitive reactance of capacitor C is much lower than the resistance of resistor R and decreases with an increase in frequency, causing the output voltage to decrease 20 dB

Per decade, increase in frequency. At the cut off frequency, the capacitive reactance of capacitor C is equal to the resistance of the resistor R, causing the out voltage to be 0.707 times the input voltage (-3dB). The expected cut off frequency ( $f_c$ ) of the low pass filter in figure 19.0, based on the circuit component values, can be calculated from

$$X_c = R \quad (8.3)$$

$$\frac{1}{2\pi f_o C} = R \quad (8.4)$$

Solving for  $f_c$  produces the equation

$$f_o = \frac{1}{2\pi RC} \quad (8.5)$$

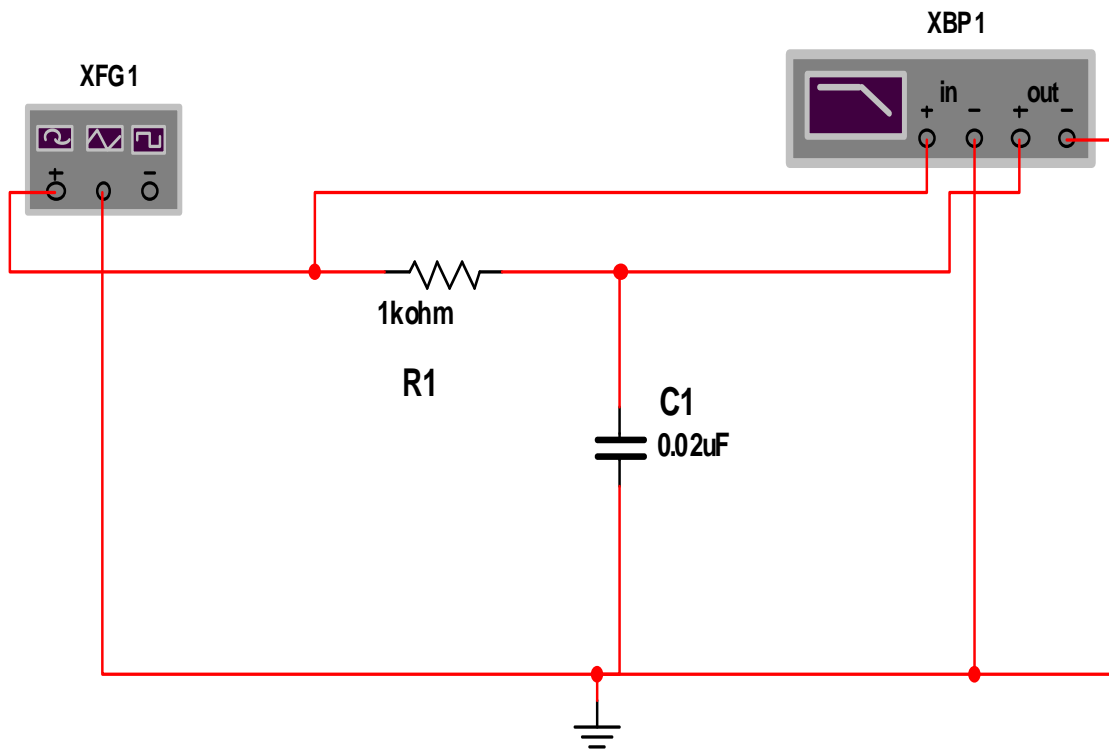
A high pass RC filter is shown in fig 19.1. At frequencies well above the cut off frequency, the capacitive reactance of capacitor C is much lower than the

resistance of resistor R, causing the output voltage to be practically equal to the input voltage {A= 1} and constant with variations in frequency. At frequencies well below the cut-off frequency, the capacitive reactance of capacitor C is much higher than the resistance of resistor R and increases with a decrease in frequency, causing the output voltage to decrease 20 dB per decade decrease in frequency. At the cut-off frequency, the capacitive reactance of capacitor C is equal to the resistor R, causing the voltage to be 0.707 times the input voltage {-3 Db). The expected cut-off frequency {fc} of the high-pass filter in fig 8.2, based on the circuit component values, can be calculated from

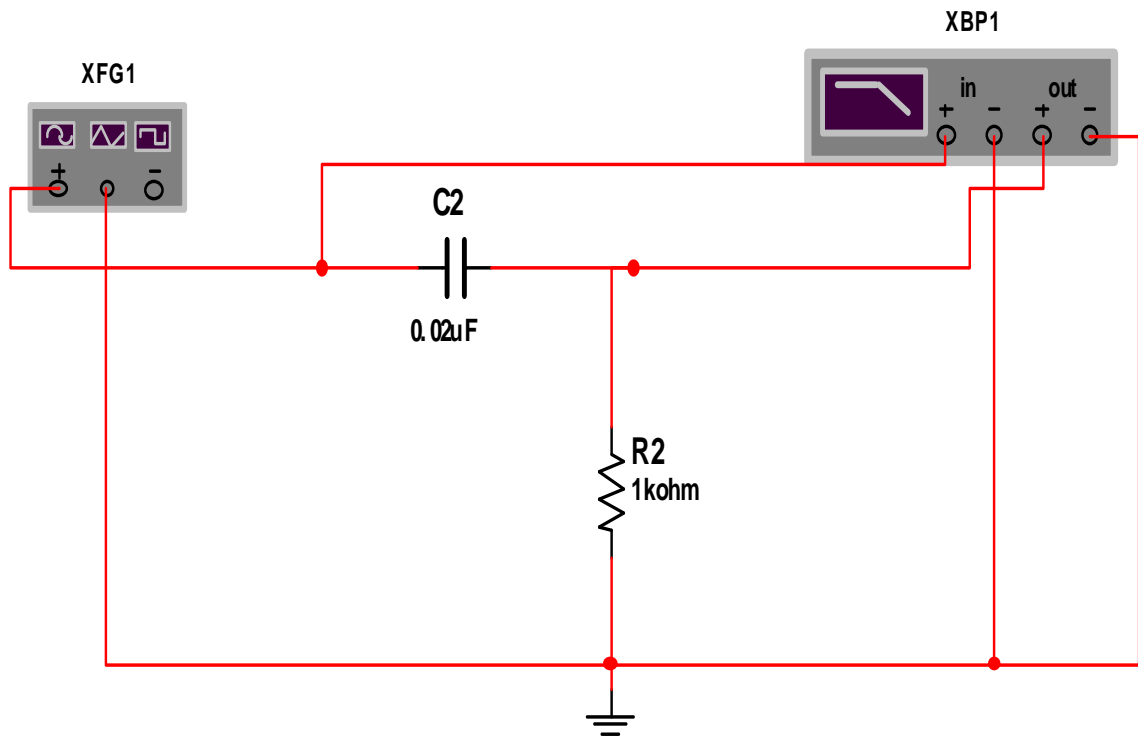
$$f_o = \frac{1}{2\pi RC} \quad (8.6)$$

When the frequency at the input of a low-pass filter increases above the cut-off frequency, the filter output voltage drops at a constant rate. When the frequency at the input of a high- pass filter decreases below the cut-off frequency, the filter output voltage also drops at a constant rate. The constant drop in filter output voltage per decade increases {×10}, or decrease {÷10}, in frequency is called roll-off. An ideal low- pass or high-pass filter would have an instantaneous drop at the cut-off frequency [fc], with full signal level on one side of the cut-off frequency and no signal level on the other side of the cut-off frequency. Although the ideal is not achievable, actual filters roll off at -20dB/decade per pole [R- C Circuit]. A one-pole filter has one R-C circuit tuned to the cut-off frequency and rolls off at -20dB/decade. A two-pole has two R-C circuits tuned to the same cut-off frequency and rolls at -40dB/decade. Each additional pole [R-C circuit] will cause the filter to roll an additional -20dB/decade. Therefore, an R-C filter with more poles [R-C circuits] more closely approaches an ideal filter.

In a one- pole filter, as shown in fig 8.0 and 8.1, the phase  $[\phi]$  between the input and the output will change by 90 degrees over the frequency range and be 45 degrees at the cut-off frequency. In a two- pole filter, the phase  $[\phi]$  will change by 180 degrees over the frequency range and be 90 degrees at the cut-off frequency.



**Fig. 8.0: Low-pass R-C Filter**



**Fig. 8.1: High-pass R-C Filter**

### 8.3 PROCEDURE

#### *Low-pass filter*

**Step 1:** Connect the circuit in Fig 8.0. Make sure that the following Bode plotter settings are selected: Magnitude, Vertical (Log, F = 0dB, I= -40dB), Horizontal (Log, F = 1 MHz, I = 100Hz).

**Step 2:** Run the circuit. Plot the response curves by taking measurements at different frequencies between 100HZ and 1MHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequencies of 100Hz and 1MHz.

#### **Question 8.0:**

- a. Is the frequency response curves that of a low-pass filter? Explain why.

**Step 3:** Calculate the actual voltage gain [A] from the dB voltage gain [AdB].

**Questions 8.1:**

- a. Was the voltage gain on the flat part of the frequency response curve what you expected for the circuit in Fig 8.0? Explain why.

**Step 4:** Calculate the expected cut-off frequency ( $f_c$ ) based on the circuit component values in Fig 8.0.

**Questions 8.2:**

- a. How did the calculated value for the cut-off frequency compare with the measured value recorded on the curve plot? How much did the dB gain decrease for a one-decade increase ( $\times 10$ ) in frequency? Was it what you expected for a single-pole (single R-C) low pass filter?

**Step 5:** Connect the circuit in fig 8.1. Plot the response curves by taking measurements at different frequencies between 100HZ and 1MHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequencies of 100Hz and 1MHz.

**Question 8.3:**

- a. Is the frequency response curves that of a high-pass filter? Explain why.

**Step 6:** Calculate the actual voltage gain [A] from the dB voltage gain [AdB].

**Step 7:** Calculate the expected cut-off frequency ( $f_c$ ) based on the circuit component values in Fig 8.1

**Questions 8.3:**

- a. How did the calculated value for the cut-off frequency compare with the measured value recorded on the curve plot? How much did the dB gain decrease for a one-decade increase ( $\times 10$ ) in frequency? Was it what you expected for a single-pole (single R-C) high-pass filter?



## **EXPERIMENT NINE: PASSIVE BAND-PASS AND BAND-STOP FILTERS**

### **9.0 OBJECTIVES**

1. Plot the gain-frequency response of an L-C series resonant and an L-C parallel resonant band-pass filter.
2. Determine the centre frequency and the bandwidth of the L-C band –pass filters.
3. Determine how the circuit resistance affects the bandwidth of an L-C band-pass filter.
4. Plot the gain-frequency response of an L-C series resonant and an L-C parallel resonant band-stop [notch] filter.
5. Determine the centre frequency and bandwidth of the L-c band-stop filters.
6. Determine how the circuit resistance affects the bandwidth of an L-C band-stop filter.

### **9.1 MATERIALS**

One function generator

One dual-trace oscilloscope

Capacitors: one  $0.1\mu\text{F}$ , one  $0.25\mu\text{F}$

Inductors: one  $50\text{mH}$ , one  $100\text{mH}$

Resistors:  $100\Omega$ ,  $200\Omega$ ,  $2\text{k}$ ,  $4\text{k}$ ,  $5\text{k}$ ,  $200\text{k}$

## 9.2 PREPARATION

In electronic communications systems, it is often necessary to separate a specific range of frequencies from the total frequency spectrum. This is normally accomplished with filters. A Filter is a circuit that passes a specific range of frequencies while rejecting other frequencies. A passive filter consists of passive circuit elements, such as capacitors, inductors, and resistors. There are four basic types of filters; low-pass, high-pass filter band-pass and band-stop. A low-pass filter is designed to pass all frequencies below the cut-off frequency and reject all frequencies above the cut-off frequency. A high-pass filter is designed to pass all frequencies above the cut-off frequency and rejects all frequencies below the cut-off frequency. A band-pass filter passes all frequencies within a band of frequencies and rejects all other frequencies outside the band. A band-stop filter rejects all frequencies within a band of frequencies and passes all other frequencies outside the band. A band-stop filter is often referred to as a notch filter. In this experiment, you will study band-pass and band-stop [notch] filters. The most common way to describe the frequency response characteristics of a filter is to plot the filter voltage gain  $[V_o/V_{in}]$  in dB as function of frequency  $[f]$ . The frequency at which the output power gain drops to 50%, the maximum value is called the cut-off frequency  $[f_c]$ . When the output power drops 50%, the voltage gain drops 3db  $[0.707$  of the maximum value]. When the filter dB voltage gain is plotted as a function of frequency on a semi log graph using straight lines to approximate the actual frequency response, it is called a Bode plot. A Bode plot is an ideal plot of frequency response because it assumes that the voltage gain remains constant in the pass band until the cut-off frequency is reached, and then drops in a straight line. The filter network voltage gain in db calculated from the actual voltage gain  $[A]$  using the equation

$$A \text{ dB} = 20 \log A \quad (9.1)$$

$$\text{Where } A = \frac{V_o}{V_{in}} \quad (9.2)$$

An L-C series resonant band-pass filter is shown in fig 9.0. The impedance of the series L-C circuit is lowest at the frequency and increases on both sides of the resonant frequency. This will cause the output voltage to be highest at the resonant frequency and decrease on both sides of the resonant frequency. An L-C parallel resonant band-pass filter is shown in figure 9.1. The impedance of the parallel L-C circuit is highest at the resonant frequency and decreases on both sides of the resonant frequency. This will also cause the output voltage to be highest at the resonant frequency and decrease on both sides the resonant frequency.

An L-C series resonant band-stop [notch] filter is shown in fig 9.2. The impedance of the series L-C circuit is lowest at the resonant frequency and increases on both sides of the resonant frequency. This will cause the output voltage to be lowest at the resonant frequency and increase on both sides of the resonant frequency. An L-C parallel resonant band-stop [notch] filter is shown in fig 9.3. The impedance of the parallel L-C circuit is highest at the resonant frequency and decreases on both sides of the resonant frequency. This will also cause the output voltage to be lowest at the resonant frequency and increase on both sides of the resonant frequency.

The centre frequency  $[f_o]$  for the L-C Series resonant and the L-C parallel resonant band-pass and band-stop [[notch] filter is equal to the resonant frequency of the L-C circuit, which can be calculated from

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (9.3)$$

For an L-C parallel resonant filter, the equation is accurate only for a high Q inductor coil  $[Q_L \geq 10]$ , where  $Q_L$  is calculated

$$Q_L = \frac{X_L}{R_w} \quad (9.4)$$

In addition,  $X_L$  is the inductive reactance at the resonant frequency [centre frequency,  $f_o$ ] and  $R_w$  is the inductor coil resistance.

In the band-pass and band-stop [notch] filters, the low-cut-off frequency [ $f_{c1}$ ] and the high-cut-off frequency [ $f_{c2}$ ] on the gain-frequency plot are the frequencies where the voltage gain has dropped 2dB[0.707] from the highest db gain. The filter bandwidth [BW] is the difference between the high- cut-off frequency [ $f_{c2}$ ] and the low-cut-off frequency [ $f_{c1}$ ]. Therefore

$$BW = f_{c2} - f_{c1}. \quad (9.5)$$

The centre frequency [ $f_o$ ] is the geometric mean of the low-cut-off frequency and the high-cut-off frequency. Therefore,

$$f_o = \sqrt{f_{c1}f_{c2}} \quad (9.6)$$

The quality factor [Q] of the band-pass and band-stop [notch] is the ratio of the centre frequency [ $f_o$ ] and the bandwidth [BW], and it is the indication of the selectivity of the filter. Therefore,

$$Q = \frac{f_o}{BW} \quad (9.7)$$

A higher value of Q means a narrower bandwidth and a more selective filter.

The quality factor [Qs] of a series resonant filter is determine by first calculating the inductive reactance [ $X_L$ ] of the inductor at the resonant frequency [centre frequency,  $f_o$ ], and then dividing the total parallel resistance

[R<sub>p</sub>] by the inductive reactance [X<sub>L</sub>] by the total series resistance (R<sub>T</sub>).  
Therefore,

$$Q_s = \frac{X_L}{R_T} \quad (9.8)$$

$$\text{Where } X_L = 2\pi f_0 L \quad (9.9)$$

The quality factor (Q<sub>p</sub>) of a parallel resonant filter is determined by first calculating the inductive reactance (X<sub>L</sub>) of the inductor at the resonant frequency (centre frequency, f<sub>0</sub>), and then dividing the total parallel resistance (R<sub>p</sub>) by the inductive reactance (X<sub>L</sub>)

$$Q_p = \frac{R_0}{X_L} \quad (9.10)$$

Because the inductor wire resistance [R<sub>w</sub>] is in series with inductor L, the circuit in fig 9.1 and 9.3 are exactly parallel resonant circuits. In order to make them be true parallel resonant circuits, the series combination of inductance [L] and resistance [R<sub>w</sub>] must first be converted into an equivalent parallel network with resistance R<sub>eq</sub> in parallel with inductance L. in fig 9.1, the parallel equivalent resistance [R<sub>eq</sub>] will also be in parallel with resistor R and resistor, R<sub>s</sub>, making the total resistance of the parallel resonant circuit [R<sub>p</sub>] equal to the parallel equivalent of resistors R, R<sub>s</sub>, and R<sub>eq</sub>. therefore, R<sub>p</sub> can be solved from

$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R_s} + \frac{1}{R_{eq}} \quad (9.11)$$

In fig 9.3, the parallel equivalent resistance [R<sub>eq</sub>] will be in parallel with resistor, making the total resistance of the parallel resonant circuit [R<sub>p</sub>] equal to the parallel equivalent of resistors R and R<sub>eq</sub>. therefore, R<sub>p</sub> can be solved from

$$R_P = \frac{[R][R_{eq}]}{R+R_{eq}} \quad (9.12)$$

The equation for converting resistance  $R_w$  to the equivalent parallel

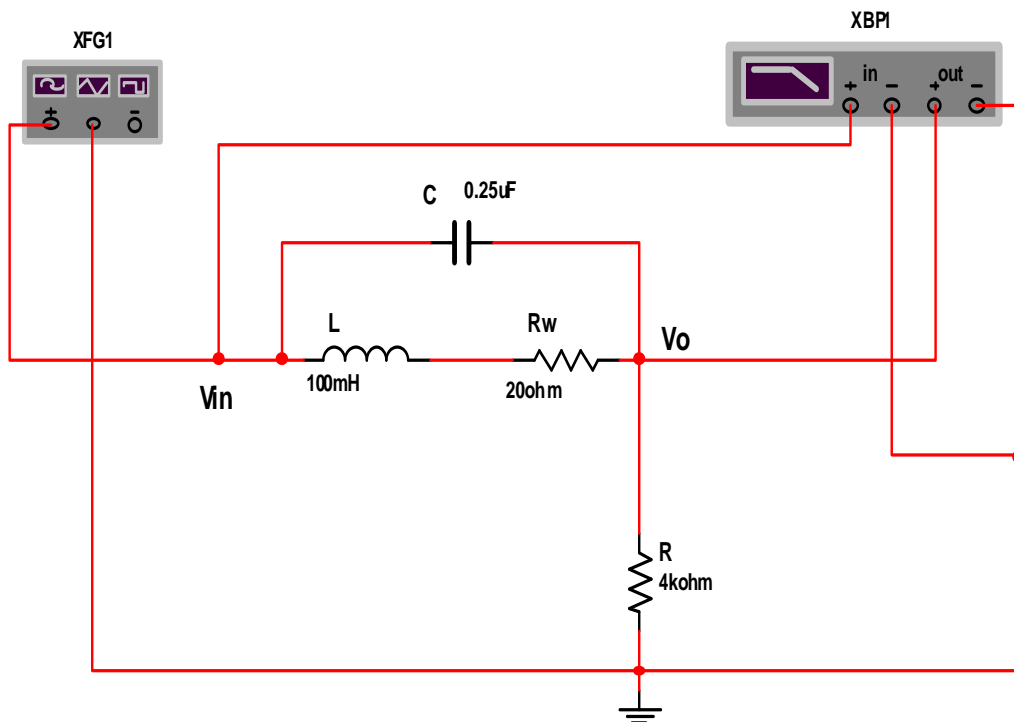
Resistance  $[R_{eq}]$  is

$$R_{eq} = R_w [Q_L^2 + 1] \quad (9.13)$$

The parallel equivalent inductance  $[L_{eq}]$  is calculated from

$$L_{eq} = L [Q_L^2 + 1]/Q_L^2 \quad (9.14)$$

This equivalent inductance can be considered equal to the original inductance  $[L]$  for a high Q coil  $[Q_L \geq 10]$ .



**Fig. 9.0: L-C Parallel Resonant Band-stop (Notch) Filter**

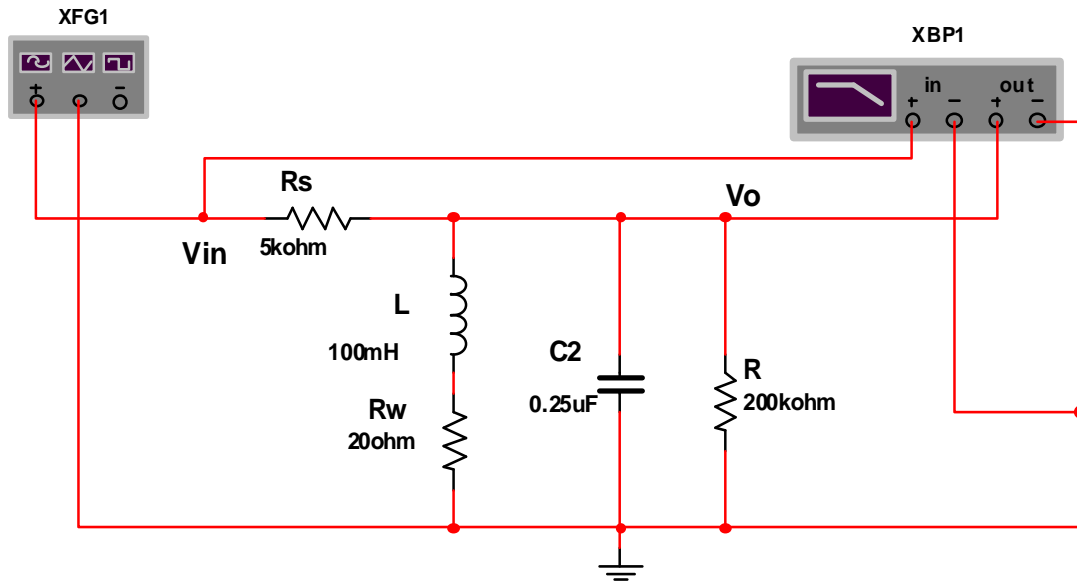


Fig. 20.1: L-C Parallel Resonant Band-pass Filter

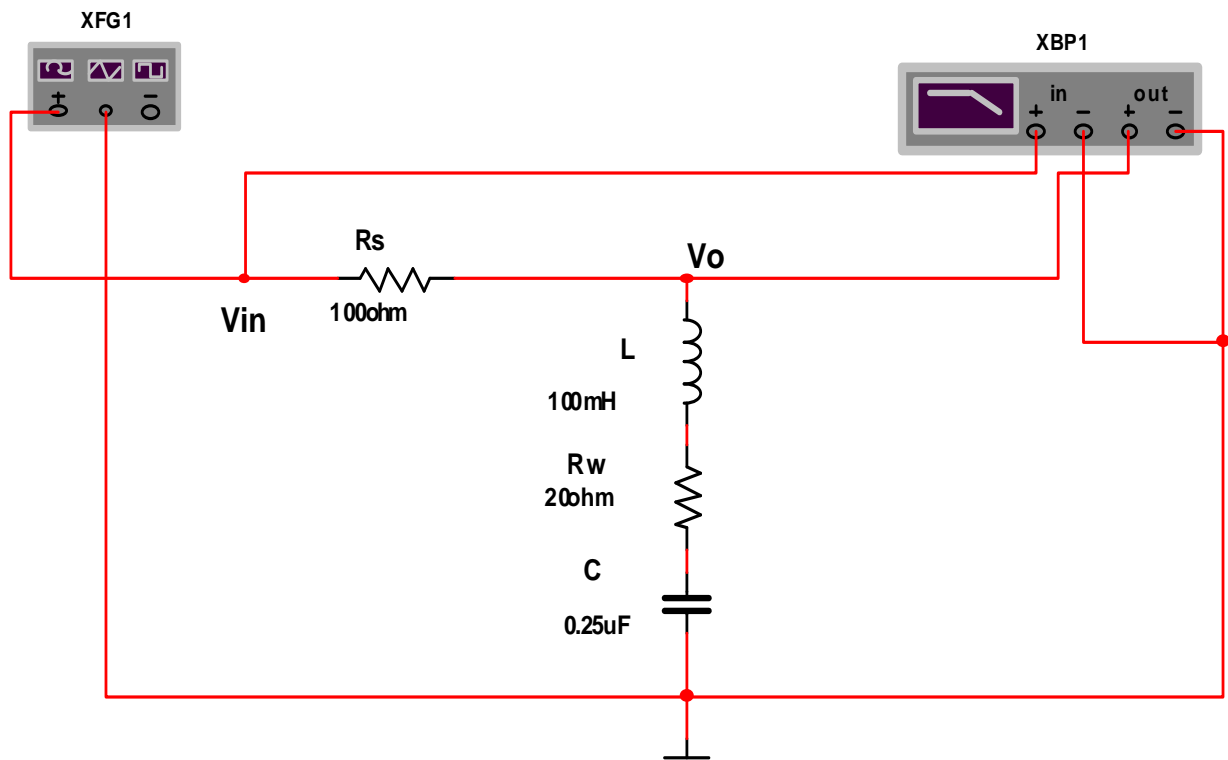
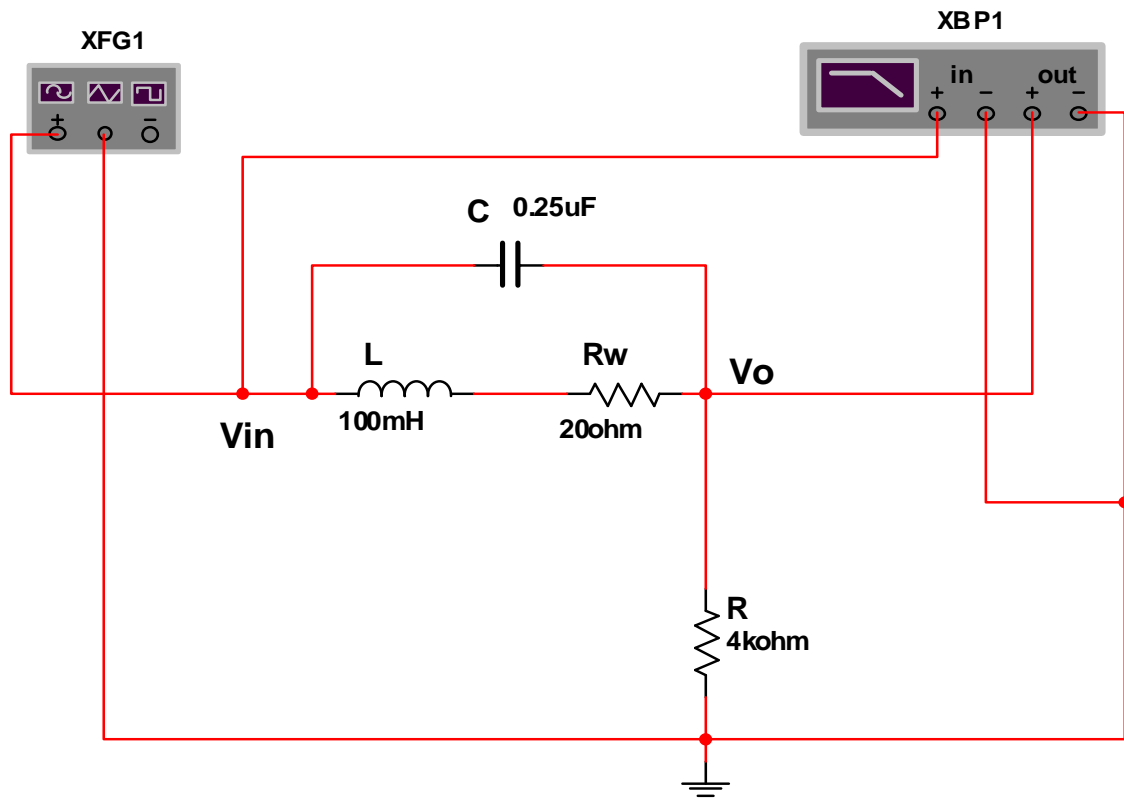


Fig. 9.2: L-C Series Resonant Band-Stop (Notch) Filter



**Fig. 9.3: L-C Parallel Resonant Band-Stop (Notch) Filter**

### 9.3 PROCEDURE

#### *Band-pass filters*

**Step 1:** Connect the circuit in Fig 9.0. Make sure that the following Bode plotter settings are selected: Magnitude, Vertical (Log, F = 0dB, I= -20dB), Horizontal (Log, F = 2 KHz, I = 500Hz).

**Step 2:** Run the circuit. Plot the response curves by taking measurements at different frequencies between 500HZ and 2KHZ using oscilloscope. Plot



the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 500Hz and 2KHz

**Question 9.0:**

- a. Is the frequency response curves that of a band-pass filter? Explain why.

**Step 3:** Based on the dB voltage gain, calculate the actual voltage gain [A] of the series resonant band-pass filter at the centre frequency.

**Step 4:** Record the approximate frequency [low-cut-off frequency,  $f_{c1}$ ] on the curve plot. Record the approximate frequency [high-cut-off frequency,  $f_{c2}$ ] on the curve plot.

**Step 5:** Based on the values of  $f_{c1}$  and  $f_{c2}$  measured on the curve plot, determine the bandwidth [BW] of the series resonant band-pass filter.

**Step 6:** Based on the circuit component values in fig 9.0, calculate the expected centre frequency [ $f_0$ ] of the series resonant band-pass filter.

**Question 9.1:**

- a. How did the calculated values of the centre frequency [ $f_0$ ] based on the circuit component values compare with the measured value recorded on the curve plot?

**Step 7:** Based on the values of  $f_{c1}$  and  $f_{c2}$ ; calculate the centre frequency [ $f_0$ ].

**Question 9.2:**

- a. How did the calculated value of the centre frequency [ $f_c$ ] based on  $f_{c1}$  and  $f_{c2}$  compare with the measured value on the curve plot?

**Step 8:** Based on the component values, calculate the quality factor [Qs] of the series resonant band-pass filter.

**Step 9:** Based on the circuit quality factor [Qs] and the centre frequency [fo], calculate the expected bandwidth BW of the series resonant band-pass filter.

**Question 9.3:**

- a. How did the expected bandwidth calculated from the value of centre frequency compare with the bandwidth measured on the curve plot?

**Step 10:** Change the resistance of R to 200ohms. Run the circuit again. Measure the centre frequency [fo] and the bandwidth [BW] from the curve plot and record the values.

Fo =

BW=

**Questions 9.4:**

- a. What effect did changing the resistance of R have on the centre frequency of the series resonant band-pass filter? What effect did changing the resistance of R have on the bandwidth of the series resonant band-pass filter? Explain.

**Step 11:** Change the capacitance of C to 0.1μF. Run the circuit again. Measure the centre frequency [fo] and the bandwidth [BW] on the curve plot and record the values.

Fo =

BW=

**Questions 9.5:**

- a. What effect did changing the capacitance of C have on the centre frequency of the series resonant band-pass filter? What effect did changing the capacitance of C have on the bandwidth of the series resonant band-pass filter? Explain.

Change the inductance of L to 50 mH. Run the circuit again. Measure the centre frequency [fo] the bandwidth [BW] on the curve plot and record the values.

Fo=

BW=

### Questions 9.6:

- a. What effect did changing the inductance of L have on the centre frequency of the series resonant band-pass filter? What effect did changing the inductance of L have on the bandwidth of the series resonant band-pass filter? Explain.

**Step 13:** Connect the circuit in Fig 9.1 Run the circuit. Plot the response curves by taking measurements at different frequencies between 500HZ and 2KHZ using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 500Hz and 2KHz.

### Question 9.7:

Is the frequency response curves that of a band-pass filter? Explain why.

**Step 14:** Record the centre frequency [fo] and the voltage gain in dB on the curve plot.

**Step 15:** Based on the dB voltage gain, calculate the actual voltage gain [A] of the parallel resonant band-pass filter at the centre frequency.

**Step 16:** Record the approximate frequency [low-cut-off frequency,  $f_{c1}$ ] on the curve plot. Record the approximate frequency [high-cut-off frequency,  $f_{c2}$ ] on the curve plot.

**Step 17:** Based on the circuit component values in fig 9.1, calculate the expected centre frequency [ $f_0$ ] of the parallel resonant band-pass filter.

**Question 9.8:**

- a. How did the calculate value of the centre frequency [ $f_0$ ] based on the circuit component values compare with the measured value recorded on the curve plot?

**Step 18:** Based on the values of  $f_{c1}$  and  $f_{c3}$ , calculate the centre frequency [ $f_0$ ].

**Question 9.9:**

- a. How did the calculate value of the centre frequency [ $f_0$ ] based on  $f_{c1}$  and  $f_{c2}$  compare with the measured value on the curve plot?

**Step 19:** Based on the value of L and  $R_w$ ; calculate the quality factor [ $Q_L$ ] of the inductor.

**Step 20:** Based on the quality factor [ $Q_L$ ] of the inductor, calculate the equivalent parallel inductor resistance [ $R_{eq}$ ] across the tank circuit.

**Step 21:** Based on the value of  $R_{eq}$ ,  $R_s$ , and R, calculate the total parallel resistance [ $R_p$ ] across the tank circuit.

**Step 22:** Based on the value of  $R_p$ ; calculate the quality factor  $[Q_p]$  of the parallel resonant band-pass filter.

**Step 23:** Based on the filter quality factor  $[Q_p]$  the centre frequency  $[f_o]$ , calculate the expected bandwidth  $[BW]$  of the parallel resonant band-pass filter.

**Question 9.10:**

- a. How did the expected bandwidth calculated from the value of  $Q_p$  and the centre frequency compare with the bandwidth measured on the curve plot?

**Step 24:** Change the resistance of  $R$  to  $5k\Omega$ . Run the circuit again. Measure the centre frequency  $[f_o]$  and the bandwidth  $[BW]$  from the curve plot and record the values.

$F_o=$

$BW=$

**Questions 9.11:**

- a. what effect did changing the resistance of  $R$  have on the centre frequency of the parallel resonant band-pass filter? What effect did changing the resistance of  $R$  have on the bandwidth of the parallel band-pass filter? Explain why.

***Band-stop [notch] filters***

**Step 25:** Connect the circuit in Fig 9.2. Run the circuit. Plot the response curves by taking measurements at different frequencies between  $500\text{Hz}$  and  $2\text{KHz}$  using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency  $500\text{Hz}$  and  $2\text{KHz}$

**Question 9.12:**

- a. Is the frequency response curves that of a band-stop [notch] filter? Explain why.

**Step 26:** Record the centre frequency [fo] on the curve plot.

**Step 27:** Record the dB gain on the curve plot.

**Step 28:** Record the approximate frequency [low- cut-off frequency,  $f_{c1}$ ]

on the curve plot. Record the approximate frequency [high-cut-off frequency,  $f_{c2}$ ] on the curve plot.

**Step 29:** Based on the values of  $f_{c1}$  and  $f_{c2}$ ; determine the bandwidth [BW] of the series resonant band-stop filter.

**Step 30:** Based on the circuit component values in figure 20.2, calculate the expected centre [fo] of the series resonant band-stop [notch] filter.

**Question 9.13:**

- a. How did the calculated value of the centre frequency [fo] based on the circuit component values compare with the measured value recorded on the curve plot?

**Step 31:** Based on the values of  $f_{c1}$  and  $f_{c2}$ ; calculate the centre frequency [fo].

**Question 9.14:**

- a. How did the calculated value of the centre frequency [fo] based on  $f_{c1}$  and  $f_{c2}$  compare with the measured value on the curve plot?

**Step 32:** Based on the circuit component values, calculate the quality factor  $[Q_s]$  of the series resonant band-stop [notch] filter.

**Step 33:** Based on the circuit quality factor  $[Q_s]$  and the centre frequency  $[f_o]$ , calculate the expected bandwidth  $[BW]$  of the series resonant band-stop [notch] filter.

**Question 9.15:**

- a. How did the expected bandwidth calculated from the value of  $Q_s$  and the centre frequency compare with the bandwidth measured on the curve plot?

**Step 34:** Connect the circuit in file Fig 9.3. Run the circuit. Plot the response curves by taking measurements at different frequencies between 500HZ and 2KHz using oscilloscope. Plot the curves on semilog paper Notice that voltage gain in dB has been plotted between the frequency 500Hz and 2KHz.

**Question 9.16:**

- a. Is the frequency response curves that of a band-stop [notch] filter? Explain why.

**Step 35:** Record the centre frequency  $[f_o]$  on the curve plot.

**Step 36:** Record the dB gain on the curve plot.

**Step 37:** Record the approximate frequency [low-cut-off frequency,  $f_{c1}$ ] on the curve plot. Record the approximate frequency [high-cut-off frequency,  $f_{c2}$ ] on the curve plot.

**Step 38:** Based on the values of  $f_{c1}$  and  $f_{c2}$ ; determine the bandwidth [BW] of the parallel resonant band-stop [notch] filter.

**Step 39** Based on the circuit component values in fig 9.3, calculate the expected centre frequency [ $f_0$ ] of the parallel resonant band-stop [notch] filter.

**Question 9.17:**

- a. How did the calculate value of the centre frequency [ $f_0$ ] based on the circuit component values compare with the measured value recorded on the curve plot?

**Step 40:** Based on the values of  $f_{c1}$  and  $f_{c2}$  calculate the centre frequency [ $f_0$ ].

**Question 9.18:**

- a. How did the calculated value of the centre frequency [ $f_0$ ] based on  $f_{c1}$  and  $f_{c2}$  compare with the measured value on the curve plot?

**Step 41:** Based on the value of L and  $R_w$ ; calculate the quality factor [ $Q_L$ ] of the inductor.

**Step 42:** Based on the quality factor [ $Q_L$ ] of the inductor, calculate the equivalent parallel inductor resistance [ $R_{eq}$ ] across the tank circuit.

**Step 43:** Based on the value of  $R_{eq}$  and R; calculate the total parallel resistance [ $R_p$ ] across the tank circuit.

**Step 44:** Based on the value of  $R_p$ , calculate the quality factor [ $Q_p$ ] of the parallel resonant band-stop [notch] filter.



**Step 45:** Based on the filter quality factor [Qp] and the centre frequency [fo], calculate the expected bandwidth [BW] of the parallel resonant band-stop [notch] filter.

**Question 9.19:**

- a. How did the expected bandwidth calculated from the value of Qp and the centre frequency compare with the bandwidth measured on the curve lot?

**Step 46:** Change the resistance of R to 2kohms. Run the circuit again. Measure the centre frequency [fo] and the bandwidth [BW] from the curve plot and record the values.

Fo = \_\_\_\_\_

BW= \_\_\_\_\_

**Questions 9.20:**

- a. What effect did changing the resistance of R have on the centre frequency of the parallel resonant band-stop [notch] filter? What effect did changing the resistance of R have on the bandwidth of the parallel resonant band-stop [notch] filter? Explain.