Basic Electronics Lab (P242) Manual 2015-16

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IDENTIFICATION OF CIRCUIT COMPONENTS

Breadboards:

In order to temporarily construct a circuit without damaging the components used to build it, we must have some sort of a platform that will both hold the components in place and provide the needed electrical connections. In the early days of electronics, most experimenters were amateur radio operators. They constructed their radio circuits on wooden breadboards. Although more sophisticated techniques and devices have been developed to make the assembly and testing of electronic circuits easier, the concept of the breadboard still remains in assembling components on a temporary platform.

(a)

(b)

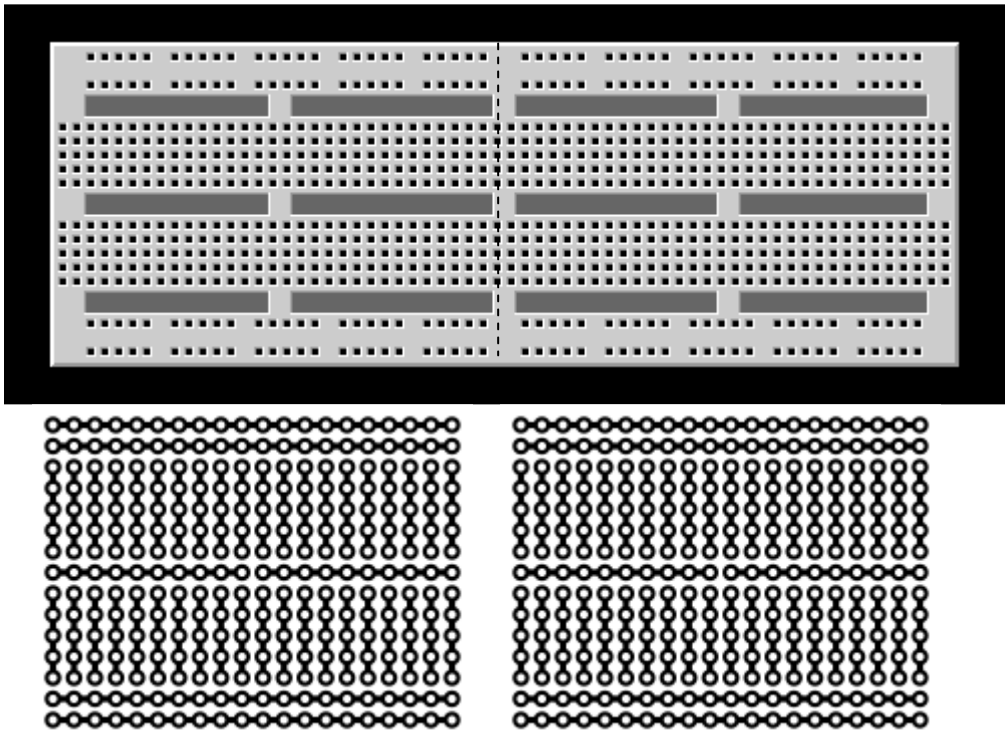


Fig. 1: (a) A typical Breadboard and (b) its connection details

A real breadboard is shown in Fig. 1(a) and the connection details on its rear side are shown in Fig. 1(b). The five holes in each individual column on either side of the central groove are electrically connected to each other, but remain insulated from all other sets of holes. In addition to the main columns of holes, however, you'll note four sets or groups of holes along the top and bottom. Each of these consists of five separate sets of five holes each, for a total of 25 holes. These groups of 25 holes are all connected together on either side of the dotted line indicated on Fig.1(a) and needs an external connection if one wishes the entire row to be connected. This makes them ideal for distributing power to multiple ICs or other circuits.

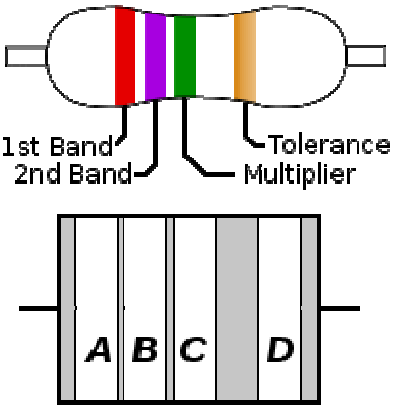
These breadboard sockets are sturdy and rugged, and can take quite a bit of handling. However, there are a few rules you need to observe, in order to extend the useful life of the electrical contacts and to avoid damage to components. These rules are:

- Always make sure power is disconnected when constructing or modifying your experimental circuit. It is possible to damage components or incur an electrical shock if you leave power connected when making changes.
- Never use larger wire as jumpers. #24 wire (used for normal telephone wiring) is an excellent choice for this application. Observe the same limitation with respect to the size of component leads.
- Whenever possible, use ¼ watt resistors in your circuits. ½ watt resistors may be used when necessary; resistors of higher power ratings should never be inserted directly into a breadboard socket.
- Never force component leads into contact holes on the breadboard socket. Doing so can damage the contact and make it useless.
- Do not insert stranded wire or soldered wire into the breadboard socket. If you must have stranded wire (as with an inductor or transformer lead), solder (or use a wire nut to connect) the stranded wire to a short length of solid hookup wire, and insert only the solid wire into the breadboard.

If you follow these basic rules, your breadboard will last indefinitely, and your experimental components will last a long time.

Resistors

Most axial resistors use a pattern of colored stripes to indicate resistance. A 4 band identification is the most commonly used color coding scheme on all resistors. It consists of four colored bands that are painted around the body of the resistor. Resistor values are always coded in ohms (Ω). The color codes are given in the following table in Fig. 1.



Band Color	Digit	Multiplier	Tolerance
Black	0	1	---
Brown	1	10	±1%
Red	2	100	±2%
Orange	3	1,000	±3%
Yellow	4	10,000	±4%
Green	5	100,000	---
Blue	6	1,000,000	---
Violet	7	10,000,000	---
Gray	8	100,000,000	---
White	9	---	---
Gold	---	0.1	±5%
Silver	---	0.01	±10%
None	---	---	±20%

Fig. 1: Color codes of Resistors

- band **A** is first significant figure of component value
- band **B** is the second significant figure
- band **C** is the decimal multiplier
- band **D** if present, indicates tolerance of value in percent (no color means 20%)

For example, a resistor with bands of *yellow, violet, red, and gold* will have first digit 4 (yellow in table below), second digit 7 (violet), followed by 2 (red) zeros: 4,700 ohms. Gold signifies that the tolerance is ±5%, so the real resistance could lie anywhere between 4,465 and 4,935 ohms.

Tight tolerance resistors may have three bands for significant figures rather than two, and/or an additional band indicating temperature coefficient, in units of ppm/K. For large power resistors and potentiometers, the value is usually written out implicitly as "10 kΩ", for instance.

Capacitors:

You will mostly use electrolytic and ceramic capacitors for your experiments.

Electrolytic capacitors

An **electrolytic capacitor** is a type of capacitor that uses an electrolyte, an ionic conducting liquid, as one of its plates, to achieve a larger capacitance per unit volume than other types. They are used in relatively high-current and low-frequency electrical circuits. However, the voltage applied to these capacitors must be polarized; one specified terminal must always have positive potential with respect to the other. These are of two types, axial and radial capacitors as shown in adjacent figure. The arrowed stripe indicates the polarity, with the arrows pointing towards the negative pin.

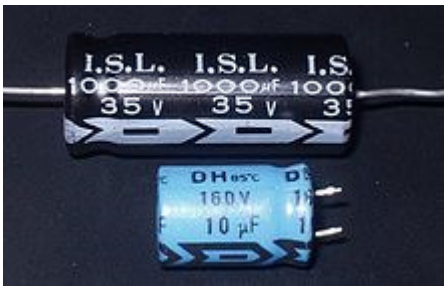


Fig. 2:Axial and Radial Electrolytic capacitors

Warning: connecting electrolytic capacitors in reverse polarity can easily damage or destroy the capacitor. Most large electrolytic capacitors have the voltage, capacitance, temperature ratings, and company name written on them without having any special color coding schemes.

Axial electrolytic capacitors have connections on both ends. These are most frequently used in devices where there is no space for vertically mounted capacitors.

Radial electrolytic capacitors are like axial electrolytic ones, except both pins come out the same end. Usually that end (the "bottom end") is mounted flat against the PCB and the capacitor rises perpendicular to the PCB it is mounted on. This type of capacitor probably accounts for at least 70% of capacitors in consumer electronics.

Ceramic capacitors are generally non-polarized and almost as common as radial electrolytic capacitors. Generally, they use an alphanumeric marking system. The number part is the same as for resistors, except that the value represented is in pF. They may also be written out directly, for instance, 2n2 = 2.2 nF.

SMT

Fig. 3: Ceramic capacitors

Diodes:

A standard specification sheet usually has a brief description of the diode. Included in this description is the type of diode, the major area of application, and any special features. Of particular interest is the specific application for which the diode is suited. The manufacturer also provides a drawing of the diode which gives dimension, weight, and, if appropriate, any identification marks. In addition to the above data, the following information is also provided: a static operating table (giving spot values of parameters under fixed conditions), sometimes a characteristic curve (showing how parameters vary over the full operating range), and diode ratings (which are the limiting values of operating conditions outside which could cause diode damage). Manufacturers specify these various diode operating parameters and characteristics with "letter symbols" in accordance with fixed definitions. The following is a list, by letter symbol, of the major electrical characteristics for the rectifier and signal diodes.

RECTIFIER DIODES

DC BLOCKING VOLTAGE [V_R]—the maximum reverse dc voltage that will not cause breakdown.

AVERAGE FORWARD VOLTAGE DROP [$V_{F(AV)}$]—the average forward voltage drop across the rectifier given at a specified forward current and temperature.

AVERAGE RECTIFIER FORWARD CURRENT [$I_{F(AV)}$]—the average rectified forward current at a specified temperature, usually at 60 Hz with a resistive load.

AVERAGE REVERSE CURRENT [$I_{R(AV)}$]—the average reverse current at a specified temperature, usually at 60 Hz.

PEAK SURGE CURRENT [I_{SURGE}]—the peak current specified for a given number of cycles or portion of a cycle.

SIGNAL DIODES

PEAK REVERSE VOLTAGE [PRV]—the maximum reverse voltage that can be applied before reaching the breakdown point. (PRV also applies to the rectifier diode.)

REVERSE CURRENT [I_R]—the small value of direct current that flows when a semiconductor diode has reverse bias.

MAXIMUM FORWARD VOLTAGE DROP AT INDICATED FORWARD CURRENT [$V_F@I_F$]— the maximum forward voltage drop across the diode at the indicated forward current.

REVERSE RECOVERY TIME [t_{rr}]—the maximum time taken for the forward-bias diode to recover its reverse bias.

The ratings of a diode (as stated earlier) are the limiting values of operating conditions, which if exceeded could cause damage to a diode by either voltage breakdown or overheating.

The PN junction diodes are generally rated for: MAXIMUM AVERAGE FORWARD CURRENT, PEAK RECURRENT FORWARD CURRENT, MAXIMUM SURGE CURRENT, and PEAK REVERSE VOLTAGE

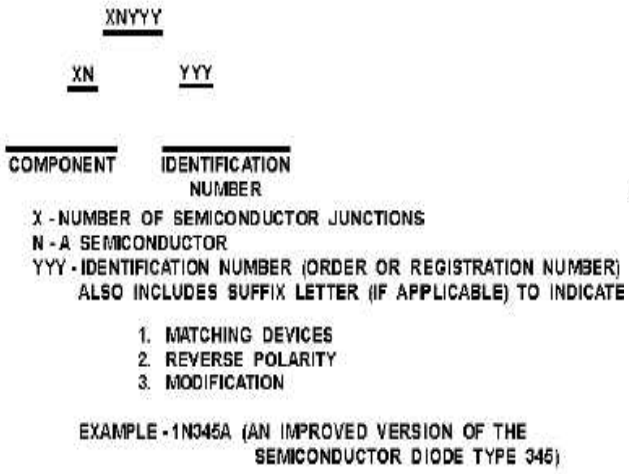
Maximum average forward current is usually given at a special temperature, usually 25º C, (77º F) and refers to the maximum amount of average current that can be permitted to flow in the forward direction. If this rating is exceeded, structure breakdown can occur.

Peak recurrent forward current is the maximum peak current that can be permitted to flow in the forward direction in the form of recurring pulses.

Maximum surge current is the maximum current permitted to flow in the forward direction in the form of nonrecurring pulses. Current should not equal this value for more than a few milliseconds.

Peak reverse voltage (PRV) is one of the most important ratings. PRV indicates the maximum reverse-bias voltage that may be applied to a diode without causing junction breakdown. All of the above ratings are subject to change with temperature variations. If, for example, the operating temperature is above that stated for the ratings, the ratings must be decreased.

There are many types of diodes varying in size from the size of a pinhead (used in subminiature circuitry) to large 250-ampere diodes (used in high-power circuits). Because there are so many different types of diodes, some system of identification is needed to distinguish one diode from another. This is accomplished with the semiconductor identification system shown in Fig. 4. This system is not only used for diodes but transistors and many other special semiconductor devices as well. As illustrated in this figure, the system uses numbers and letters to identify different types of semiconductor devices. The first number in the system indicates the number of junctions in the semiconductor device and is a number, one less than the number of active elements. Thus 1 designates a diode; 2 designates a transistor (which may be considered as made up of two diodes); and 3 designates a tetrode (a four-element transistor). The letter "N" following the first number indicates a semiconductor. The 2- or 3-digit number following the letter "N" is a serialized identification number. If needed, this number may contain a suffix letter after the last digit. For example, the suffix letter "M" may be used to describe matching pairs of separate semiconductor devices or the letter "R" may be used to indicate reverse polarity. Other letters are used to indicate modified versions of the device which can be substituted for the basic numbered unit. For example, a semiconductor diode designated as type 1N345A signifies a two-element diode (1) of semiconductor material (N) that is an improved version (A) of type 345.



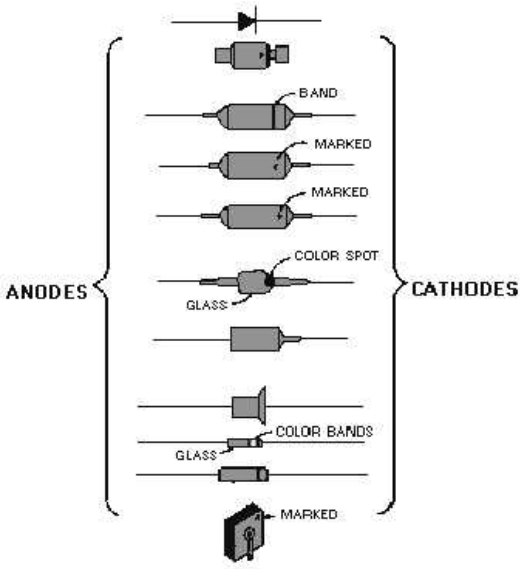


Fig. 4: Identification of Diode **Fig. 5: Identification of Cathode**

When working with different types of diodes, it is also necessary to distinguish one end of the diode from the other (anode from cathode). For this reason, manufacturers generally code the cathode end of the diode with a "k," "+," "cath," a color dot or band, or by an unusual shape (raised edge or taper) as shown in Fig. 5. In some cases, standard color code bands are placed on the cathode end of the diode. This serves two purposes: (1) it identifies

the cathode end of the diode, and (2) it also serves to identify the diode by number.

Transistors:
Transistors are identified by a Joint Army-Navy (JAN) designation printed directly on the case of the transistor. If in doubt about a transistor's markings, always replace a transistor with one having identical markings, or consult an equipment or transistor manual to ensure that an identical replacement or substitute is used.

Example:

2	N	130	A
NUMBER OF JUNCTIONS (TRANSISTOR)	SEMICONDUCTOR	IDENTIFICATION NUMBER	FIRST MODIFICATION

There are three main series of transistor codes used:

- **Codes beginning with B (or A), for example BC108, BC478**
  The first letter B is for silicon, A is for germanium (rarely used now). The second letter indicates the type; for example C means low power audio frequency; D means high power audio frequency; F means low power high frequency. The rest of the code identifies the particular transistor. There is no obvious logic to the numbering system. Sometimes a letter is added to the end (eg BC108C) to identify a special version of the main type, for example a higher current gain or a different case style. If a project specifies a higher gain version (BC108C) it must be used, but if the general code is given (BC108) any transistor with that code is suitable.
- **Codes beginning with TIP, for example TIP31A**
  TIP refers to the manufacturer: Texas Instruments Power transistor. The letter at the end identifies versions with different voltage ratings.
- **Codes beginning with 2N, for example 2N3053**
  The initial '2N' identifies the part as a transistor and the rest of the code identifies the particular transistor. There is no obvious logic to the numbering system.

TESTING A TRANSISTOR to determine if it is good or bad can be done with an ohmmeter or transistor tester. PRECAUTIONS should be taken when working with transistors since they are susceptible to damage by electrical overloads, heat, humidity, and radiation. TRANSISTOR LEAD IDENTIFICATION plays an important part in transistor maintenance because before a transistor can be tested or replaced, its leads must be identified. Since there is NO standard method of identifying transistor leads, check some typical lead identification schemes or a transistor manual before attempting to replace a transistor. Identification of leads for some common case styles is shown in Fig. 6.

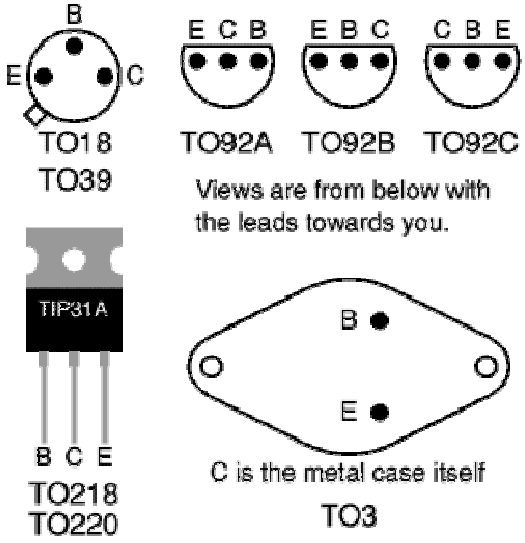


Fig. 6

Testing a transistor

Transistors are basically made up of two *Diodes* connected together back-to-back (Fig. 7). We can use this analogy to determine whether a transistor is of the type PNP or NPN by testing its Resistance between the three different leads, Emitter, Base and Collector.

Testing with a multimeter

Use a multimeter or a simple tester (battery, resistor and LED) to check each pair of leads for conduction. Set a digital multimeter to diode test and an analogue multimeter to a low resistance range.

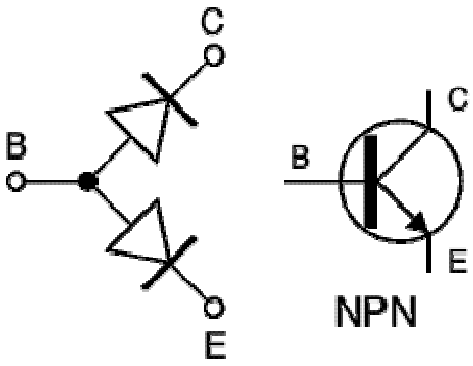


Fig. 7: Testing an NPN transistor

Test each pair of leads both ways (six tests in total):

- The **base-emitter (BE)** junction should behave like a diode and conduct one way only.
- The **base-collector (BC)** junction should behave like a diode and conduct one way only.
- The **collector-emitter (CE)** should not conduct either way.

The diagram shows how the junctions behave in an NPN transistor. The diodes are reversed in a PNP transistor but the same test procedure can be used.

Transistor Resistance Values for the PNP and NPN transistor types

Between Transistor Terminals		PNP	NPN
Collector	Emitter	R_{HIGH}	R_{HIGH}
Collector	Base	R_{LOW}	R_{HIGH}
Emitter	Collector	R_{HIGH}	R_{HIGH}
Emitter	Base	R_{LOW}	R_{HIGH}
Base	Collector	R_{HIGH}	R_{LOW}
Base	Emitter	R_{HIGH}	R_{LOW}

Lab # 1A: Study of Normal and Zener Diode Characteristics

Objectives:

i) To study and plot the forward and reverse bias characteristics of a normal diode and to determine the threshold voltage, static and dynamic resistance.

ii) To study and plot forward and reverse bias characteristics of a zener diode and to determine the threshold and zener break-down voltage.

Overview:

A diode is a nonlinear circuit element. The symbol of a diode and a real commercial diode is shown in Fig. 1. Generally there is a band marked at its cathode for its identification. There exists another type of diode known as zener diode, which has a heavily doped PN junction.

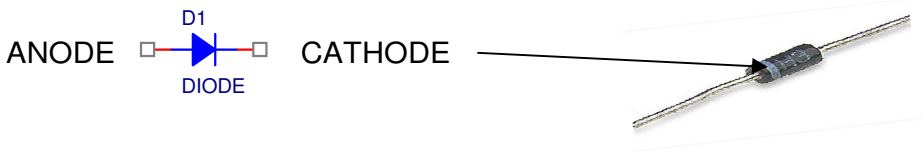


Fig. 1

The theoretical equation for the diode current I_D is

$$I_D = I_S\left[\exp(\frac{V_D}{nV_T}) - 1\right]$$

where V_D is the diode voltage drop, I_S is the saturation current, n is the emission coefficient, and $V_T = kT/q$ ($\approx 0.026V$ at T=300K) is the thermal voltage. The emission coefficient accounts for recombinations of electrons and holes in the depletion region, which tend to decrease the current. For discrete diodes, it has the value n is 2.

The I~V characteristic of an ideal diode is shown in Fig. 2-a. Under forward biased condition of a real PN junction diode, the P-side is connected to the positive and N-side is connected to the negative terminal of the power supply. This reduces the potential barrier. As a result current flows from P to N-type in forward direction. When the applied voltage is more than the barrier potential, the resistance is small (ideally 0) and the current increases rapidly. This point is called the *Knee-point* or *turn-on voltage* or *threshold voltage* (Fig. 2-b). This voltage is about 0.3 volts for Ge diodes and 0.7 volts for Si diodes.

Under reverse biased condition, the P-side of the junction diode is connected to the negative and N-side is connected to the positive terminal of the power supply. This increases the potential barrier due to which no current should flow ideally. But in practice, the minority carriers can travel down the potential barrier to give very small current. This is called as the *reverse saturation current*. This current is about 2-20 μA for Ge diodes and 2-20 nA for Si diodes (the values might differ for diodes of different makes).

However, if the reverse bias is made too high, the current through the PN junction increases abruptly. The voltage at which this phenomenon occurs is known as the *break-down or reverse voltage* and the mechanism involved depends on the construction of the diode. In conventional diodes with a lightly doped junction, application of higher reverse voltage leads to large number of carriers produced by collision of thermally generated electrons and the phenomenon is called *avalanche breakdown*. When the reverse bias exceeds this breakdown voltage, a conventional diode is subject to high current. Unless this current is limited by external circuitry, the diode will be permanently damaged. If the junction is heavily doped with narrow depletion layers, break-down occurs when the reverse voltage is strong enough to rupture the covalent bonds generating large number of electron-hole pairs. This phenomenon is called *zener breakdown*.

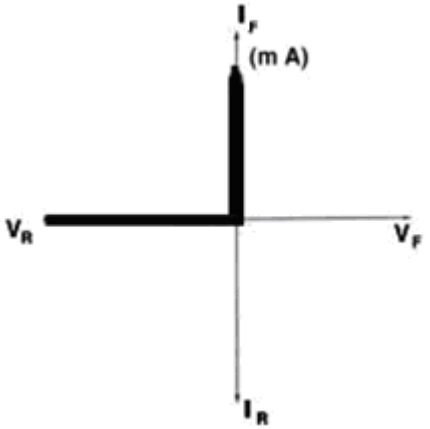


Fig. 2 (a)

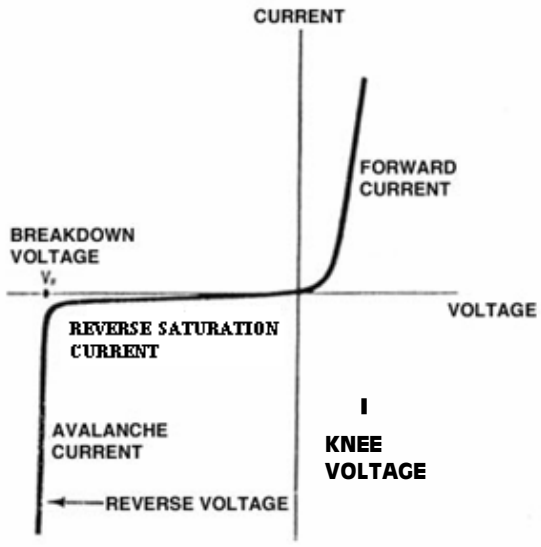


Fig. 2 (b)

Zener diode:

It is a reverse biased heavily doped PN junction diode generally operated in zener breakdown region. Zener voltage is the reverse voltage above which there is a controlled *breakdown* which does not damage the diode. The voltage drop across the diode remains constant at zener voltage no matter how high the reverse bias voltage is. The forward characteristic of a zener diode is similar to a normal diode. The symbol of a zener diode is shown in Figure 3.

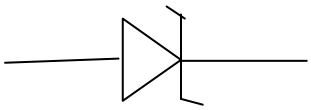


Fig. 3

Static and Dynamic Resistance:

At a given operating point, the static and dynamic resistance of a diode can be determined from its characteristics as shown in Fig. 4. The *static or dc resistance*, R_D, of the diode at the operating point (the point where the load line intersects the diode characteristics), Q, is simply the quotient of the corresponding levels of V_D and I_D. The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics.

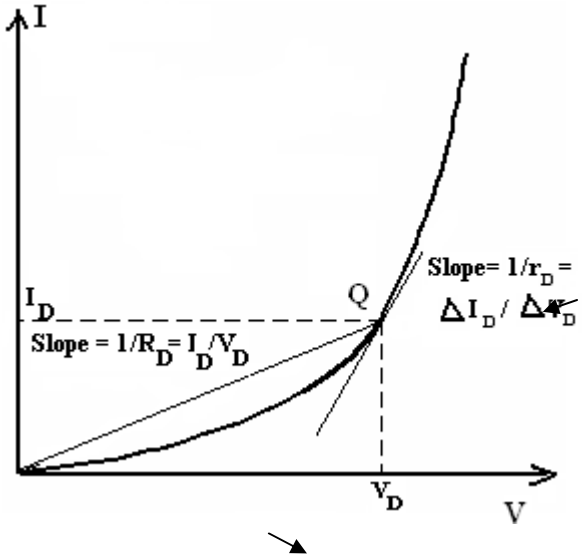


Fig. 4

$$R_D = V_D/I_D$$

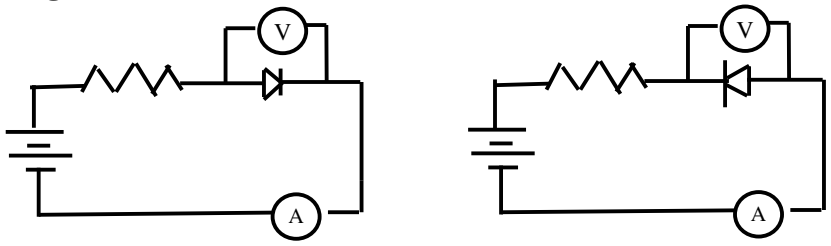
The diode circuits generally operate with varying inputs, which will move the instantaneous operating point up and down a region of the characteristics and defines a specific change in current and voltage. *Dynamic or ac Resistance*, r_d, is defined as the quotient of this change in voltage and change in current around the dc operating point.

$$r_d = \Delta V_D / \Delta I_D$$

Components/Equipments:

(i) Junction diodes (Si,Ge), (ii) Zener diode, (iii) A current limiting Resistor (1kΩ), (iv) D.C. Power supply, (iv) 2 multimeters and (vi) Breadboard, (vii) Connecting wires

Circuit Diagram:



Forward Biasing Reverse Biasing

Procedure:

Before you proceed, identify the p and n-side of the diode in order to connect properly in forward and reverse bias mode.

(i) Forward and reverse bias characteristics of a normal diode:

Forward Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(a). Connect to the 0-30V dc power supply.
2. Switch on the power supply. Slowly increase the supply voltage in steps of 0.1 Volt using the fine adjustment knob and note down the corresponding readings of diode current. When you find the change in current is larger (which means you have already crossed the threshold point!), increase the supply voltage in steps of 0.5 to note down current.
3. Using multimeters in appropriate modes, measure voltage drop across the diode and the current in the circuit. Switch off the supply after taking sufficient readings.
4. Plot the I~V characteristics and estimate the threshold voltage.
5. Choose two operating points below and above the threshold point and determine the static and dynamic resistance at each of the points.

Reverse Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(b). Connect to the 0-30V dc power supply.
2. Switch on the supply. Increase the supply voltage in steps of 0.5 Volt to note down the diode current.
3. Use multimeters for voltage and current measurements. Keep in mind that magnitude of current flowing in the circuit will be very small, so choose current range properly. Switch off the supply after taking sufficient readings.
4. Plot the I~V characteristics on the same graph sheet and estimate the reverse saturation current.

(ii) Forward and reverse bias characteristics of a zener diode:

Forward Bias characteristics:

1. Assemble the circuit on your breadboard as shown in Fig 1(a). Use a zener diode this time in your circuit and repeat steps 2-4 of forward bias characteristics of normal diode.

Reverse Bias characteristics:

1. Assemble the circuit on your breadboard with the zener diode, as shown in Fig 1(b). Keep in mind that initially the magnitude of current flowing in the circuit will be very small.
2. Switch on the power supply. Increase the supply voltage in steps of 0.5 Volt and note down the corresponding readings of diode current. When you find the change in current is larger (which means you have already crossed the break-down point!), using the fine adjustment knob increase the supply voltage in steps of 0.1 to note down diode current.
3. Plot the I~V characteristics on the same graph sheet and estimate the threshold and break-down voltages.

Observation:

Code Number of Diode: (i) normal diode: _____ (Si)

_____ (Ge)

(ii) Zener Diode: _____

Table (i) For normal Diode (Si)

Obs. No.	Forward Biasing			Reverse biasing		
	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (mA)	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (μA)
1						

(ii) For normal Diode (Ge)

Obs. No.	Forward Biasing			Reverse biasing		
	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (mA)	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (μA)
1						

(iii) For zener Diode:

Obs. No.	Forward Biasing			Reverse biasing		
	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (mA)	Voltage Applied (V)	Voltage, V_D (V)	Current, I_D (μA)
1						

Graphs:

Plot I~V characteristics for both the diodes and estimate the required parameters.

Discussions/Results:

i) Describe the behavior of the I~V curve for each diode.

ii) Threshold voltage for normal diode is _____V (What type of a diode it is, Si/Ge?)

Static resistance = ------, Dynamic resistance = ------ at operating point Q.

iii) Threshold voltage for Zener diode = --------

Zener Break-down voltage = -------

Precautions:

LAB#1B: RECTIFIER CIRCUITS WITHOUT AND WITH FILTER

A.Half-Wave Rectifier

Objectives:

iii) To construct a half-wave rectifier circuit and analyze its output.

iv) To analyze the rectifier output using a capacitor in shunt as a filter.

Overview:

The process of converting an alternating current into direct current is known as rectification. The unidirectional conduction property of semiconductor diodes (junction diodes) is used for rectification. Rectifiers are of two types: (a) Half wave rectifier and (b) Full wave rectifier. In a half-wave rectifier circuit (Fig. 1), during the positive half-cycle of the input, the diode is forward biased and conducts. Current flows through the load and a voltage is developed across it. During the negative half-cycle, it is reverse bias and does not conduct. Therefore, in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it. Thus the dc voltage across the load is sinusoidal for the first half cycle only and a pure a.c. input signal is converted into a unidirectional pulsating output signal.

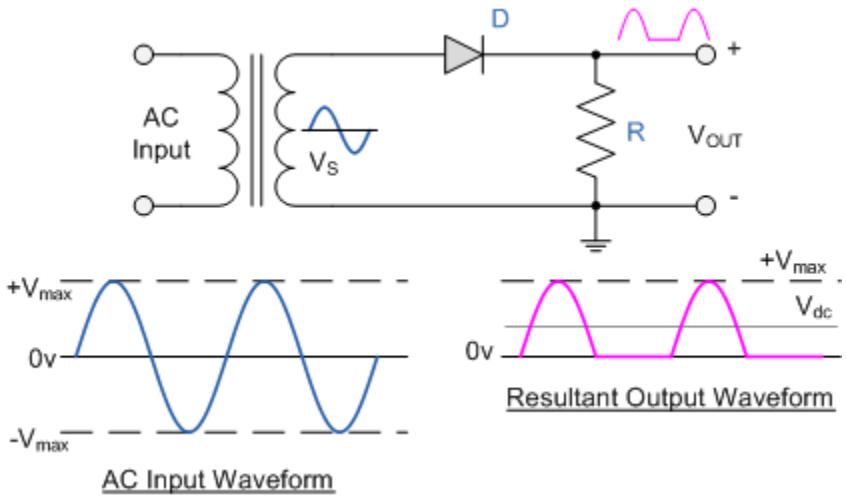


Fig.1: Half-wave rectifier circuit

Since the diode conducts only in one half-cycle (0-π), it can be verified that the d.c. component in the output is V_{max}/π, where V_{max} is the peak value of the voltage. Thus,

$$V_{dc} = \frac{V_{\max}}{\pi} = 0.318 V_{\max}$$

The current flowing through the resistor, $I_{dc} = \frac{V_{dc}}{R}$ and power consumed by the load, $P = I_{dc}^{\,2} R$.

Ripple factor:

As the voltage across the load resistor is only present during the positive half of the cycle, the resultant voltage is "ON" and "OFF" during every cycle resulting in a low average dc value. This variation on the rectified waveform is called "**Ripple**" and is an undesirable feature. The ripple factor is a measure of purity of the d.c. output of a rectifier and is defined as

$$r = \left.\frac{V_{ac}}{V_{dc}}\right|_{output} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{\left(\frac{0.5}{0.318}\right)^2 - 1} = 1.21$$

In case of a half-wave rectifier $V_{rms} = V_{max}/2 = 0.5V_{max}$. (How?)

Rectification Efficiency:

Rectification efficiency, η, is a measure of the percentage of total a.c. power input converted to useful d.c. power output.

$$\begin{aligned}\eta &= d.c.power\ delivered\ to\ load / a.c.power\ at\ input \\ &= V_{dc} I_{dc} / V_{ac} I_{ac} \\ &= \frac{I_{dc}^2 R}{I_{ac}^2 (r_d + R)} = \frac{(0.318 V_{\max})^2}{(0.5 V_{\max})^2 \left(1 + \frac{r_d}{R}\right)} = \frac{0.405}{\left(1 + \frac{r_d}{R}\right)}\end{aligned}$$

Here r_d is the forward resistance of diode. Under the assumption of no diode loss (r_d<<), the rectification efficiency in case of a half-wave rectifier is approximately 40.5%.

Filters:

The output of a rectifier gives a pulsating d.c. signal (Fig.1) because of presence of some a.c. components whose frequency is equal to that of the a.c. supply frequency. Very often when rectifying an alternating voltage we wish to produce a "steady" direct voltage free from any voltage variations or ripple. Filter circuits are used to smoothen the output. Various filter circuits are available such as shunt capacitor, series inductor, choke input LC filter and

π-filter etc. Here we will use a simple **shunt capacitor** filter circuit (Fig. 2). Since a capacitor is open to d.c. and offers low impedance path to a.c. current, putting a capacitor across the output will make the d.c. component to pass through the load resulting in small ripple voltage.

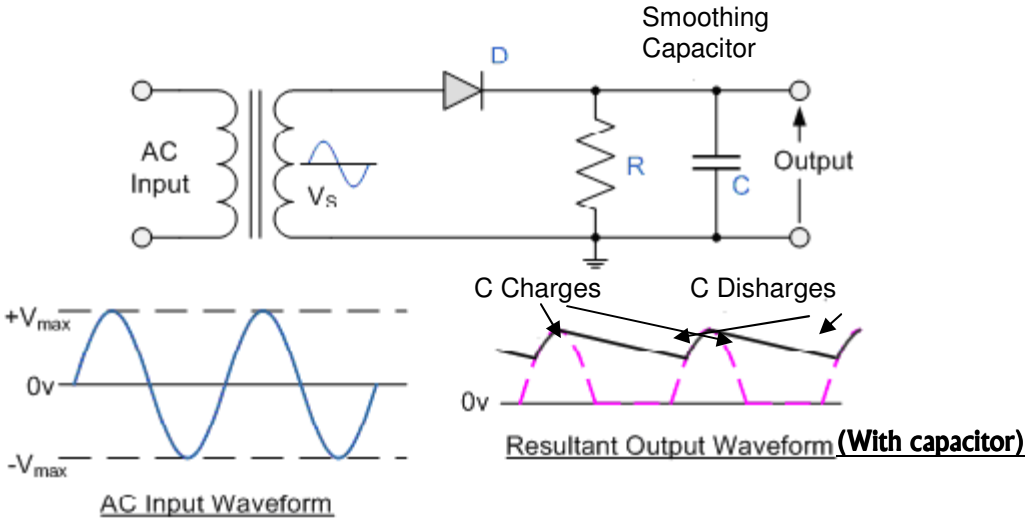


Fig.2: Half-wave rectifier circuit with capacitor filter

The working of the capacitor can be understood in the following manner. When the rectifier output voltage is increasing, the capacitor charges to the peak voltage $V_{m.}$ Just past the positive peak the rectifier output voltage tries to fall. As the source voltage decreases below V_m , the capacitor will try to send the current back to diode making it reverse biased. Thus the diode separates/disconnects the source from the load and hence the capacitor will discharge through the load until the source voltage becomes more than the capacitor voltage. The diode again starts conducting and the capacitor is again charged to the peak value V_m and the process continues. Although in the output waveform the discharging of capacitor is shown as a straight line for simplicity, the decay is actually the normal exponential decay of any capacitor discharging through a load resistor. The extent to which the capacitor voltage drops depends on the capacitance and the amount of current drawn by the load; these two factors effectively form the RC time constant for voltage decay. A proper combination of large capacitance and small load resistance can give out a steady output.

Circuit components/Equipments:

(ii) A step-down transformer, (ii) A junction diode, (iii) 3 Load resistors, (iv) 3 Electrolytic Capacitors, (v) Oscilloscope, (vi) Multimeters, (vii) Connecting wires, (viii) Breadboard.

Circuit Diagram: (As shown in Figs. 1 and 2)

Procedure:

i) Configure the half-wave rectifier circuit as shown in the circuit diagram. Note down all the values of the components being used.

ii) Connect the primary side of the transformer to the a.c. Mains and secondary to the input of the circuit.

iii) Measure the input a.c. voltage (V_{ac}) and current (I_{ac}) and the output a.c. (V_{ac}), d.c. (V_{dc}) voltages using multimeter for at least 3 values of load resistor (Be careful to choose proper settings of multimeter for ac and dc measurement).

iv) Multiply the V_{ac} at the input by $\sqrt{2}$ to get the peak value and calculate V_{dc} using the formula $V_{dc} = V_{max}/ \pi$. Compare this value with the measured V_{dc} at the output.

v) Feed the input and output (in DC coupling mode) to the two channels of oscilloscope. We will use oscilloscope here only to trace the output waveform. Save the data for each measurement using SAVE/LOAD or STORAGE button of the oscilloscope.

vi) Calculate the ripple factor and efficiency.

vii) Connect an electrolytic capacitor (with –ve terminal connected to ground) across the output for each load resistor and measure the output a.c. and d.c. voltages once again and calculate the ripple factor. Trace the input and output waveforms in oscilloscope and notice the change.

viii) Repeat the above measurement foe all values of capacitors and study the output.

Observations:

iv) Code number of diode = _____

v) Input Voltage: V_{ac} = _____ Volt

Table(I): Half wave rectifier w/o filter

Sl. No	Load R (kΩ)	Input Current I_{ac} (mA)	Output Voltage			Ripple Factor *r*	Efficiency η $(V^2dc/R)/V_{ac}I_{ac}$ (%)
			V_{ac} (Volt)	V_{dc} (Volt)	V_{max}/π (Volt)		
1							
2							
3							

Table(II): Half wave rectifier with filter (C = ____ μF) (Make separate tables for each capacitor)

Sl. No	Load R (kΩ)	Output Voltage		Ripple Factor *r*
		V_{ac} (Volt)	V_{dc} (Volt)	
1				
2				
3				

(III) Input and output waveforms:

Waveforms without Filter:

R = _____ **Input** **Output**

(Paste data here)

Waveforms with Capacitor Filter: C = _____ μF

R = _____ **Input** **Output**

(Paste data here)

B.Full –Wave bridge Rectifier

Objectives:

v) To construct a full-wave bridge rectifier circuit and analyze its output.

vi) To analyze the rectifier output using a capacitor in shunt as a filter.

Overview:

As you have seen already a half-wave rectifier circuit is unsuitable to applications which need a "steady and smooth" dc supply voltage. One method to improve on this is to use every half-cycle of the input voltage instead of every other half-cycle. The circuit which allows us to do this is called a Full-wave Rectifier. Here, unidirectional current flows in the output for both the cycles of input signal and rectifies it. The rectification can be done either by a center tap full wave rectifier (using two diodes) or a full wave bridge rectifier (using four diodes). In this experiment we will study a full wave bridge rectifier.

The Full-wave Bridge Rectifier

Another type of circuit that produces the same output as a full-wave rectifier is that of the Bridge Rectifier (Fig. 1). This type of single phase rectifier uses 4 individual rectifying diodes connected in a "bridged" configuration to produce the desired output but does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown in figure. The 4 diodes labeled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below (Fig. 2). During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch of as they are now reverse biased. The current flowing through the load is the same direction as before.

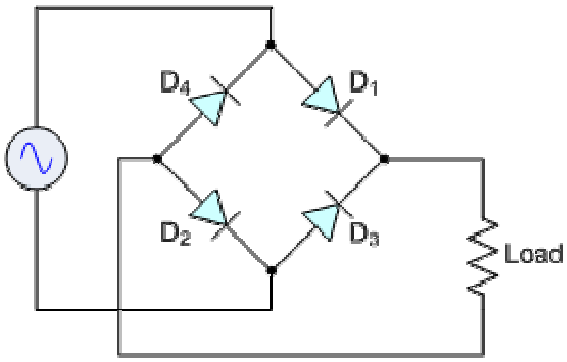


Fig. 1: Full-wave Bridge Rectifier

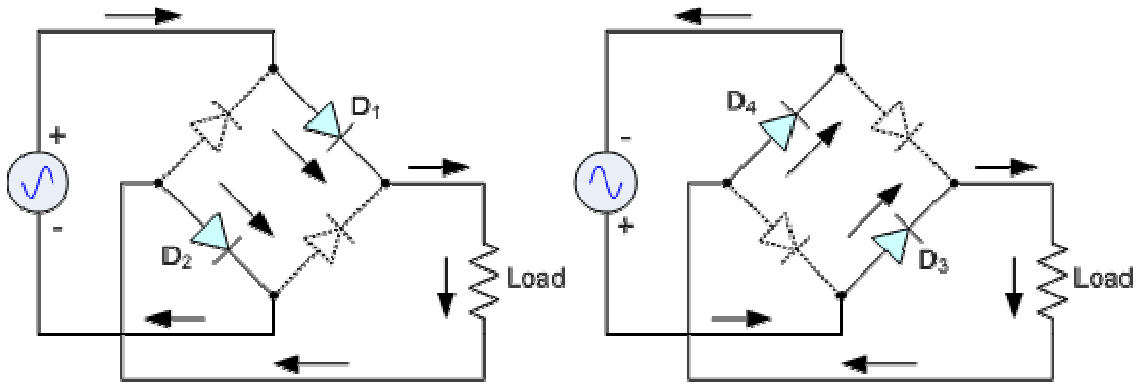


Fig. 2: Working of Full-wave bridge rectifier

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional during both the half cycles. Thus, the average dc output voltage across the load resistor is double that of a half-wave rectifier circuit, assuming no losses.

$$V_{dc} = \frac{2V_{\max}}{\pi} = 0.637V_{\max}$$

Ripple factor:

As mentioned in the previous lab the ripple factor is a measure of purity of the d.c. output of a rectifier and is defined as

$$r = \frac{V_{ac}(output)}{V_{dc}(output)} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{\left(\frac{0.707}{0.637}\right)^2 - 1} = 0.48$$

In case of a full-wave rectifier $V_{rms} = V_{max}/\sqrt{2} = 0.707V_{max}$. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply).

Rectification Efficiency:

Rectification efficiency, η, is given by

$$\eta = d.c.power\ delivered\ to\ load / a.c.power\ at\ input$$
$$= V_{dc} I_{dc} / V_{ac} I_{ac}$$
$$= \frac{V_{dc}^2 / R_L}{V_s^2 / (r_d + R_L)} = \frac{(0.637V_{\max})^2}{(0.707V_{\max})^2\left(1 + \frac{r_d}{R_L}\right)} = \frac{0.811}{\left(1 + \frac{r_d}{R_L}\right)}$$

where r_d is the forward resistance of diode. Under the assumption of no diode loss (r_d<<), the rectification efficiency in case of a full-wave rectifier is approximately 81.1%,

which is twice the value for a half-wave rectifier.

Filter:

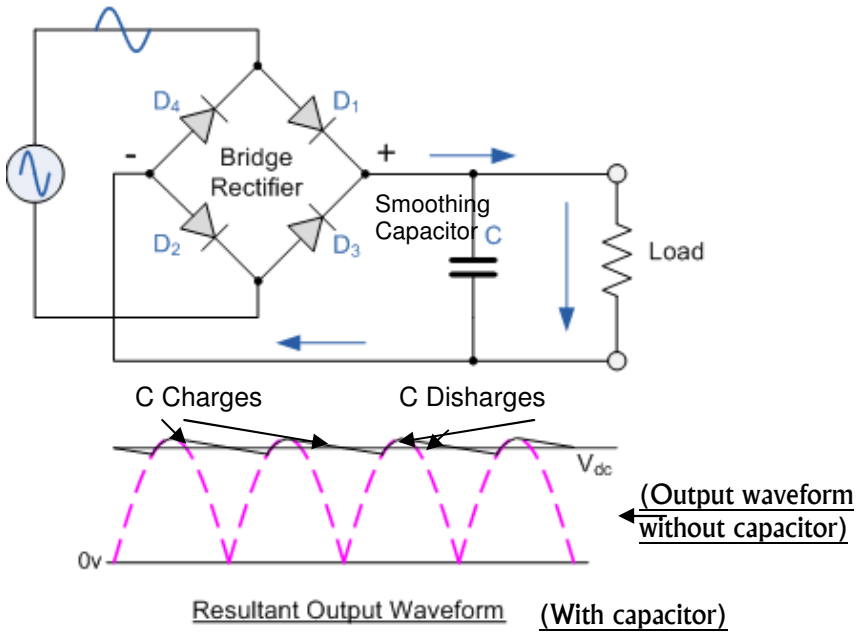


Fig.3: Full-wave rectifier circuit with capacitor filter

The full-wave rectifier circuit with capacitor filter is shown in Fig. 3. The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth dc output voltage. The detailed description of its filtering action is already explained in half-wave rectifier handout. Two important parameters to consider when choosing a suitable a capacitor are its *working voltage*, which must be higher than the no-load output value of the rectifier and its *capacitance value*, which determines the amount of ripple that will appear superimposed on top of the dc voltage.

Apart from rectification efficiency, the main advantages of a full-wave bridge rectifier is that it has a smaller ac ripple value for a given load and a smaller smoothing capacitor than an equivalent half-wave rectifier. The amount of ripple voltage that is superimposed on top of the dc supply voltage by the diodes can be virtually eliminated by adding other improved filters such as a pi-filter.

Circuit components/Equipments:

(iii)A step-down transformer, (ii) 4 junction diodes, (iii) 3 Load resistors, (iv) Capacitor, (v) Oscilloscope, (vi) Multimeters, (vii) Connecting wires, (viii) Breadboard.

Circuit Diagram: (As shown in Fig. 1 and 3)

Procedure:

ix) Configure the full-wave rectifier circuit as shown in the circuit diagram. Note down all the values of the components being used.

x) Connect the primary side of the transformer to the a.c. Mains and secondary to the input of the circuit.

xi) Measure the input a.c. voltage (V_{ac}) and current (I_{ac}) and the output a.c. (V_{ac}) and d.c. (V_{dc}) voltages using multimeter for at least 3 values of load resistor (Be careful to choose proper settings of multimeter for ac and dc measurement).

xii) Feed the input and output to the oscilloscope (we will use oscilloscope here only to trace the output waveform) and save the data for each measurement. BE CAREFUL NOT TO MEASURE THE INPUT AND OUTPUT VOLTAGES SIMULTANEOUSLY.

xiii) Multiply the V_{ac} at the input by $\sqrt{2}$ to get the peak value and calculate V_{dc} Using the formula $V_{dc} = 2V_{max}/ \pi$. Compare this value with the measured V_{dc} at the output.

xiv) Calculate the ripple factor and efficiency.

xv) Connect the capacitor across the output for each load resistor. Measure the output a.c. and d.c. voltages once again and calculate the ripple factor. Trace the input and output waveforms in oscilloscope and notice the change. (If time permits you could also use different values of capacitors and study the output)

Observations:

vi) Code number of diode = _____

vii) Input Voltage: V_{ac} = _____ Volt

Table(I): Full-wave rectifier w/o filter

Sl. No	Load R_L (kΩ)	Input Current I_{ac} (mA)	Output Voltage			Ripple Factor r	Efficiency η $(V_{dc}^2/R_L)/V_{ac}I_{ac}$ (%)
			V_{ac} (Volt)	V_{dc} (Volt)	$2V_{max}/\pi$ (Volt)		
1							
2							
3							

Table(II): Full-wave rectifier with filter (C = ____ μF)

Sl. No	Load R_L (kΩ)	Output Voltage		Ripple Factor r
		V_{ac} (Volt)	V_{dc} (Volt)	
1				
2				
3				

(III) Input and output waveforms:

Waveforms without Filter:

R_L = _____

Input **Output**

(Paste data here)

Waveforms with Capacitor Filter:

R_L = _____

Input **Output** (Paste data here)

Discussions:

Precautions:

Lab#2A: Setting up a Power Supply using a Zener Diode as Voltage Regulator

Objectives:

To set up a power supply using a zener diode as a voltage regulator and to calculate percentage of regulation.

Overview:

Zener diodes are generally used in the reverse bias mode. You have seen already in one of your previous experiments that the zener diode has a region of almost a constant voltage in its reverse bias characteristics, regardless of the current flowing through the diode. This voltage across the diode (zener Voltage, V_z) remains nearly constant even with large changes in current through the diode caused by variations in the supply voltage or load. This ability to control itself can be used to great effect to regulate or stabilize a voltage source against *supply* or *load* variations. The zener diode maintains a constant output voltage until the diode current falls below the minimum Iz value in the reverse breakdown region, which means the supply voltage, V_S, must be much greater than V_z for a successful breakdown operation. When no load resistance, R_L, is connected to the circuit, no load current ($I_L = 0$), is drawn and all the circuit current passes through the zener diode which dissipates its maximum power. So, a suitable current limiting resistor, (R_S) is always used in series to limit the zener current to less than its maximum rating under this "no-load" condition.

From the previous experiments on rectifiers, you know that the d.c. output voltage from the half or full-wave rectifiers contains ripples superimposed on the d.c. voltage and that the average output voltage changes with load. As shown in the circuit diagram, a more stable reference voltage can be produced by connecting a simple zener regulator circuit across the output of the rectifier. The breakdown condition of the zener can be confirmed by calculating the Thevenin voltage, V_{TH}, facing the diode is given as:

$$V_{TH} = \frac{R_L}{R_S + R_L} V_S$$

This is the voltage that exists when the zener is disconnected from the circuit. Thus, V_{TH} has to be greater than the zener voltage to facilitate breakdown. Now, under this breakdown condition, irrespective of the load resistance value, the current through the current limiting resistor, I_S, is given by

$$I_S = \frac{V_S - V_Z}{R_S}$$

The output voltage across the load resistor, V_L, is ideally equal to the zener voltage and the load current, I_L, can be calculated using Ohm's law:

$$V_L = V_Z \text{ and } I_L = \frac{V_L}{R_L}$$

Thus the zener current, I_Z, is $I_Z = I_S - I_L$.

Now that you have constructed a basic power supply, its quality depends on its load and line regulation characteristics as defined below.

Load Regulation: It indicates how much the load voltage varies when the load current changes. Quantitatively, it is defined as: $\textbf{Load regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$, where V_{NL} = load voltage with no load current ($I_L = 0$) and V_{FL} = load voltage with full load current. The smaller the regulation, the better is the power supply.

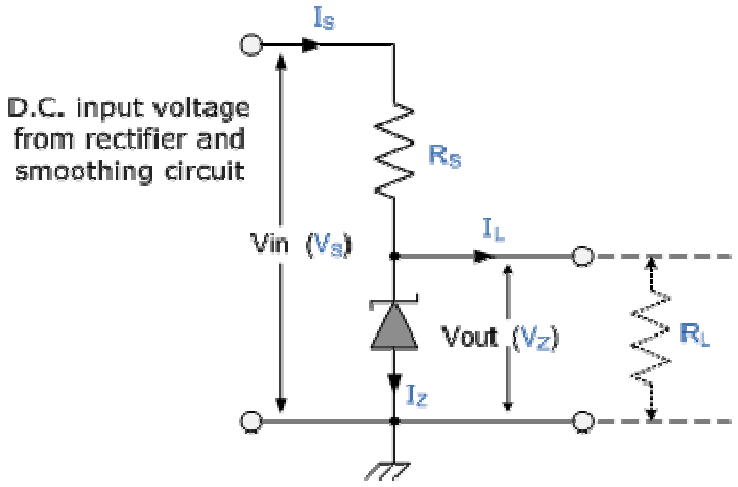
Line Regulation: It indicates how much the load voltage varies when the input line voltage changes. Quantitatively, it is defined as: $\textbf{Line regulation} = \frac{V_{HL} - V_{LL}}{V_{LL}} \times 100\%$,

where V_{HL} = load voltage with high input line voltage, and V_{LL} = load voltage with low input line voltage. As with load regulation, the smaller the regulation, the better is the power supply.

Circuit components/Equipments:

(i) A variable transformer, (ii) 4 junction diodes, (iii) A zener diode, (iv) Current limiting resistor, (v) Load resistors, (vi) Capacitor, (vii) Multimeters, (viii) Connecting wires, (ix) Breadboard.

Circuit Diagram:



Procedure:

1. Use the full-wave rectifier circuit configured in your previous lab (with capacitor filter minus the load). Connect the primary of a variable transformer to a.c. mains and the secondary as the a.c. source for the rectifier circuit. This will facilitate to change the magnitude of input voltage to rectifier by choosing different secondary terminals. You can use only those secondary terminals whose voltage is much more than the zener breakdown voltage you are using.
2. Complete the rest part of the circuit as shown in the circuit diagram. Note down all the values of the components being used including the zener breakdown voltage.
3. Keeping input voltage suitably fixed, use different values of R_L and measure both the output d.c. voltage and current using multimeter (in d.c. mode). Measure input unregulated d.c. voltage across capacitor. Calculate V_{TH} before each measurement and ensure that the zener is operating in breakdown region.
4. Similarly, keeping R_L fixed, vary the input voltage and measure again the output d.c. voltage, current and input unregulated d.c. voltage across capacitor. Calculate V_{TH} before each measurement.
5. Tabulate all your data and calculate percentage regulation in each case.

Observations:

Specifications of zener diode: Breakdown voltage = _____ V

R_S = _____kΩ

Table (i) Load Regulation: Input unregulated d.c. voltage = _____V

Sl. No	Load (R_L) (kΩ)	D.C. input voltage (V) (unregulated)	$V_{TH} = \frac{R_L}{R_S + R_L} V_S$ (V)	Output D.C. Voltage (V_L) (V)	Output Current (I_L) (mA)	Percentage Regulation (%)
1	..			V_{FL} =..		$\frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$
..	Increasing order					
..	∞			V_{NL} = ..	0	

Table (ii) Line regulation: R_L = _____ kΩ

Sl. No	Input D.C. Voltage (V_i) (V)	$V_{TH} = \frac{R_L}{R_S + R_L} V_S$ (V)	Output D.C. Voltage (V_L) (V)	Output Current (I_L) (mA)	Percentage Regulation (%)
1			V_{LL} = ..		$\frac{V_{HL} - V_{LL}}{V_{LL}} \times 100$
..	Increasing order				
..			V_{HL} = ..		

Graphs:

Plot graphs R_L (X-axis) vs V_L (Y-axis) and V_i (X-axis) vs V_L (Y-axis) using data of tables (ii) and (iii), respectively. Also plot I_L (X-axis) and V_L (Y-axis) for each set of observations.

Discussions/Results:

Precautions:

Lab # 2B: Study of LCR Resonant Circuit

Objectives:

(i) To study the behavior of a series LCR resonant circuit and to estimate the resonant frequency and Q-factor.
(ii) To study the behavior of voltage drop across inductor and capacitor and hence estimate the resonant frequency.

Overview:

Circuits containing an inductor *L*, a capacitor *C*, and a resistor *R*, have special characteristics useful in many applications. Their frequency characteristics (impedance, voltage, or current vs. frequency) have a sharp maximum or minimum at certain frequencies. These circuits can hence be used for selecting or rejecting specific frequencies and are also called tuning circuits. These circuits are therefore very important in the operation of television receivers, radio receivers, and transmitters.

Let an **alternating voltage V_i** be applied to an inductor L, a resistor R and a capacitor *C* all in series as shown in the circuit diagram. If *I* is the instantaneous current flowing through the circuit, then the applied voltage is given by

$$V_i = V_{R_{d.c.}} + V_L + V_C = \left[R_{d.c.} + j(\omega L - \frac{1}{\omega C}) \right] I \qquad (1)$$

Here $R_{d.c.}$ is the total d.c. resistance of the circuit that includes the resistance of the pure resistor, inductor and the internal resistance of the source. This is the case when the resistance of the inductor and source are not negligible as compared to the load resistance R. So, the total impedance is given by

$$Z = \left[R_{d.c.} + j(\omega L - \frac{1}{\omega C}) \right] \qquad (2)$$

The magnitude and phase of the impedance are given as follows:

$$|Z| = \left[R_{d.c.}{}^2 + (\omega L - \frac{1}{\omega C})^2 \right]^{1/2} \qquad (3)$$

$$\tan \phi = \frac{(\omega L - \frac{1}{\omega C})}{R_{d.c.}} \qquad (4)$$

Thus three cases arise from the above equations:

(a) $\omega L > (1/\omega C)$, then tan φ is positive and applied voltage leads current by phase angle φ.

(b) $\omega L < (1/\omega C)$, then tan φ is negative and applied voltage lags current by phase angle φ.

(c) $\omega L = (1/\omega C)$, then tan φ is zero and applied voltage and current are in phase. Here $V_L = V_C$, the circuit offers minimum impedance which is purely resistive. Thus the current flowing in the circuit is maximum (I_0) and also V_R is maximum and V_{LC} (V_L+V_C) is minimum. This condition is known as resonance and the corresponding frequency as resonant frequency (ω_0) expressed as follows:

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad or \quad f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (5)$$

At resonant frequency, since the impedance is minimum, hence frequencies near f_0 are passed more readily than the other frequencies by the circuit. Due to this reason LCR-series circuit is called ***acceptor circuit***. The band of frequencies which is allowed to pass readily is called **pass-band**. The band is arbitrarily chosen to be the range of frequencies between which the current is equal to or greater than $I_0/\sqrt{2}$. Let f_1 and f_2 be these limiting values of frequency. Then the width of the band is $BW = f_2 - f_1$.

The **selectivity** of a tuned circuit is its ability to select a signal at the resonant frequency and reject other signals that are close to this frequency. A measure of the selectivity is the **quality factor** (**Q**), which is defined as follows:

$$Q = \frac{f_0}{f_2 - f_1} = \frac{\omega_0 L}{R_{d.c.}} = \frac{1}{R_{d.c.}\omega_0 C} \qquad (6)$$

In this experiment, you will measure the magnitude and phase of V_R and V_{LC} with respect to V_i ($\left|(V_R/V_i)\right|$, $\left|(V_{LC}/V_i)\right|$, Φ_R and Φ_{LC} in the vicinity of resonance using following working formulae.

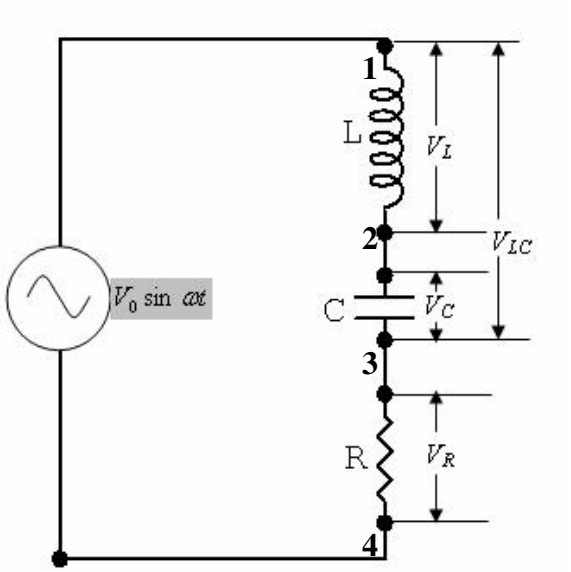
$$\left|\frac{V_R}{V_i}\right| = \frac{R}{|Z|} \qquad (7) \qquad \phi_R = -\tan^{-1}\left(\frac{\omega L - \frac{1}{\omega C}}{R_{d.c.}}\right) \qquad (8)$$

and $$\left|\frac{V_{LC}}{V_i}\right| = \frac{\omega L - \frac{1}{\omega C}}{|Z|} \qquad (9) \qquad \phi_{LC} = \tan^{-1}\left(\frac{R_{d.c,}}{\omega L - \frac{1}{\omega C}}\right) \qquad (10)$$

Circuit Components/Instruments:

(i) Inductor, (ii) Capacitor, (iii) Resistors, (iv) Function generator, (v) Oscilloscope, (vi) Multimeter/LCR meter, (vii) Connecting wires, (viii) Breadboard

Circuit Diagram:



Procedure:

(I) Measuring V_R, V_{LC} and Φ_R, Φ_{LC}:

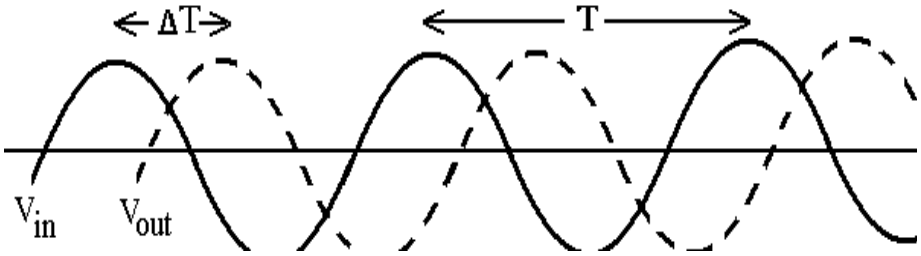
(a) Using the multimeter/LCR meter, note down all the measured values of the inductance, capacitance and resistance of the components provided. Also, measure the resistance of the inductor. Calculate the d.c. resistance of the circuit. Calculate the resonant frequency.

(b) Configure the circuit on a breadboard as shown in circuit diagram. Set the function generator **Range** in 20 KHz and **Function** in sinusoidal mode. Set an input voltage of 5V (peak-to-peak) with the oscilloscope probes set in X1 position. Set the function generator probe in X1 position.

(c) Feed terminals 1,4 in the circuit diagram to channel 1 and 3,4 to channel 2 of the oscilloscope to measure input voltage V_i and output voltage V_R, respectively. Note that terminal 4 is connected to the ground pin of the function generator and oscilloscope.

(d) Vary the frequency in the set region slowly and record V_R and V_i (which may not remain constant at the set value, guess why?). Read the frequency from oscilloscope.

For each listed frequency, measure the phase shift angle Φ_R with proper sign as shown in the diagram below using the expression, $\phi_R\,(\text{deg}) = \left(\frac{\Delta T}{T}\right) \times 360^0$.



(e) Replace the resistor with another value and repeat steps (c) and (d). No phase measurement is required.

(f) Now, interchange the probes of the function generator and oscilloscope, i.e. make terminal 1 as the common ground so that you will measure V_{LC} output between terminal 3 and 1 and V_i between 4 and 1. Repeat step-(d) to record V_{LC}, V_i and Φ_{LC}.

(II) Measuring V_L and V_C:

(a) Go back to the original circuit configuration you started with. Interchange R with L to measure V_i and V_L (see steps (c) and (d) of the previous procedure). Calculate V_L/V_i for each frequency.

(b) Now, interchange the inductor with capacitor and measure V_i and V_C. Calculate V_C/V_i for each frequency.

Observations:

L = _____ mH, C = _____ µF, $f_0 = \frac{1}{2\pi\sqrt{LC}}$ = _____ kHz

Internal resistance of inductor = _____ Ω

Output impedance of Function generator = _____ Ω

Table:1 R_1 = _____ Ω

Sl.No.	f (kHz)	V_i (V)	V_R (V)	V_R/V_i	V_R/V_i (Calculated)	Φ_R	Φ_R (Calculated)

Table:2 R_2 = _____ Ω

Sl.No.	Frequency,f (kHz)	V_i (V)	V_R (V)	V_R/V_i	V_R/V_i (Calculated)

Table:3 R_1 = _____ Ω

Sl.No.	Frequency,f (kHz)	V_i (V)	V_{LC} (V)	V_{LC}/V_i	V_{LC}/V_i (Calculated)	Φ_{LC} (deg)	Φ_{LC} (deg) (Calculated)

Table:4 R_1 = _____ Ω

Sl.No.	f (kHz)	V_i (V)	V_L (V)	V_L/V_i

Table: R_1 = _____ Ω

Sl.No.	f (kHz)	V_i (V)	V_C (V)	V_C/Vi

Graphs:

(a) Plot the observed values of V_R/V_i, V_{LC}/V_i, Φ_R and Φ_{LC} versus frequency. Estimate the resonant frequency.

(b) Plot V_R/V_i versus frequency for both the resistors on the same graph-sheet and compare their behavior. Estimate the Q-factor in each case and compare with calculated values.

(c) Plot V_L/V_i and V_C/V_i versus frequency on the same graph-sheet and estimate the resonant frequency from the point of intersection and compare with other estimations.

Discussions/Results:

Precautions: Make the ground connections carefully.

Lab#3: RC CIRCUIT AS A FILTERING AND PHASE SHIFTING NETWORK

OBJECTIVES:

(I) **S**tudy the transfer function and phase shift of a low pass RC filter network.
(II) Study the transfer function and phase shift of a high pass RC filter network.

OVERVIEW:

Filter circuits are used in a wide variety of applications. In the field of telecommunication, band-pass filters are used in the audio frequency range (20 Hz to 20 kHz) for modems and speech processing. High-frequency band-pass filters (several hundred MHz) are used for channel selection in telephone central offices. Data acquisition systems usually require anti-aliasing low-pass filters as well as low-pass noise filters in their preceding signal conditioning stages. System power supplies often use band-rejection filters to suppress the 50-Hz line frequency and high frequency transients.

Frequency-selective or filter circuits pass only those input signals to the output that are in a desired range of frequencies (called pass band). The amplitude of signals outside this range of frequencies (called stop band) is reduced (ideally reduced to zero). The frequency between pass and stop bands is called the cut-off frequency (ω_c). Typically in these circuits, the input and output currents are kept to a small value and as such, the current transfer function is not an important parameter. The main parameter is the voltage transfer function in the frequency domain, Hv(jω) = Vo/Vi. Subscript v of Hv is frequently dropped. As H(jω) is complex number, it has both a magnitude and a phase, filters in general introduce a phase difference between input and output signals.

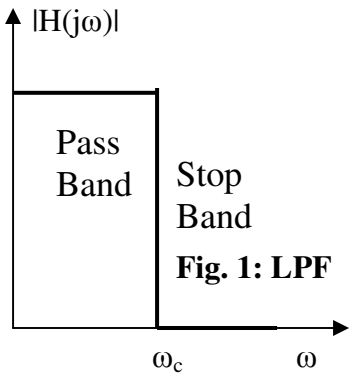


Fig. 1: LPF

LOW AND HIGH-PASS FILTERS

A low pass filter or LPF attenuates or rejects all high frequency signals and passes only low frequency signals below its characteristic frequency called as cut-off frequency, ω_c. An ideal low-pass fillter's transfer function is shown in Fig. 1. A high pass filter or HPF, is the exact opposite of the LPF circuit. It attenuates or rejects all low frequency signals and passes only high frequency signals above ω_c.

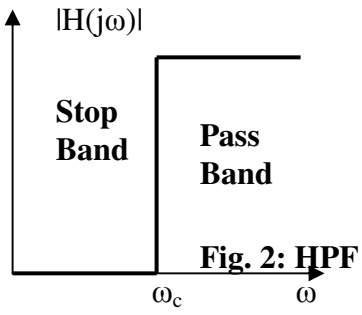


Fig. 2: HPF

In practical filters, pass and stop bands are not clearly defined, |H(jω)| varies continuously from its maximum towards zero. The cut-off frequency is, therefore, defined as the frequency at which |H(jω)| is reduced to $1/\sqrt{2}$ or 0.7 of its maximum value. This corresponds to signal power being reduced by 1/2 as $P \alpha V^2$.

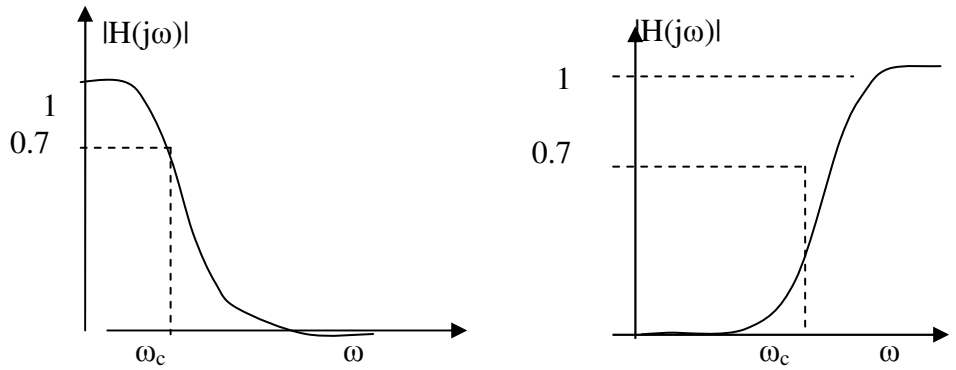


Fig.3: Transfer functions of practical low and high pass filter

RC Filter:

The simplest passive filter circuit can be made by connecting together a single resistor and a single capacitor in series across an input signal, (Vin) with the output signal, (Vout) taken from the junction of these two components. Depending on which way around we connect the resistor and the capacitor with regards to the output signal determines the type of filter construction resulting in either a Low Pass or a High Pass Filter. As there are two passive components within this type of filter design the output signal has amplitude smaller than its corresponding input signal, therefore passive RC filters attenuate the signal and have a gain of less than one, (unity).

Low-pass RC Filter

A series RC circuit as shown also acts as a low-pass filter. For no load resistance (output is open circuit, R → ∞):

$$V_0 = \frac{1/(j\omega C)}{R + (1/j\omega C)} V_i = \frac{1}{1 + j(\omega RC)} V_i$$

$$H(j\omega) = \frac{V_0}{V_i} = \frac{1}{1 + j\omega RC}$$

To find the cut-off frequency (ω_c), we note

$$|H(j\omega)| = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

When ω→0, |H(jω)| is maximum and →1.
For $\omega = \omega_c$, $|H(j\omega_c)| = 1/\sqrt{2}$. Thus

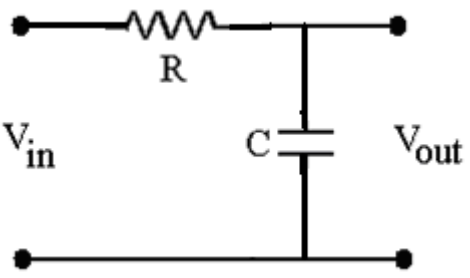


Fig.4: Low pass RC filter circuit

$$|H(j\omega_c)| = \frac{1}{\sqrt{1 + (\omega_c RC)^2}} = \frac{1}{\sqrt{2}}$$

$$\Rightarrow \quad \omega_c = \frac{1}{RC}, \quad H(j\omega) = \frac{1}{1 + \frac{j\omega}{\omega_c}}, |H(j\omega)| = \frac{1}{\sqrt{1 + \left(\frac{\omega}{\omega_c}\right)^2}} \quad and \quad phase, \phi = -\tan^{-1}\left(\frac{\omega}{\omega_c}\right)$$

Input Impedance:

$$Z_i = R + \frac{1}{j\omega C} \quad and \quad |Z_i| = \sqrt{R^2 + \frac{1}{\omega^2 C^2}}$$

The value of the input impedance depends on the frequency ω. For good voltage coupling, we need to ensure that the input impedance of this filter is much larger than the output impedance of the previous stage. Thus, the minimum value of Z_i is an important number. Z_i is minimum when the impedance of the capacitor is zero (ω→∞), i.e. $Z_i|_{min} = R$.

Output Impedance:

The output impedance can be found by shorting the source and finding the equivalent impedance between output terminals:

$$Z_0 = R \| \frac{1}{j\omega C}$$

where the source resistance is ignored. Again, the value of the output impedance also depends on the frequency ω. For good voltage coupling, we need to ensure that the output impedance of this filter is much smaller than the input impedance of the next stage, the maximum value of Z_0 is an important number. Z_0 is maximum when the impedance of the capacitor is ∞ (ω→0), i.e. $Z_0|_{max} = R$.

Bode Plots and Decibel

The ratio of output to input power in a two-port network is usually expressed in Bell:

$$\textbf{Number of Bels} = \log_{10}\left(\frac{P_0}{P_i}\right) = 2\log_{10}\left(\frac{V_0}{V_i}\right)$$

Bel is a large unit and decibel (dB) is usually used:

$$\textbf{Number of decibels} = 10\log_{10}\left(\frac{P_0}{P_i}\right) = 20\log_{10}\left(\frac{V_0}{V_i}\right)$$

There are several reasons why decibel notation is used:

1) Historically, the analog systems were developed first for audio equipment. Human ear 'hears" the sound in a logarithmic fashion. A sound which appears to be twice as loud actually has 10 times power, etc. Decibel translates the output signal to what ear hears.

2) If several two-port network are placed in a cascade (output of one is attached to the input of the next), it is easy to show that the overall transfer function, H, is equal to the product of all transfer functions:

$$|H(j\omega)| = |H_1(j\omega)| \times |H_2(j\omega)| \times \ldots$$
$$20\log_{10}|H(j\omega)| = 20\log_{10}|H_1(j\omega)| + 20\log_{10}|H_2(j\omega)| + \ldots$$
$$|H(j\omega)|_{dB} = |H_1(j\omega)|_{dB} + |H_2(j\omega)|_{dB} + \ldots$$

making it easier to understand the overall response of the system.

3) Plot of $|H(j\omega)|_{dB}$ versus frequency has special properties that again makes analysis simpler as is seen below.

For example, using dB definition, we see that, there is 3 dB difference between maximum gain and gain at the cut-off frequency:

$$20\log_{10}|H(j\omega_c)| - 20\log_{10}|H(j\omega)|_{\max} = 20\log_{10}\frac{|H(j\omega_c)|}{|H(j\omega)|_{\max}} = 20\log\left(\frac{1}{\sqrt{2}}\right) = -3dB$$

Bode plots are plots of magnitude in dB and phase of H(jω) versus frequency in a semi-log format. Bode plots of first-order low-pass filters (include one capacitor) display the following typical characteristics:

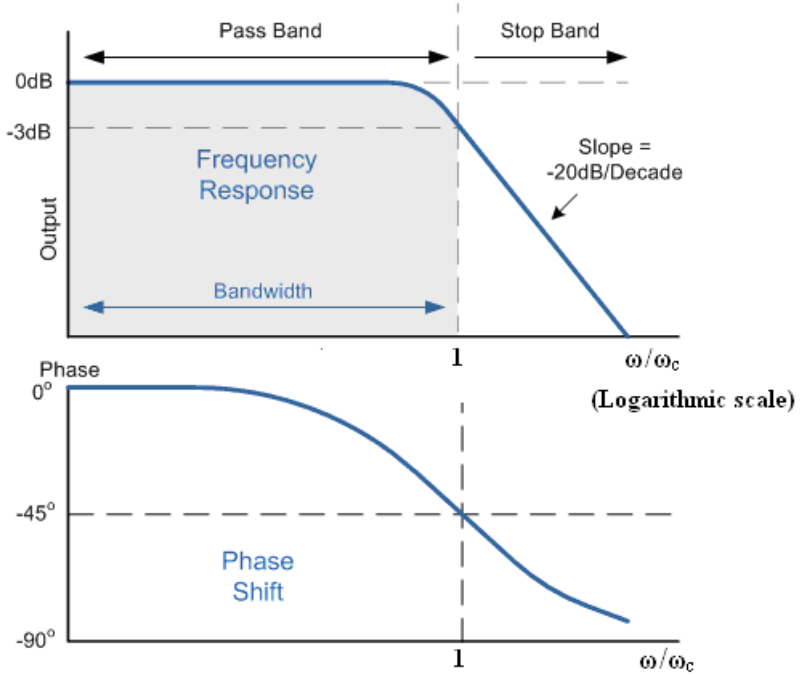


Fig.5: Bode Plots for low-pass RC filter

At high frequencies, $\omega/\omega_c >> 1$, $|H(j\omega)| \approx 1/(\omega/\omega_c)$ and $|H(j\omega)|_{dB} = 20 \log(\omega_c) - 20 \log \omega$, which is a straight line with a slope of -20 dB/decade in the Bode plot. It means that if ω is increased by a factor of 10 (a decade), $|H(j\omega)|_{dB}$ changes by -20 dB.

At low frequencies $\omega/\omega_c << 1$, $|H(j\omega)| \approx 1$, which is also a straight line in the Bode plot. The intersection of these two "asymptotic" values is at $1 = 1/(\omega/\omega_c)$ or $\omega = \omega_c$. Because of this, the cut-off frequency is also called the "corner" frequency.

The behavior of the phase of H(jω) can be found by examining $\boldsymbol{\phi = -\tan^{-1}(\frac{\omega}{\omega_c})}$. At high frequencies, $\omega/\omega_c >> 1$, $\boldsymbol{\phi \approx -90^0}$ and at low frequencies, $\omega/\omega_c << 1$, $\boldsymbol{\phi \approx 0}$. At cut-off frequency, $\boldsymbol{\phi \approx -45^0}$.

High-pass RC Filter

A series RC circuit as shown acts as a high-pass filter. For no load resistance (output open circuit), we have:

$$\boldsymbol{V_0 = \frac{R}{R + (1/j\omega C)} V_i = \frac{1}{1 - j(1/\omega RC)} V_i}$$

$$\boldsymbol{H(j\omega) = \frac{V_0}{V_i} = \frac{1}{1 - j(1/\omega RC)}}$$

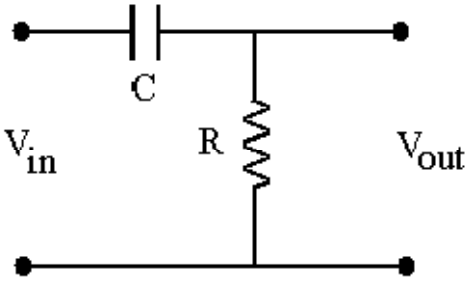


Fig.6: High pass RC filter circuit

The gain of this filter, |H(jω)| is maximum is maximum when denominator is smallest, i.e., ω→ ∞, leading to $|H(j\omega)|_{max} = 1$. Then, the cut-off frequency can be found as

$$|H(j\omega_c)| = \frac{1}{\sqrt{1+(1/\omega_c RC)^2}} = \frac{1}{\sqrt{2}}$$

$$\Rightarrow \quad \omega_c = \frac{1}{RC}, \quad |H(j\omega)| = \frac{1}{\sqrt{1+(\frac{\omega_c}{\omega})^2}} \quad and \quad phase, \phi = \tan^{-1}(\frac{\omega_c}{\omega})$$

Input and output impedances of this filter can be found similar to the procedure used for low-pass filters:

$$Input\ impedance: Z_i = R + \frac{1}{j\omega C} \quad and \quad Z_i|_{min} = R$$

$$Output\ Impedance: Z_0 = R \left\| \frac{1}{j\omega C} \right. \quad and \quad Z_0|_{max} = R$$

Bode Plots of first-order high-pass filters display the following typical characteristics:
At low frequencies, $\omega/\omega_c << 1$, $|H(j\omega)| \alpha\ \omega$ (a +20dB/decade line) and $\phi \approx 90^0$.
At high frequencies, $\omega/\omega_c >> 1$, $|H(j\omega)| \approx 1$ (a line with a slope of 0) and $\phi \approx 0^0$.

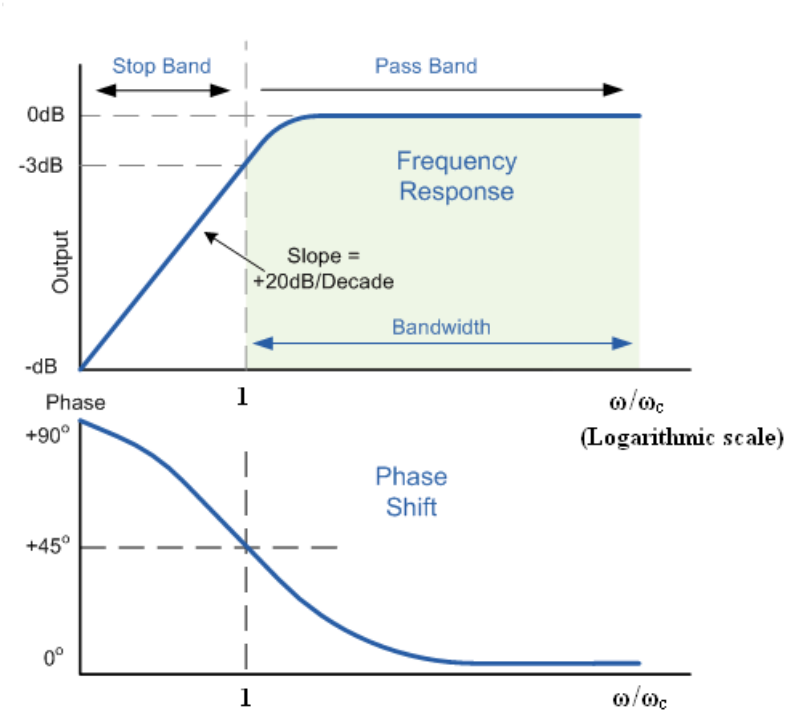
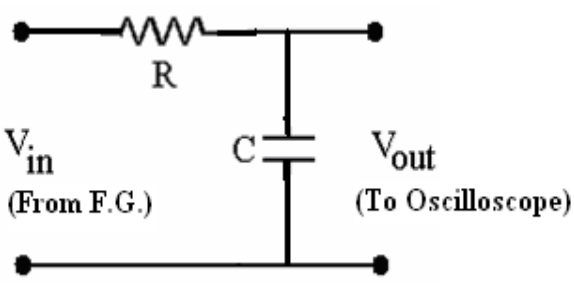


Fig.7: Bode Plots for high-pass RC filter

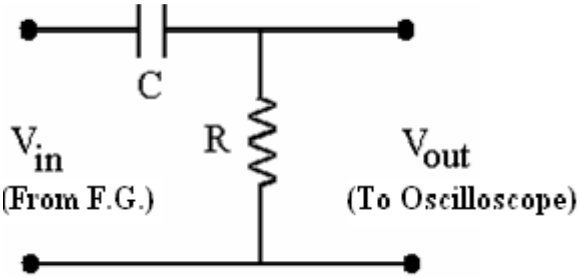
Circuit Components/Instruments:

(i) Resistor (5.6 kΩ), (ii) Capacitor (10 kpF), (iii) Function generator, (iv) Oscilloscope, (v) Connecting wires, (vi) Breadboard

Circuit Diagrams:



(Low pass RC filter)



(High pass RC filter)

Procedure:

1. Begin lab by familiarizing yourself with the function generator and oscilloscope.
2. Read and also measure the values of R and C.
3. Using the scope set the function generator to produce a 10 V(pp) sine wave. This signal will be used for the input. Do not change the amplitude of this signal during the experiment.
4. Set up the low/high pass RC filter on the breadboard as shown in the circuit diagram. Use the function generator to apply a 10 V(pp) sine wave signal to the input. Use the dual trace oscilloscope to look at both V_{in} and V_{out}. Be sure that the two oscilloscope probes have their grounds connected to the function generator ground.
5. For several frequencies between 20 Hz and 20 kHz (the audio frequency range) measure the peak-to-peak amplitude of V_{out}. Check often to see that V_{in} remains roughly at the set value and that VOLTS/DIV dials are in their calibrated positions. Take enough data (at least up to 10 times the cut-off frequency, for low pass and down to 1/10 times cut-off frequency, for high pass filter) so as to make your analysis complete. If needed use the STOP button of oscilloscope at a desired frequency to acquire data.
6. From your measurements determine the ratio

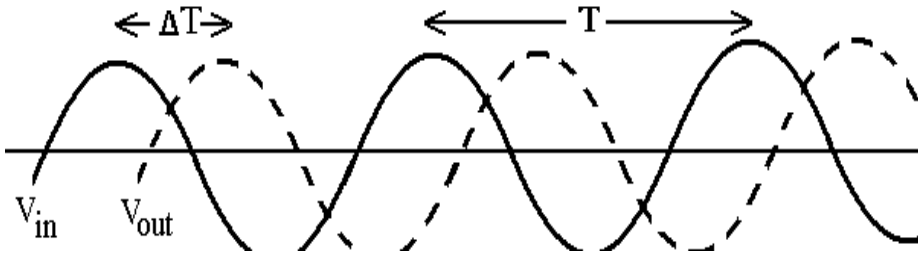
$$|H(j\omega)| = \left|\frac{V_o}{V_i}\right| = \frac{V_o(pp)}{V_i(pp)}$$

and compute this ratio by using the formula

$|H(j\omega)| = \dfrac{1}{\sqrt{1+\left(\dfrac{\omega}{\omega_c}\right)^2}}$, for low pass filter and

$$|H(j\omega)| = \frac{1}{\sqrt{1+\left(\frac{\omega_c}{\omega}\right)^2}}$$, for high pass filter

7. For each listed frequency, measure the phase shift angle ϕ with proper sign as shown in the diagram below.



8. The phase shift angle in degrees is $\phi = \left(\frac{\Delta T}{T}\right) \times 360^0$

9. Compute the phase shift angle for each frequency for low/high pass filter.

Observations:

R = _____, C = _____

(I) For Low Pass Filter: $V_{in}(pp)$ **= _____,** ω_c = 1/RC = _____

(a) Table for |H(jω)|:

Sl. No.	**Frequency, f (kHz)** ($\omega = 2\pi f$)	$\frac{\omega}{\omega_c}$	**V_0(pp) (Volt)**	**$\lvert H(j\omega)\rvert = \frac{V_o(pp)}{V_i(pp)}$**	**$\lvert H(j\omega)\rvert_{dB}$**	$\lvert H(j\omega)\rvert = \frac{1}{\sqrt{1+\left(\frac{\omega}{\omega_c}\right)^2}}$
1	0.02					
2	..					
..	..					
..	..					

(b) Table for phase angle ϕ:

Sl. No.	**Frequency, f (kHz)** ($\omega = 2\pi f$)	$\frac{\omega}{\omega_c}$	**ΔT (ms)**	**T (ms)**	$\phi = \left(\frac{\Delta T}{T}\right) \times 360^0$ **(deg)**	$\phi = -\tan^{-1}(\frac{\omega}{\omega_c})$ **(deg)**
1	0.02					
2	..					
..	..					
..	..					

(II) For High Pass Filter: $V_{in}(pp)$ = _____, ω_c = 1/RC = _____

(c) Table for |H(jω)|:

Sl. No.	Frequency, f (kHz) ($\omega = 2\pi f$)	$\frac{\omega_c}{\omega}$	V_0(pp) (Volt)	$\lvert H(j\omega)\rvert = \frac{V_o(pp)}{V_i(pp)}$	$\lvert H(j\omega)\rvert_{dB}$	$\lvert H(j\omega)\rvert = \frac{1}{\sqrt{1+\left(\frac{\omega_c}{\omega}\right)^2}}$
1	0.02					
2	..					
..	..					
..	..					

(d) Table for phase angle ϕ:

Sl. No.	Frequency, f (kHz) ($\omega = 2\pi f$)	$\frac{\omega_c}{\omega}$	ΔT (ms)	T (ms)	$\phi = \left(\frac{\Delta T}{T}\right)\times 360^0$ (deg)	$\phi = -\tan^{-1}(\frac{\omega_c}{\omega})$ (deg)
1	0.02					
2	..					
..	..					
..	..					

Graphs: Trace and study bode plots of $|H(j\omega)|_{dB}$ and ϕ versus $f(\times 2\pi)$ in a semi-log format for low/high pass RC filter. Determine the cut-off frequency from graph. Also, estimate the frequency roll-off for each filter.

Discussions:

Precautions:

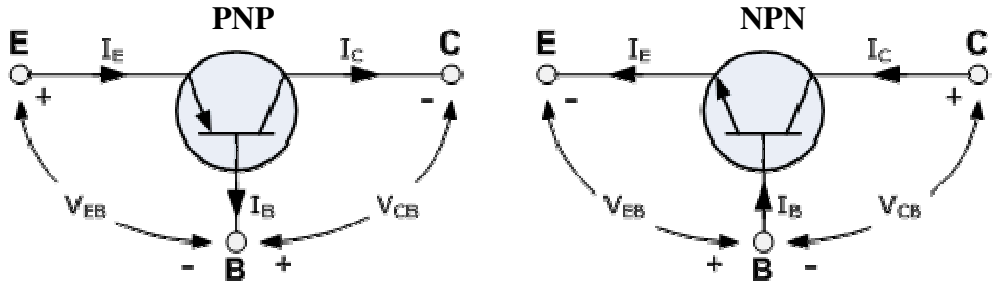
Lab# 4: Bipolar Junction Transistor Static Characteristics

Objective:

(i) To study the input and output characteristics of a PNP transistor in Common Base mode and determine transistor parameters.
(ii) To study the input and output characteristics of an NPN transistor in Common Emitter mode and determine transistor parameters.

Overview:

A **Bipolar Junction Transistor**, or **BJT** is a three terminal device having two PN-junctions connected together in series. Each terminal is given a name to identify it and these are known as the Emitter (E), Base (B) and Collector (C). There are two basic types of bipolar transistor construction, NPN and PNP, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made. Bipolar Transistors are "CURRENT" Amplifying or current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing current applied to their base terminal. The principle of operation of the two transistor types NPN and PNP, is exactly the same the only difference being in the biasing (base current) and the polarity of the power supply for each type.



The symbols for both the NPN and PNP bipolar transistor are shown above along with the direction of conventional current flow. The direction of the arrow in the symbol shows current flow between the base and emitter terminal, pointing from the positive P-type region to the negative N-type region, exactly the same as for the standard diode symbol. For normal operation, the emitter-base junction is forward-biased and the collector-base junction is reverse-biased.

Transistor Configurations

There are three possible configurations possible when a transistor is connected in a circuit: (a) Common base, (b) Common emitter (c) Common collector. We will be focusing on the first two configurations in this experiment. The behaviour of a transistor can be represented by d.c. current-voltage (I-V) curves, called the static characteristic curves of the device. The three important characteristics of a transistor are: (i) Input characteristics, (ii) Output characteristics and (iii) Transfer Characteristics. These characteristics give information about various transistor parameters, e.g. input and out dynamic resistance, current amplification

factors, etc.

Common Base Transistor Characteristics

In common base configuration, the base is made common to both input and output as shown in its circuit diagram.

(1) ***Input Characteristics:*** The input characteristics is obtained by plotting a curve between I_E and V_{EB} keeping voltage V_{CB} constant. This is very similar to that of a forward-biased diode and the slope of the plot at a given operating point gives information about its input dynamic resistance.

Input Dynamic Resistance (r_i) This is defined as the ratio of change in base emitter voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-emitter voltage (V_{CB}). This is dynamic as its value varies with the operating current in the transistor.

$$r_i = \left.\frac{\Delta V_{EB}}{\Delta I_E}\right|_{V_{CB}}$$

(2) ***Output Characteristics:*** The output characteristic curves are plotted between I_C and V_{CB}, keeping I_E constant. The output characteristics are controlled by the input characteristics. Since I_C changes with I_E, there will be different output characteristics corresponding to different values of I_E. These curves are almost horizontal. This shows that the output dynamic resistance, defined below, is very high.

Output Dynamic Resistance (r_o): This is defined as the ratio of change in collector-base voltage (ΔV_{CB}) to the change in collector current (ΔI_C) at a constant base current I_E.

$$r_o = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E}$$

(3) ***Transfer Characteristics****:* The transfer characteristics are plotted between the input and output currents (I_E versus I_C).

Current amplification factor (α)

This is defined as the ratio of the change in collector current to the change in emitter current at a constant collector-base voltage (V_{CB}) when the transistor is in active state.

$$\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}}$$

This is also known as small signal current gain and its value is very large. The ratio of I_C and I_E is called α_{dc} of the transistor. Hence,

$$\alpha_{dc} = \left.\frac{I_C}{I_E}\right|_{V_{CB}}$$

Since I_C increases with I_E almost linearly, the values of both α_{dc} and α_{ac} are nearly equal.

Common Emitter Transistor Characteristics

In a common emitter configuration, emitter is common to both input and output as shown in its circuit diagram.

(1) ***Input Characteristics:*** The variation of the base current I_B with the base-emitter voltage V_{BE} keeping the collector-emitter voltage V_{CE} fixed, gives the input characteristic in CE mode.

Input Dynamic Resistance (r_i): This is defined as the ratio of change in base emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage (V_{CE}). This is dynamic and it can be seen from the input characteristic, its value varies with the operating current in the transistor:

$$r_i = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}}$$

The value of r_i can be anything from a few hundreds to a few thousand ohms.

(2) ***Output Characteristics:*** The variation of the collector current I_C with the collector-emitter voltage V_{CE} is called the output characteristic. The plot of I_C versus V_{CE} for different fixed values of I_B gives one output characteristic. Since the collector current changes with the base current, there will be different output characteristics corresponding to different values of I_B.

Output Dynamic Resistance (r_o): This is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at a constant base current I_B.

$$r_o = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B}$$

The high magnitude of the output resistance (of the order of 100 kW) is due to the reverse-biased state of this diode.

(3) ***Transfer Characteristics****:* The transfer characteristics are plotted between the input and output currents (I_B versus I_C). Both I_B and I_C increase proportionately.

Current amplification factor (β)

This is defined as the ratio of the change in collector current to the change in base current at a constant collector-emitter voltage (V_{CE}) when the transistor is in active state.

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}}$$

This is also known as small signal current gain and its value is very large. The ratio of I_C and I_B we get what is called β_{dc} of the transistor. Hence,

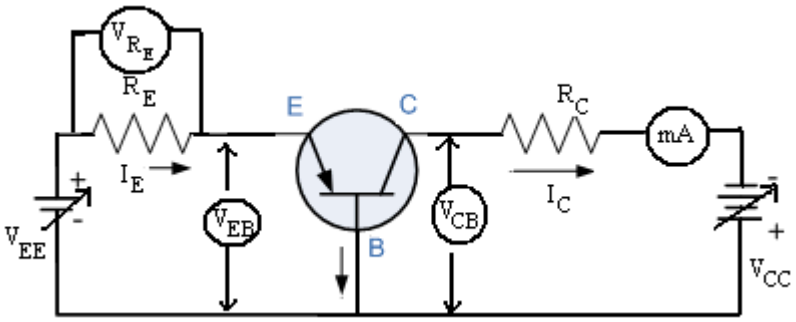
$$\beta_{dc} = \left.\frac{I_C}{I_B}\right|_{V_{CE}}$$

Since I_C increases with I_B almost linearly, the values of both β_{dc} and β_{ac} are nearly equal.

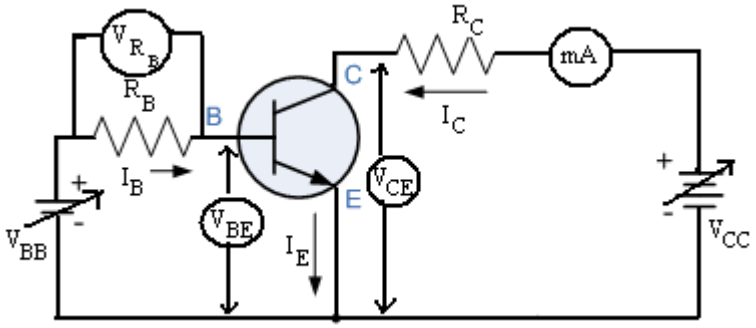
Circuit components/Equipments:

(i) Transistors (2 Nos: 1 PNP (CK 100 or equivalent) and 1 NPN (BC 107 or equivalent)), (ii) Resistors (4 Nos.) (iii) Multimeters (3 Nos.), (iv) D.C. power supply, (v) Connecting wires and (vi) Breadboard.

Circuit Diagrams:



PNP transistor in CB configuration



NPN transistor in CE configuration

Procedure:

1. Note down the type number of both the transistors.
2. Identify different terminals (E, B and C) and the type (PNP/NPN) of the transistors. For any specific information refer the datasheet of the transistors.

(I) PNP Common Base (CB) characteristics

1. Configure CB circuit using the PNP transistor as per the circuit diagram. Use $R_E = R_C = 150\ \Omega$.
2. For input characteristics, first fix the voltage V_{CB} by adjusting V_{CC} to the minimum possible position. Now vary the voltage V_{EB} slowly (say, in steps of 0.05V) by varying V_{EE}. Measure V_{EB} using a multimeter. If V_{CB} varies during measurement bring it back to the initial set value To determine I_E, measure V_{RE} across the resistor R_E and use the relation $I_E = V_{RE}/R_E$.
3. Repeat the above step for another value of V_{CB} say, 2V.
4. Take out the multimeter measuring V_{EB} and connect in series with the output circuit to measure I_C. For output characteristics, first fix $I_E = 0$, i.e. $V_{RE} = 0$. By adjusting V_{CC}, vary the collector voltage V_{CB} in steps of say 1V and measure V_{CB} and the corresponding I_C using multimeters. After acquiring sufficient readings, bring back V_{CB} to 0 and reduce it further to get negative values. Vary V_{CB} in negative direction and measure both V_{CB} and I_C, till you get 0 current.
5. Repeat the above step for at least 5 different values of I_E by adjusting V_{EE}. You may need to adjust V_{EE} continuously during measurement in order to maintain a constant I_E.
6. Plot the input and output characteristics by using the readings taken above and determine the input and output dynamic resistance.
7. To plot transfer characteristics, select a suitable voltage V_{CB} well within the active region of the output characteristics, which you have tabulated already. Plot a graph between I_C and the corresponding I_E at the chosen voltage V_{CB}. Determine α_{ac} from the slope of this graph.

(II) NPN Common Emitter (CE) characteristics

1. Now configure CE circuit using the NPN transistor as per the circuit diagram. Use $R_B = 100k\Omega$ and $R_C = 1\ k\Omega$.
2. For input characteristics, first fix the voltage V_{CE} by adjusting V_{CC} to the minimum possible position. Now vary the voltage V_{BE} slowly (say, in steps of 0.05V) by varying V_{BB}. Measure V_{BE} using a multimeter. If V_{CE} varies during measurement bring it back to the set value To determine I_B, measure V_{RB} across the resistor R_B and use the relation $I_B = V_{RB}/R_B$.
3. Repeat the above step for another value of V_{CE} say, 2V.

4. For output characteristics, first fix $I_B = 0$, i.e. $V_{RB} = 0$. By adjusting V_{CC}, vary the collector voltage V_{CE} in steps of say 1V and measure V_{CE} and the corresponding I_C using multimeters. If needed vary V_{CE} in negative direction as described for CB configuration and measure both V_{CE} and I_C, till you get 0 current.
5. Repeat the above step for at least 5 different values of I_B by adjusting V_{BB}. You may need to adjust V_{BB} continuously during measurement in order to maintain a constant I_B.
6. Plot the input and output characteristics by using the readings taken above and determine the input and output dynamic resistance.
7. Plot the transfer characteristics between I_C and I_B as described for CB configuration for a suitable voltage of V_{CE} on the output characteristics. Determine β_{ac} from the slope of this graph.

Observations:

CB configuration:

Transistor code: _____, Transistor type: _____ (PNP/NPN)
R_E = _____, R_C = _____.

Table (1): Input Characteristics

Sl. No.	V_{CB} = ___V			V_{CB} = ___V		
	V_{EB} (V)	V_{RE} (V)	I_E (mA)	V_{EB} (V)	V_{RE} (V)	I_E (mA)
1						
2						
..						
..						
10						

Table (2): Output Characteristics

Sl. No.	$I_{E1} = 0$		I_{E2} = __		I_{E3} = __		I_{E4} = __		I_{E5} = __	
	V_{CB} (V)	I_C (mA)	V_{CB} (V)	I_C (mA)	V_{CB} (V)	I_C (mA)	V_{CB} (V)	I_C (mA)	V_{CB} (V)	I_C (mA)
1										
2										
..										
..										
10										

Table (3): Transfer Characteristics V_{CB} = _____ V

Sl. No.	I_E (mA)	I_C (mA)
1		
2		
3		
4		
5		

CE configuration: Transistor code: _____, Transistor type: _____ (PNP/NPN)
R_B = _____, R_C = _____.

Table (5): Input Characteristics

Sl. No.	V_{CE} = ___V			V_{CE} = ___V		
	V_{BE} (V)	V_{RB} (V)	I_B (µA)	V_{BE} (V)	V_{RB} (V)	I_B (µA)
1						
2						
..						
..						
10						

Table (4): Output Characteristics

Sl. No.	I_{B1} = 0		I_{B2} = __		I_{B3} = __		I_{B4} = __		I_{B5} = __	
	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)
1										
2										
..										
..										
10										

Table (6): Transfer Characteristics V_{CE} = _____ V

Sl. No.	I_B (μA)	I_C (mA)
1		
2		
3		
4		
5		

Graphs:

Plot the input, output and transfer characteristics for each configuration.

CB configuration:

(1) Input characteristics: Plot V_{EB} ~ I_E, for different V_{CB} and determine the input dynamic resistance in each case at suitable operating points.
(2) Output characteristics: Plot V_{CB} ~ I_C, for different I_E and determine the output dynamic resistance in each case at suitable operating points in the active region.
(3) Transfer characteristics: Plot I_E ~ I_C, for a fixed V_{CB} and determine α_{ac}.

CE configuration:

(1) Input characteristics: Plot V_{BE} ~ I_B, for different V_{CE} and determine the input dynamic resistance in each case at suitable operating points.
(2) Output characteristics: Plot V_{CE} ~ I_C, for different I_B and determine the output dynamic resistance in each case at suitable operating points in the active region.
(3) Transfer characteristics: Plot I_B ~ I_C, for a fixed V_{CE} and determine β_{ac}.

Results/Discussions:

Precautions:

Lab#5a: Study of Common Emitter Transistor Amplifier circuit

Objectives:

1. To design a common emitter transistor (NPN) amplifier circuit.
2. To obtain the frequency response curve of the amplifier and to determine the mid-frequency gain, A_{mid}, lower and higher cutoff frequency of the amplifier circuit.

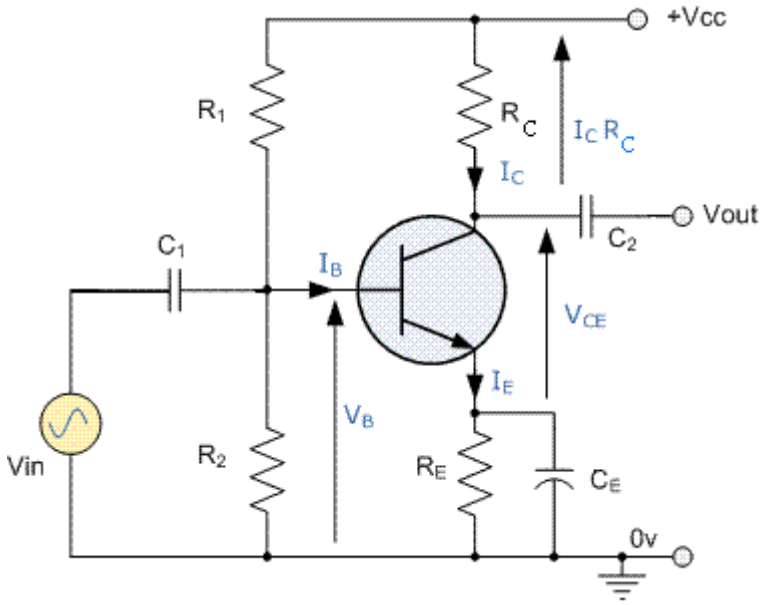
Overview:

The most common circuit configuration for an NPN transistor is that of the *Common Emitter Amplifier* and that a family of curves known commonly as the *Output Characteristics Curves*, relates the Collector current (I_C), to the output or Collector voltage (V_{CE}), for different values of Base current (I_B). All types of transistor amplifiers operate using AC signal inputs which alternate between a positive value and a negative value. Presetting the amplifier circuit to operate between these two maximum or peak values is achieved using a process known as *Biasing*. Biasing is very important in amplifier design as it establishes the correct operating point of the transistor amplifier ready to receive signals, thereby reducing any distortion to the output signal.

The single stage common emitter amplifier circuit shown below uses what is commonly called "Voltage Divider Biasing". The Base voltage (V_B) can be easily calculated using the simple voltage divider formula below:

$$V_B = \frac{V_{CC} R_2}{R_1 + R_2}$$

Thus the base voltage is fixed by biasing and independent of base current provided the current in the divider circuit is large compared to the base current. Thus assuming $I_B \approx 0$, one can do the approximate analysis of the voltage divider network without using the transistor



gain, ***β***, in the calculation. Note that the approximate approach can be applied with a high degree of accuracy when the following condition is satisfied:

$$\beta R_E \geq 10 R_2$$

Load line and Q-point

A static or DC load line can be drawn onto the output characteristics curves of the transistor to show all the possible operating points of the transistor from fully "ON" ($I_C = V_{CC}/(R_C + R_E)$) to fully "OFF" ($I_C = 0$). The quiescent operating point or **Q-point** is a point on this load line which represents the values of I_C and V_{CE} that exist in the circuit when no input signal is applied. Knowing V_B, I_C and V_{CE} can be calculated to locate the operating point of the circuit as follows:

$$V_E = V_B - V_{BE}$$

So, the emitter current,

$$I_E \approx I_C = \frac{V_E}{R_E}$$

$$\text{and } V_{CE} = V_{CC} - I_C(R_C + R_E)$$

It can be noted here that the sequence of calculation does not need the knowledge of β and I_B is not calculated. So the Q-point is stable against any replacement of the transistor.

Since the aim of any small signal amplifier is to generate an amplified input signal at the output with minimum distortion possible, the best position for this Q-point is as close to the centre position of the load line as reasonably possible, thereby producing a Class A type amplifier operation, i.e. $V_{CE} = 1/2V_{CC}$.

Coupling and Bypass Capacitors

In CE amplifier circuits, capacitors C_1 and C_2 are used as Coupling Capacitors to separate the AC signals from the DC biasing voltage. The capacitors will only pass AC signals and block any DC component. Thus they allow coupling of the AC signal into an amplifier stage without disturbing its Q point. The output AC signal is then superimposed on the biasing of the following stages. Also a bypass capacitor, C_E is included in the Emitter leg circuit. This capacitor is an open circuit component for DC bias, meaning that the biasing currents and voltages are not affected by the addition of the capacitor maintaining a good Q-point stability. However, this bypass capacitor acts as a short circuit path across the emitter resistor at high frequency signals increasing the voltage gain to its maximum. Generally, the value of the bypass capacitor, C_E is chosen to provide a reactance of at most, 1/10th the value of R_E at the lowest operating signal frequency.

Amplifier Operation

Once the Q-point is fixed through DC bias, an AC signal is applied at the input using coupling capacitor C_1. During positive half cycle of the signal V_{BE} increases leading to increased I_B. Therefore I_C increases by β times leading to decrease in the output voltage, V_{CE}. Thus the CE amplifier produces an amplified output with a phase reversal. The voltage Gain of the common emitter amplifier is equal to the ratio of the change in the output voltage to the change in the input voltage. Thus,

$$A_V = \frac{V_{out}}{V_{in}} = \frac{\Delta V_{CE}}{\Delta V_{BE}}$$

The input (Z_i) and output (Z_o) impedances of the circuit can be computed for the case when the emitter resistor R_E is completely bypassed by the capacitor, C_E:

$$\mathbf{Z_i = R_1 \| R_2 \| \beta r_e \text{ and } Z_o = R_C \| r_o}$$

where r_e (26mV/I_E) and r_o are the emitter diode resistance and output dynamic resistance (can be determined from output characteristics of transistor). Usually $r_o \geq 10\ R_C$, thus the gain can be approximated as

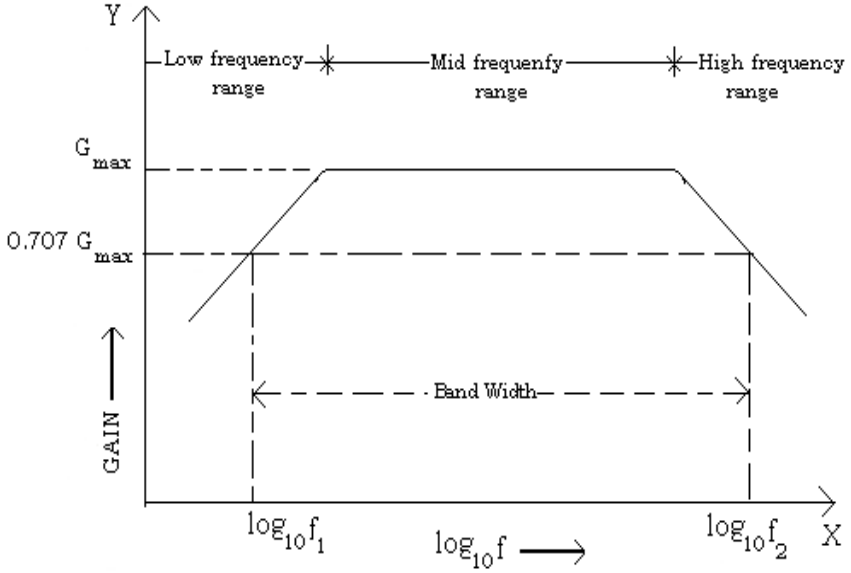
$$A_V = \frac{V_{out}}{V_{in}} = -\frac{\beta I_B (R_C \| r_o)}{I_B \beta r_e} \cong -\frac{R_C}{r_e}$$

The negative sign accounts for the phase reversal at the output. In the circuit diagram provided below, the emitter resistor is split into two in order to reduce the gain to avoid distortion. So the expression for gain is modified as

$$A_V \cong -\frac{R_C}{(R_{E1} + r_e)}$$

Frequency Response Curve

The performance of an amplifier is characterized by its frequency response curve that shows output amplitude (or, more often, voltage gain) plotted versus frequency (often in log scale). Typical plot of the voltage gain of an amplifier versus frequency is shown in the figure below. The frequency response of an amplifier can be divided into three frequency ranges.



The frequency response begins with the lower frequency range designated between 0 Hz and lower cutoff frequency. At lower cutoff frequency, f_L , the gain is equal to 0.707 A_{mid}. A_{mid} is a constant mid-band gain obtained from the mid-frequency range. The third, the higher frequency range covers frequency between upper cutoff frequency and above. Similarly, at higher cutoff frequency, f_H, the gain is equal to 0.707 A_{mid}. Beyond this the gain decreases with frequency increases and dies off eventually.

The Lower Frequency Range

Since the impedance of coupling capacitors increases as frequency decreases, the voltage gain of a BJT amplifier decreases as frequency decreases. At very low frequencies, the capacitive reactance of the coupling capacitors may become large enough to drop some of the input voltage or output voltage. Also, the emitter-bypass capacitor may become large enough

so that it no longer shorts the emitter resistor to ground.

The Higher Frequency Range

The capacitive reactance of a capacitor decreases as frequency increases. This can lead to problems for amplifiers used for high-frequency amplification. The ultimate high cutoff frequency of an amplifier is determined by the physical capacitances associated with every component and of the physical wiring. Transistors have internal capacitances that shunt signal paths thus reducing the gain. The high cutoff frequency is related to a shunt time constant formed by resistances and capacitances associated with a node.

Design:

Before designing the circuit, one needs to know the circuit requirement or specifications. The circuit is normally biased for V_{CE} at the mid-point of load line with a specified collector current. Also, one needs to know the value of supply voltage V_{CC} and the range of β for the transistor being used (available in the datasheet of the transistor).

Here the following specifications are used to design the amplifier:

V_{CC} = 12V and I_C = 1 mA

Start by making V_E= 0.1 V_{CC}. Then $R_E = V_E/I_E$ (Use $I_E \approx I_C$).

Since V_{CE} = 0.5 V_{CC}, Voltage across R_C = 0.4V_{CC}, i.e. $R_C = 4.R_E$

In order that the approximation analysis can be applied, $\boldsymbol{R_2 \leq 0.1\beta R_E}$. Here $\boldsymbol{\beta}$ is the minimum rated value in the specified range provided by the datasheet (in this case $\boldsymbol{\beta}$ =50).

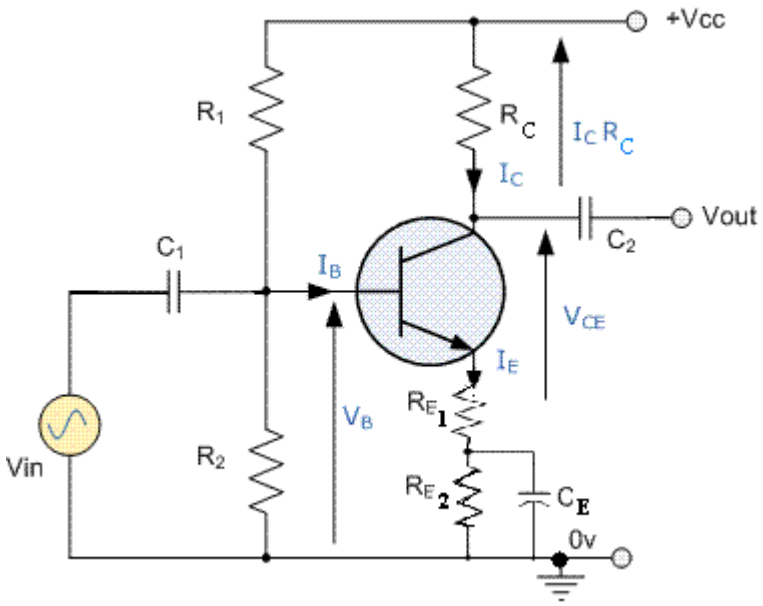
Finally, $\boldsymbol{R_1 = \frac{V_1}{V_2} R_2}$, V_1 (= V_{CC}-V_2)and V_2 (= V_E+V_{BE}) are voltages across R_1 and R_2, respectively.

Based on these guidelines the components are estimated and the nearest commercially available values are used.

Components/ Equipments:

1. Transistor: CL100 (or equivalent general purpose npn)
2. Resistors: R_1= 26 (27) KΩ, R_2= 5 (4.7+0.22) KΩ, R_C = 4 (3.9) KΩ, R_E= 1kΩ (R_{E1}=470 Ω, R_{E2}=560 Ω)
3. Capacitors: C_1= C_2= 1 μF (2 nos.), C_E= 100μF
4. Power Supply (V_{CC} = 12V)
5. Oscilloscope
6. Function Generator (~ 100-200 mV pp, sinusoidal for input signal)
7. Breadboard
8. Connecting wires

Circuit Diagram:



Procedure:

1. Measure and record all the values of resistance and capacitance and β of the transistor using a multimeter. Configure the circuit as per the diagram.
2. Apply supply voltage to the circuit. Measure and record all the dc parameters listed in Table 1 in absence of the ac signal.
3. Next, set the function generator in 20Hz "Frequency" range. Also, set the "Attenuation" button at 40dB. Connect the output to the oscilloscope and adjust the "Amplitude" knob till you get a sinusoidal input signal, Vi ≈ 100-200 mV peak-to-peak value. DO NOT CHANGE THIS SETTING THROUGHOUT THE EXPERIMENT.
4. Now apply this input signal to the circuit you have made keeping the connection to oscilloscope in tact. Feed the output of the circuit to the other channel of oscilloscope. Take care to make all the ground pins common.
5. With input signal amplitude always constant, increase signal frequency slowly. Observe, measure and record the output voltage, V_o. Scan the entire frequency in the range 20 Hz – 2 MHz. You may have to measure V_i and take the ratio V_o/V_i each time in case input fluctuation is too large to hold constant.
6. Calculate the voltage gain for each frequency. Observe the inverted output.
7. Plot the frequency response curve, i.e. voltage gain in dB versus frequency on a semi-log graph-sheet.
8. Estimate the mid-frequency gain and also the lower and higher cut off frequencies and hence the bandwidth.

Observations:

β = _____

R_1= ____, R_2= ____, R_C= ____, R_E= ____; C_1= ___, C_2= ___, C_E= ___

Table 1: D.C. analysis of the circuit

$V_{CC} = 12V$

Parameter	Computed value	Observed value
V_B (V)		
V_E (V)		
$I_C \approx I_E$ (mA)		
V_{CE} (V)		

Q-point is at (__V, __mA)

Table 2: Frequency response

$V_i(pp) =$ ___ mV

Sl. No.	Frequency, f (kHz)	V_0(pp) (Volt)	Gain, $A_V = \frac{V_o(pp)}{V_i(pp)}$	Gain (dB)
1				
2				
..				
..				

Calculations: r_e = _____ , Z_i = _____, Z_o = _____
Theoretical value of A_v in mid-frequency range = _____

Graphs: Plot the frequency response curve (semi-log plot) and determine the cut-off frequencies, bandwidth and mid- frequency gain.

Discussions:

Precautions:

1. Vary the input signal frequency slowly.
2. Connect electrolytic capacitors carefully.

Reference: Electronic devices and circuit theory, Robert L. Boylestad & Louis Nashelsky (10^{th} Edition)

Lab#5b: Two Stage RC Coupled Transistor Amplifier

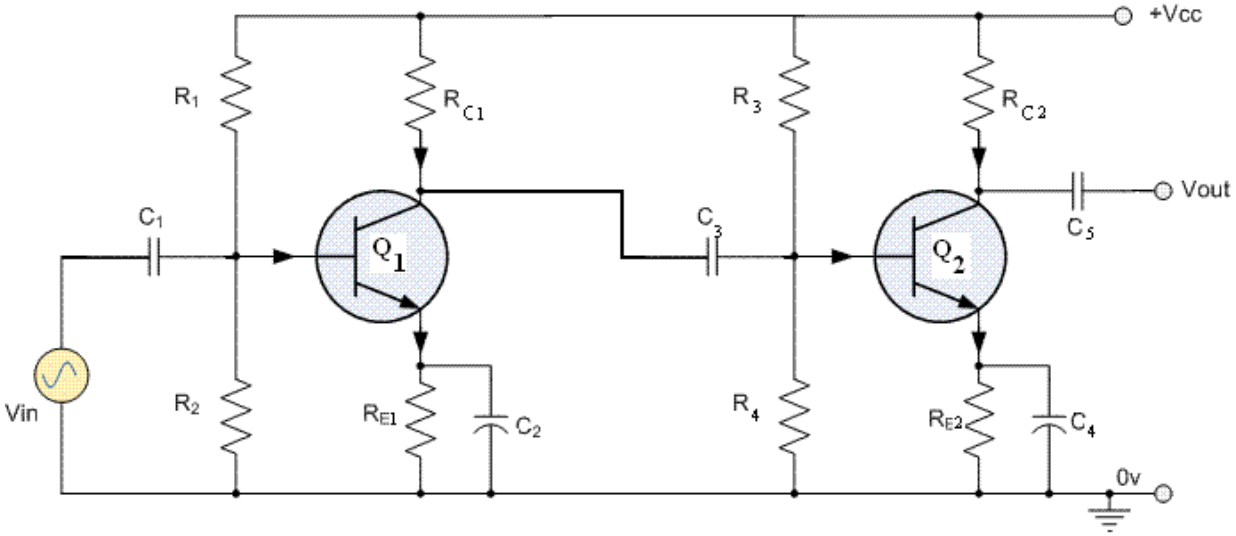
Objectives:

1. To design a two stage RC coupled common emitter transistor (NPN) amplifier circuit and to study its frequency response curve.

Overview:

A single stage of amplification is often not enough for a particular application. The overall gain can be increased by using more than one stage, so when two amplifiers are connected in such a way that the output signal of the first serves as the input signal to the second, the amplifiers are said to be connected in *cascade.* The most common arrangement is the common-emitter configuration.

Resistance-capacitance (RC) coupling is most widely used to connect the output of first stage to the input (base) of the second stage and so on. It is the most popular type of coupling because it is cheap and provides a constant amplification over a wide range of frequencies. These R-C coupled amplifier circuits are commonly used as voltage amplifiers in the audio systems.



The circuit diagram above shows the 2-stages of an R-C coupled amplifier in CE configuration using NPN transistors. Capacitors C_1 and C_3 couple the input signal to transistors Q_1 and Q_2, respectively. C_5 is used for coupling the signal from Q_2 to its load. R_1, R_2, R_{E1} and R_3, R_4, R_{E2} are used for biasing and stabilization of stage 1 and 2 of the amplifier. C_2 and C_4 provide low reactance paths to the signal through the emitter.

Overall gain:

The total gain of a 2-stage amplifier is equal to the product of individual gain of each stage.

(You may refer to the handout for single stage amplifier to calculate individual gain of the stages.) Once the second stage is added, its input impedance acts as an additional load on the first stage thereby reducing the gain as compared to its no load gain. Thus the overall gain characteristics is affected due to this loading effect.
The loading of the second stage i.e. input impedance of second stage, $\mathbf{Z_{i2} = R_3 \parallel R_4 \parallel \beta r_{e2}}$

Thus loaded gain of the first stage, $A_{V1} = -\dfrac{R_{C1} \parallel Z_{i2}}{r_{e1}}$

and the unloaded gain of second stage, $A_{V2} = -\dfrac{R_{C2}}{r_{e2}}$

In the circuit diagram provided below, the emitter resistor is split into two in order to reduce the gain to avoid distortion. So the expression for gain each stage is modified as

$$A_{V1} = -\frac{R_{C1} \parallel Z_{i2}}{(R_{E1} + r_{e1})}$$

$$A_{V2} = -\frac{R_{C2}}{R_{E2} + r_{e2}}$$

The overall gain of the 2 stage amplifier is $A_V = A_{V1} \times A_{V2}$.

Frequency Response Curve

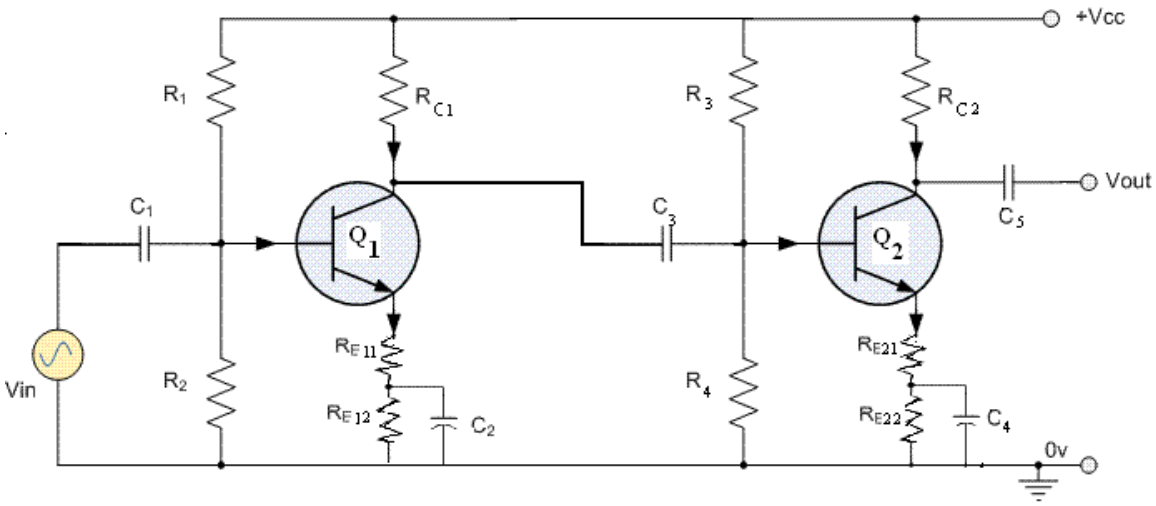
The performance of an amplifier is characterized by its frequency response curve that shows voltage gain (often expressed in dB units) plotted versus frequency. The frequency response begins with the lower frequency region designated between 0 Hz and lower cutoff frequency. At lower cutoff frequency, f_L, the gain is equal to 0.707 A_{mid}. A_{mid} is a constant mid-band gain obtained from the mid-band frequency region. The third, the upper frequency region covers frequency between upper cutoff frequency and above. Similarly, at upper cutoff frequency, f_H, the gain is equal to 0.707 A_{mid}. Beyond the upper cutoff frequency, the gain decreases as the frequency increases and dies off eventually. (More details are given in the hand out for single stage amplifier.)

Design: The design details are already given in the single stage amplifier hand out.

Components/ Equipments:

1. Transistor: CL100 (or equivalent general purpose npn, 2 nos)
2. Resistors: R_1, R_3= 26 (27) KΩ, R_2, R_4= 5 (4.7+0.22) KΩ, R_{C1}, R_{C2}= 4 (3.9) KΩ, R_{E1}, R_{E2}= 1kΩ (R_{E11}, R_{E21}=470 Ω; R_{E12}, R_{E22}=560 Ω) (2 nos. of each resistance value)
3. Capacitors: C_1= C_3= C_5= 1 μF (3 nos.), C_2= C_4= 100μF (2 nos.)
4. Power Supply (V_{CC} = 12V)
5. Oscilloscope
6. Function Generator (~ 100-200 mV pp, sinusoidal for input signal)
7. Breadboard
8. Connecting wires

Circuit Diagram:



Procedure:

9. Measure and record all the values of resistance and capacitance and β of the transistor using a multimeter. Configure the circuit as per the diagram. Make a provision so that the two stages can either be separated or connected as and when required.
10. Apply supply voltage to the circuit. Measure and record all the dc parameters of each individual stage separately as listed in Table 1 in absence of the ac signal.
11. Next, set the function generator at **20kHz by putting the frequency knob in 20KHz range and adjusting the variable knob.** Also, set the "Attenuation" button at 40dB. Connect the output to the oscilloscope and adjust the "Amplitude" knob till you get a sinusoidal input signal, Vi ≈ 100-200 mV peak-to-peak value. DO NOT CHANGE THIS SETTING THROUGHOUT THE EXPERIMENT.
12. To fill up first row of Table 2 the two stages should be separated. Now apply the input signal to the circuit at the first stage keeping the connection to oscilloscope intact. Feed the output of the first stage to the other channel of oscilloscope. Take care to make all the ground pins common. Measure the output and calculate unloaded gain of stage 1.
13. Similarly by applying input at the second stage measure the output and calculate the unloaded gain of second stage.
14. For the second row of Table 2, connect the two stages. Apply the input signal at the first stage Measure the output of first stage and calculate its loaded gain.
15. Now, with the input signal at the first stage, measure the output at the second stage and calculate the total gain of the two stage amplifier and complete Table-2.
16. To study the frequency response of the two stage amplifier, vary the input signal frequency in the range 20 Hz – 2 MHz, keeping the input signal amplitude always constant. Observe measure and record the output voltage, V_o at the second stage. (You may have to measure V_i and take the ratio V_o/V_i each time in case input fluctuation is too large to hold constant.) Calculate voltage gain for each frequency.

17. Plot the frequency response curve, i.e. voltage gain in dB versus frequency on a semi-log graph-sheet.
18. Estimate the mid-frequency gain and also the lower and higher cut off frequencies and hence the bandwidth.

Observations:

$\beta 1$ = _____ , $\beta 2$ = _____

Stage 1: R_1= ____, R_2= ____, R_C= ____, R_E= ____+___; C_1= ___, C_2= ___, C_E= ___
Stage 2: R_1= ____, R_2= ____, R_C= ____, R_E= ____+___; C_1= ___, C_2= ___, C_E= ___

Table 1: D.C. analysis of the circuit

V_{CC} = 12V

Parameter	Stage 1 (Q1)		Stage 2 (Q2)	
	Computed value	Observed value	Computed value	Observed value
V_B (V)				
V_E (V)				
$I_C \approx I_E$ (mA)				
V_{CE} (V)				
$r_e(\Omega)$				
Q-point				

Table 2: Mid frequency voltage Gain ($f \approx 20$ kHz)

Vi = _____

Parameter	Stage 1 (Q1)		Stage 2 (Q2)	
	Computed	Measured	Computed	Measured
Unloaded Voltage Gain (V_o/ V_i)				
Loaded Voltage Gain				

Total mid frequency gain = Loaded Voltage Gain (Q1) × Unloaded Voltage Gain (Q2)

Total gain (computed) = _____

Total gain (measured) = _____

Table 3: Frequency Response **V_i(pp) = _____**

Sl. No.	Frequency, f (kHz)	V_0(pp) (Volt)	Gain,$A_V = \frac{V_o(pp)}{V_i(pp)}$	Gain (dB)

1				
2				
..				
..				

Calculations: Stage 1: Z_{i1} = _____, Z_{o1} = _____

Stage 2: Z_{i2} = _____, Z_{o2} = _____

Graphs: Plot the frequency response curve and determine the cut-off frequencies, bandwidth and mid-band gain.

Discussions:

Precautions:

3. Vary the input signal frequency slowly.
4. Connect electrolytic capacitors carefully.

Reference: Electronic devices and circuit theory, Robert L. Boylestad & Louis Nashelsky (10^{th} Edition)