INSTRUCTION MANUAL

OF

CONTROL AND MEASUREMENT LAB [EEC273]

FOR

Fourth-Semester B.Tech. (*Electrical Engineering*)

MEASUREMENT LABORATORY [Room No.101]
CONTROL LABORATORY [Room No. 120]
Academic Complex
DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES), DHANBAD

Semester: Winter
Session: 2022-2023

Content

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES), DHANBAD

Laboratory Instruction and Procedure to Conduct

1. **All the students must be on or before the scheduled time for Lab-classes and be regular. It is very difficult to compensate the pending experiments. GROUP-A must report on the first day.**

2. All the students must wear shoes to avoid any electrical shocks. Student without shoes will not be allowed to perform experiments.

3. Students should come into the Lab-classes with lab manual, required stationaries, and calculators.

4. No power supply should be given to the circuit(s) until all the connection and layout are cross-checked by the concerned laboratory instructor in-charge.

5. During the Lab-class, no student should enter or leave the Lab without the permission of the concerned Instructor.

6. **Students are to submit the report (as per the specific format to be circulated on each day) of a particular experiment on the NEXT LAB DAY. Index sheet as per the format provided is to be attached with the report.**

7. **Students must get their report verified from the respective laboratory instructor/in-charge.**

Laboratory In-Charge
[S. DAS & S. PAN]

LIST OF EXPERIMENTS FOR CONTROL LAB

Exp. No.	Title
1.	To Study the Performance Characteristics of a Linear Variable Differential Transformer (LVDT)
2.	To Study DC Servomotor
3.	To Study a Temperature Control System
4.	To Study a Synchro Transmitter and Receiver Pair
5.	To Study the Effect of PID Controller Gains

EXPERIMENT NO.: 01

TITLE: To study the performance characteristics of a linear variable differential transformer (LVDT).

OBJECTIVE: To measure displacements set by a micro-meter using the LVDT and determine the performance characteristics of the LVDT.

OUTCOME:

Hands on knowledge will be gained by the students about the characteristics of the Linear variable differential transformer (LVDT). The linear variation in displacement of LVDT core is examined in the relation with measured displacement and the graph is plotted.

SAFETY PRACTICES AND DO's & DON'Ts:

(a) When plugging/unplugging a power cord from the supply mains make sure that switch is in OFF condition.
(b) Do not touch uninsulated live wires with bare hands.
(c) Avoid loose wires, cables, and connections.
(d) Main lead should be properly connected to instruments.
(e) Readings should be taken carefully.

LIST OF APPARATUS:

S. No.	Apparatus name	Specification	Maker's Name
1.	LVDT Trainer Kit	Operating voltage : 1-phase, 230 V, 50 Hz, Carrier frequency, 2500 Hz Carrier voltage, 2V (RMS)	Vinytics
2.	Micrometer	Range:0-15 mm Least count: 0.01mm	Vinytics

THEORY:

A linear variable differential transformer (LVDT) is called a linear displacement transducer. A LVDT is an electromechanical transducer that can measure very small linear movements in structures and mechanical device, mechanical motion is converted in an electrical signal that contains position information.

A LVDT is essentially a differential transformer having single primary coil and two secondary coils which are symmetrically wound for a cylindrical non – magnetic former and iron core is movable. When the primary coil is energized by an AC source voltages are induced in the two secondary coils. These coils are connected in such a manner that the induced voltages are 180° out of phase. The relationship between the output signal and the carrier is an indication of the direction of core movement from the centre position.

A residual voltage is usually observed at the zero position of the core. This voltage, though very small, is due to incomplete magnetic or electrical balance and is normally at the carrier frequency. The mechanical force needed to move the core depends on its position, *viz,* minimum at the center or zero position and maximum at the two ends. The actual force is however quite small since the primary current in most designs is kept small to avoid heating of the coils. In the same way, the output impedance of the LVDT is also dependent on the position of the core and it is therefore desirable to connect a high impedance circuit at its output to minimize LVDT loading. The linear range of commercial LVDT's may be from fraction of a mm to few hundred mm depending upon their construction and application. Also the sensitivity may typically be a few tens of mV per mm. The high sensitivity, good linearity, large range, infinite resolution and contactless operation are the important features of LVDTs which have resulted in a large number of diverse applications of these transducers. Some examples of applications include pressure measurement, force measurement, accelerometers, force and torque measurement and vibration sensing. A residual voltage is usually observed at the zero position of the core. This voltage though very small is due to incomplete magnetic or electrical balance, and is normally at the carrier frequency. The mechanical force needed to move the core depends on its position, viz, minimum at the Centre and maximum at both the ends.

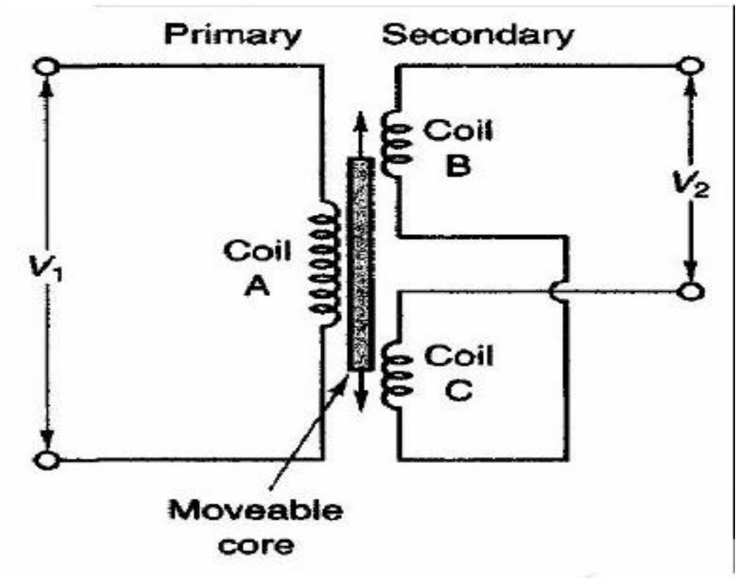
PROCEDURE:

1. Plug in the LVDT trainer kit with the board power supply.
2. Switch on the power supply of the LVDT trainer kit.
3. Assume null position of LVDT to be at 7 mm (say). Set the micrometer to 7 mm and with help of 'Zero Adj' make measured displacement to zero.
4. Gradually vary the micrometer with 0.5mm step, such that
   (a) move the micrometer to extreme right end and note the LVDT readings for each step;
   (b) then, move the micrometer to extreme left end and note the LVDT readings for each step;
   (c) then, move the micrometer to right upto the micrometer reading of 7 mm and note the LVDT readings for each step.

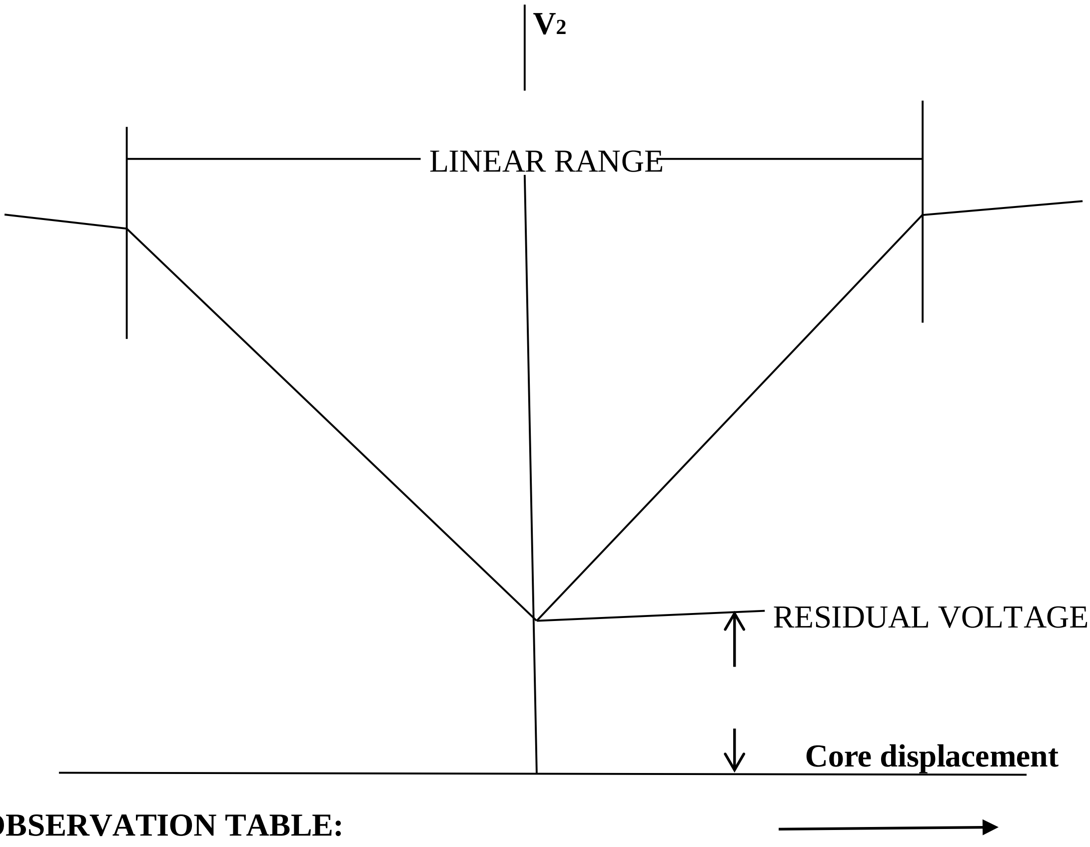
   Thus, one cycle of readings will be complete.

Plot the graphs for LVDT readings vs. micrometer readings for each cycle and observe the linearity and find the slope of it.

CIRCUIT DIAGRAM:



INPUT OUTPUT CHARACTERISTICS:



OBSERVATION TABLE:

Sr. No.	Micrometer reading. Displacement (mm)	LVDT reading. Voltage (mV)
1		
2		
3		
4		

QUESTIONS FOR STUDENTS:

1. The two secondary coils of an LVDT are series....................
   A) Aiding
   B) Opposing

2. The voltage................at the secondary indicates if the core of an LVDT is located above or below the center position.
   A) Magnitude
   B) Phase.

3. When the core of LVDT is located above the center position, the AC waveform at the secondary is ....with primary.
   A) In-phase
   B) Out-of- phase

4. The ....of the secondary voltage of an LVDT indicates how far the core has moved.
   A) Amplitude
   B) Phase.

5. What are the advantages and uses of LVDT?

6. What is least count of a micrometer and how does it be calculated?

EXPERIMENT NO.: 02

TITLE: To study DC servomotor.

OBJECTIVE: To study the operation of DC servomotor and to plot its torque-speed characteristics.

OUTCOME:

The students will understand the working principle and the torque versus speed relation of DC servomotor.

SAFETY PRACTICES AND DO's & DON'Ts:

General

(f) When plugging/unplugging a power cord from the supply mains, make sure that switch is in OFF condition.
(g) Do not touch uninsulated live wires with bare hands.
(h) Avoid loose wires, cables, and connections.

Experiment specific

(i) The armature voltage knob should always be in the minimum voltage condition before switching ON the equipment.
(j) The field excitation knob should always be in the rated field condition before switching ON the equipment.
(k) In case motor stalls switch off the armature supply and make the pulley loose and then restart.

APPARATUS REQUIRED:

SL. NO.	APPARATUS	SPECIFICATION	MAKE
1.	D.C. SERVO MOTOR UNIT	1. DC SERVO MOTOR (to write after observation) (b) Armature volt. Max. : (c) Armature current Max. : (e) Field winding volt. Max. : (f) Maximum RPM : (g) Motor : Shunt 2. 2Kg Spring Balance provided for loading	
2.	DC SERVO MOTOR TRAINER KIT	ON BOARD CIRCUIT (a) $3\frac{1}{2}$ Digit Digital Current Meter (b) $3\frac{1}{2}$ Digit Digital Voltmeter (c) 4-Digit Speed display in rpm	

(Fill up this table after observation of the set-up)

THEORY:

A DC motor can be controlled by varying either the field current or the armature current. Most of the DC Servomotors used in low power applications is of the permanent magnet (PM) type. The ease of controllable speed, along with the linear torque speed control curve make the DC servomotor ideal for servomechanism applications.

The speed-torque curve is quite similar to that of the ac servomotor. These motors are available in 6V, 12V and 24V models making them applicable to solid state circuitry. By comparison, the DC motor has some disadvantages over the AC servo motor. The DC servo motor inertia is greater than that of the AC motor. This greater inertia is due to the wound armature and commutator which produces a heavier rotor.

BLOCK DESCRIPTION

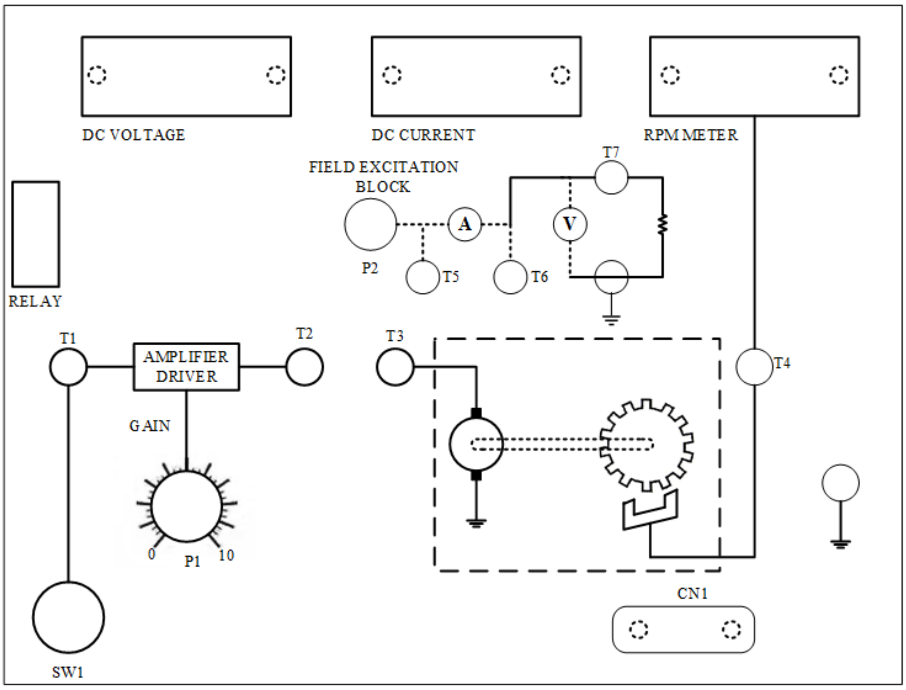


Fig 1. Control unit block description of the DC Servomotor Trainer kit.

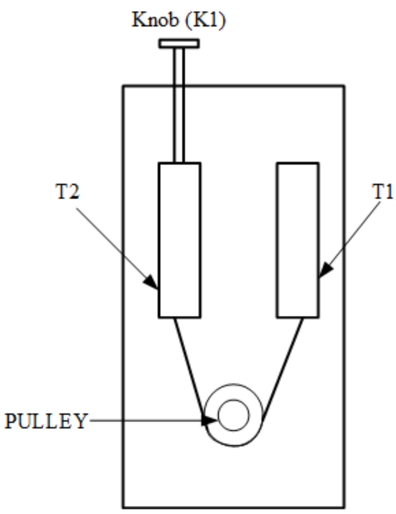


Fig. 2: Front panel of motor unit of the DC servomotor Trainer kit.

PROCEDURE (Using the Trainer Kit):

1. Set the field knob at max voltage point and the armature knob at minimum voltage point. Connect the motor terminals to the control unit. Make the loading of the motor minimum. Then, switch ON the power to the control unit.

2. Increase the armature voltage to maximum in steps and note the readings of the field and armature voltage, current and motor speed.

3. Reduce the armature voltage in steps and note all the above mentioned variables.

4. Get back to the max voltage setting of the armature knob. Tabulate and plot speed vs. armature voltage.

5. Reduce the field voltage in steps and note all the above mentioned variables.

6. Get back to the max voltage setting of the field knob. Tabulate and plot speed vs. armature voltage

7. Increase the loading of the motor in steps and note the variables. Tabulate and plot speed vs. loading and speed vs. armature current.

8. Repeat procedure in 7 for different armature and field voltages.

OBSERVATION TABLE:

Armature voltage constant V_a = ……V

Field Voltage constant V_f = …………V

S. No.	T1 (g)	T2 (g)	T1-T2 (g)	Torque (T1-T2)*R g-cm	N (rpm)	Ia (A)

QUESTIONS FOR STUDENTS:

1. Differentiate between a general motor and a servo motor.
2. Differentiate between ac and dc servo motor.
3. Which type of motors are used as DC servomotors?

Fig. 3: DC Servo Motor Trainer kit: Control unit and Motor unit.

EXPERIMENT NO. : 03

TITLE: To study a temperature control system.

OBJECTIVE: To study control performances of P, PI & PID controllers for temperature control of a compact oven.

OUTCOME:

The students will learn about the dynamics of the temperature control system (compact oven) by using different value of P, PI and PID controllers.

SAFETY PRACTICES AND DO's & DON'Ts:

(a) When plugging/unplugging a power cord from the supply mains make sure that switch is in OFF condition.
(b) Do not touch uninsulated live wires with bare hands.
(c) Avoid loose wires, cables, and connections.
(d) Ensure that 'I' is in OFF condition when not used.

APPARATUS REQUIRED:

S. No	APPARATUS	SPECIFICATION	MAKE
1.	Temperature controller	Operating temp.: 90°C, 25W oven power, 0-9999 s timer, $3\frac{1}{2}$ DVM. Supply: 220V ± 10%, 50-Hz, Single-phase.	Vinytics Peripherals Pvt. Ltd.

CIRCUIT DIAGRAM:

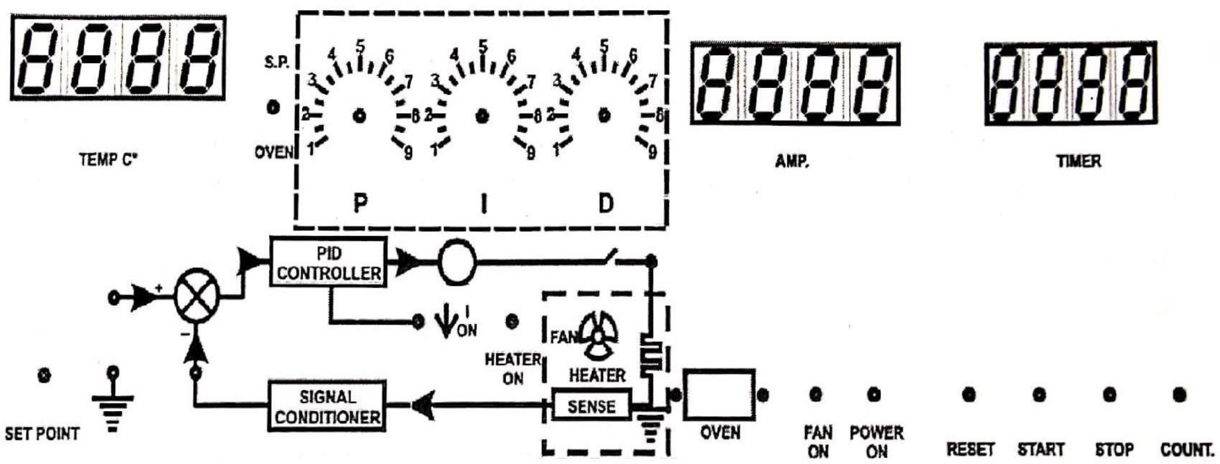


Fig.1: Front panel view of temperature control device

THEORY:

This set up is designed to study performance of analog PID controller with model process as temperature control system. The setup has built in signal source as reference, digital voltmeter as temperature indicator, PID controller with separate controls and a model process with built in regulated DC supply to operate the system.

PID Controller: The PID controller has three adjustable parameters, as P, I, D, each has 3 potentiometers with dial knobs which are subdivided for 0.5 resolution. Switch provided to add or out, I mode. At input of PID controller an error detector is provided which sums the reference and feedback signals. The input and output of PID control has no phase shift. An ammeter is fitted to observe the controller output.

Process: It is an oven housed in a painted mound in which a resistive heater heat up a small piece of aluminum. A solid state temperature sensor sense the temperature of aluminum strip and corresponding signal is further conditioned by electronic circuit. These processed signal are compared with a reference level and an error signal is produced at controller input .There is time lag produced by the stint between heating element and sense point.

Proportional control: The total proportional gain of controller is between 0- 20, thus each major gradient is equal to gain 2.

Integral control: The integral control is slightly differ from the P or D control. This control has minimum value equal to 0.8 s^{-1} and maximum value 21 s^{-1}. The major gradient values are tabulated below.

S. No.	Gradient Value	S. No.	Gradient Value
0	0.8	6	9.5
1	1.0	7	11.2
2	1.5	8	14.0
3	2.5	9	18.0
4	5.0	10	21.0
5	7.2		

Derivative control: It is similar dial has linear response between 0 - 5s. The major gradient has multiply factor equal to 0.5 value. Setting the control knob at major gradient 6 will have derivative rate of 5 ×0.5 = 2.5s.

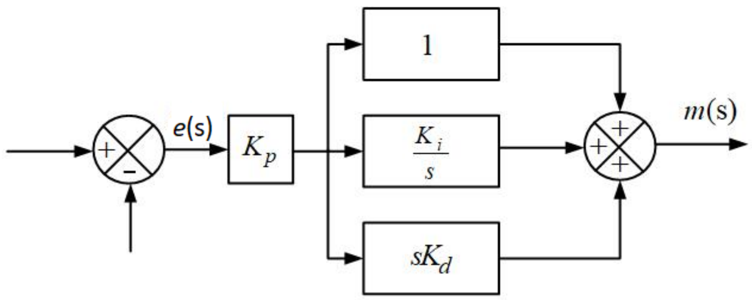


Fig. 2: PID Controller block diagram

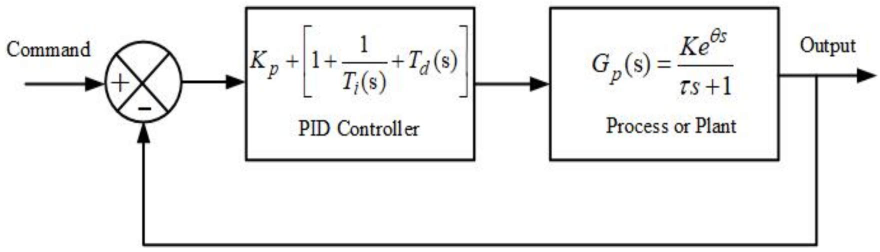


Fig.3. PID Controller for process control system (theta is of negative value)

PROCEDURE:

(a) Set the 'P' knob at 5, make the 'I' to OFF position and set the 'D' knob to ZERO position.
(b) Make the heater 'ON'.
(c) Start the Timer and take readings at an interval of about 5 seconds.
(d) Make the heater 'OFF', switch ON the fan for some time to cool the temperature of the oven, then switch OFF the fan.
(e) Again set 'P' and 'I' knob to a specified value ('P'=5, 'I'=5) and setting 'D' knob to zero position.
(f) Make the heater ON.
(g) Start the timer and take the readings at equal intervals.
(h) Repeat the same process for PID controller.

OBSERVATION TABLE:

Table 1. For P controller

Set Temp. = …, P = …

SL.NO.	TIME (s)	OVEN TEMP. (.^{o} c)

Table 2. For PI controller

Set Temp = …, P = …, I = …

SL.NO.	TIME (sec)	OVEN TEMP. (c)

Table 3. For PID controller

Set Temp = …, P = …, I = …, D = …

SL.NO.	TIME (sec)	OVEN TEMP. (c)

QUESTIONS FOR STUDENTS:

1. What is PID controller?
2. What are advantages of PID controller?
3. Why derivative mode is not used alone?
4. What are the drawbacks of P controller?

Fig. 4: The kit for Temperature Control Experiment.

EXPERIMENT NO.: 04

TITLE: To study a synchro transmitter and receiver pair.

OBJECTIVE: To measure angular displacements using a synchro transmitter and receiver pair and determine the performance characteristic for the follow-up mechanism.

OUTCOME:

The synchronized information transferred from one end to another end is studied. The rotor of the receiver follows the direction and position of the transmitter rotor.

SAFETY PRACTICES AND DO's & DON'Ts:

(a) When plugging/unplugging a power cord from the supply mains make sure that switch is in OFF condition.
(b) Do not touch uninsulated live wires with bare hands.
(c) Avoid loose wires, cables, and connections.
(d) Do not short rotor or stator terminal.
(e) Handle the pointer carefully

APPARATUS REQUIRED:

S. No.	APPARATUS NAME	SPECIFICATION	MAKER'S NAME
1.	Experimental Kit	Supply Voltage: 1-ϕ, 230 V, 50 Hz	Vinytics Peripherals Pvt. Ltd
2.	DSO	Supply Voltage: 1-ϕ, 230 V, 50 Hz	

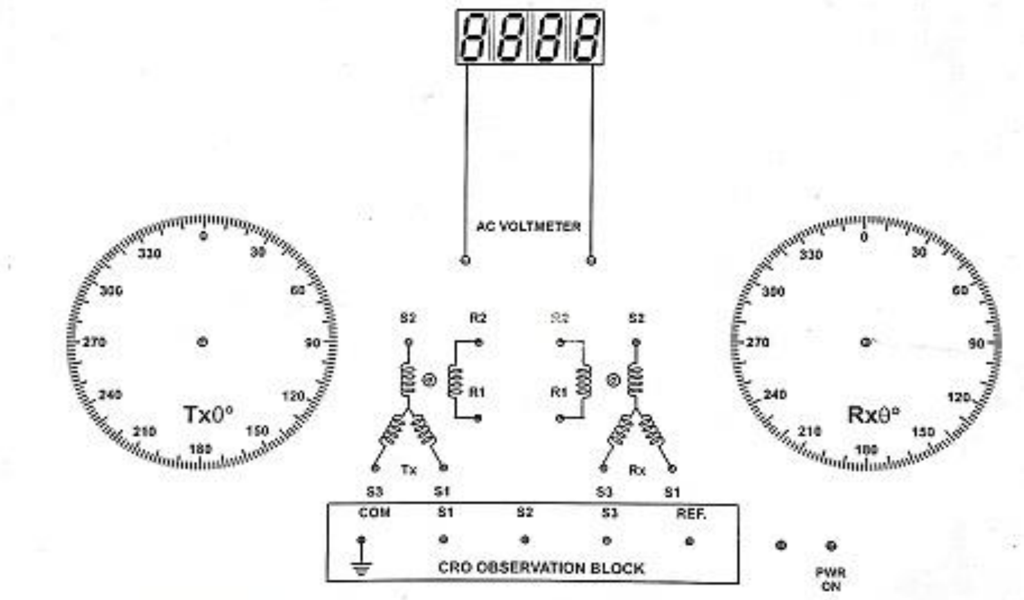


Fig-1 Front View of Experimental Kit

THEORY:

A synchro is an electromagnetic transducer commonly used to convert an angular position of a shaft into an electric signal. The system set up is made up of synchro transmitter and synchro receiver on a single rigid base provided with suitable switches and anodized angular plates. The system also contains a step down transformer for providing excitation to the rotors. Suitable test points for rotor ($R_1 and\ R_2$) and stator ($S_1, S_2\ and\ S_3$) for both $T_x$and T_r are provided.

The classical synchro systems consists of two units.
1. Synchro transmitter (T_x)
2. Synchro receiver (T_r)

1. Synchro transmitter (T_x): The basic synchro is usually called a synchro transmitter. Its construction is **similar** to that of a three phase alternator. The stator (stationary member) is of laminated silicon steel and is slotted to accommodate a balanced three phase winding which is usually of concentric coil type (Three identical coils are placed in the stator with their axis 120 degree apart) and is Y connected. The rotor is a dumb bell construction and wound with a concentric coil. An AC voltage is applied to the rotor winding through slip rings.

$$V_r(t) = V_r \sin \omega_c.t \ldots (1)$$

Let an AC voltage $V_r(t)$be supplied to the rotor of the synchro transmitter. This voltage causes a flow of magnetizing current in the rotor coil which produces a sinusoidally time varying flux directed along its axis and distributed nearly sinusoidal, in the air gap along stator periphery. Because of transformer action, voltages are induced in each of the stator coils. As the air gap flux is sinusoidally distributed, the flux linking any stator coil is proportional to the cosine of the angle between rotor and stator coil axis and so is the voltage induced in each stator coil.

The stator coil voltages are of course in time phase with each other. Thus we see that the synchro transmitter (Tx) **acts like single phase transformer** in which rotor coil is the primary and the stator coils form three secondaries.

LetV_{s1n}, $V_{s2n}$and V_{s3n} respectively be the voltages induced in the stator coils S_1, S_2 and S_3 with respect to the neutral. Then for the rotor position of the synchro transistor where the rotor axis makes an angle 0 degree with the axis of the stator coil S_2.

Let

$$V_{s1n} = KV_r \sin \omega_c.t .\cos (\theta + 120) \quad (2)$$

$$V_{s2n} = KV_r \sin \omega_c.t .\cos (\theta) \quad (3)$$

$$V_{s3n} = KV_r \sin\omega_c.t .\cos (\theta + 240) \quad (4)$$

The three terminal voltages of the stator are

$$V_{s1s2} = V_{s1n} - V_{s2n}$$

$$= \sqrt{3}\ KV_r \sin (\theta + 240) \sin \omega_c t \quad (5)$$

$$V_{s2s3} = V_{s2n} - V_{s3n}$$

$$= \sqrt{3}\ KV_r \sin (\theta + 120) \sin \omega_c.t \quad (6)$$

$$V_{s3s1} = \sqrt{3}\ KV_r \sin (\theta) \sin \omega_c.t \quad (7)$$

When θ is zero from equation (3) it is seen that maximum voltage is induced in the stator coil s2 while it follows from equation (7) that the terminal voltage Vs3s1 is zero. This position of rotor is defined as the electrical zero of the Tx and is used as a reference for specifying the angular position of the rotor.

Thus it is seen that the input to the synchro transmitter is the angular position of its rotor shaft and the output is a set of three single phase voltages given by equation (5), (6) and (7). The magnitudes of these voltages are functions of a shaft position.

2. Synchro receiver (T_r): The synchro receiver is having almost the same constructional features. The two units are connected as shown in figure No.2. Initially the winding S_2 of the stator of transmitter is positioned for maximum coupling with rotor winding. Suppose its voltage is V. The coupling between S_1 and S_2 of the stator and primary (Rotor) winding is a cosine function. Therefore the effective voltages in these winding are proportional to cos 60 degrees or they are V/2 each. So

long as the rotors of the transmitters and receivers remain in this position, no current will flow between windings because of voltage balance.
When the rotor of T_X is moved to a new position, the voltage balance is disturbed. Assume that the rotor of T_X is moved through 30 degrees, the stator winding voltages will be changed to zero, 0.866V and 0.866V respectively. Thus there is a voltage imbalance between the windings causes currents to 1 flow through the close circuit producing torque that tends to rotate the rotor of the receiver to a new position where the voltage balance is again restored. This balance is restored only if the receiver turns through the same angle as the transmitter and also the direction of the rotation is the same as that of T_X.

The T_x,T_r pair thus serves to transmit information regarding angular position at one point to a remote point.

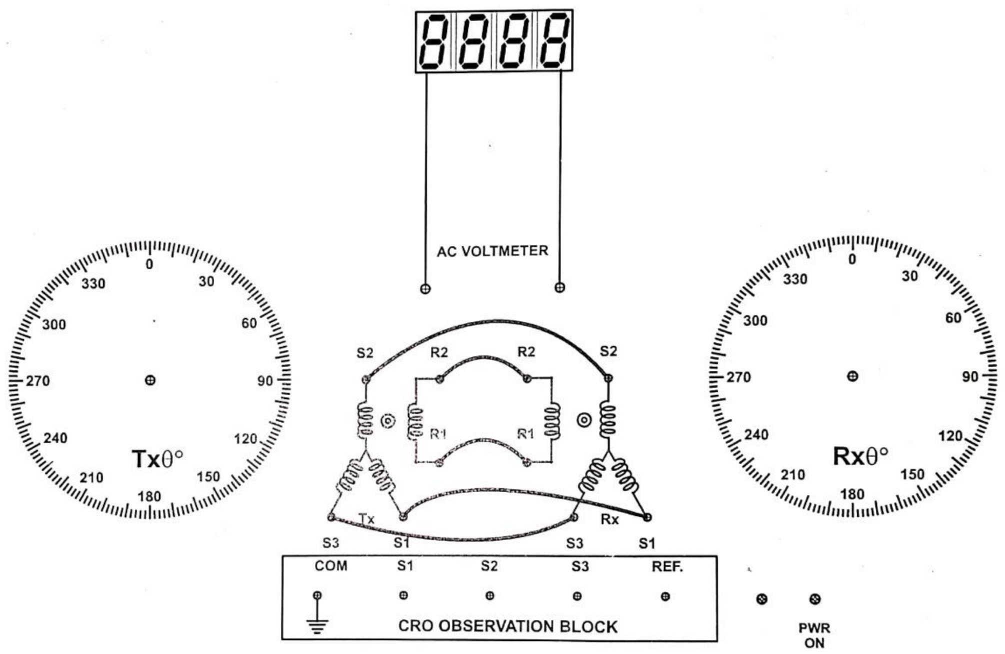


Fig. 2: Circuit connection of experimental kit

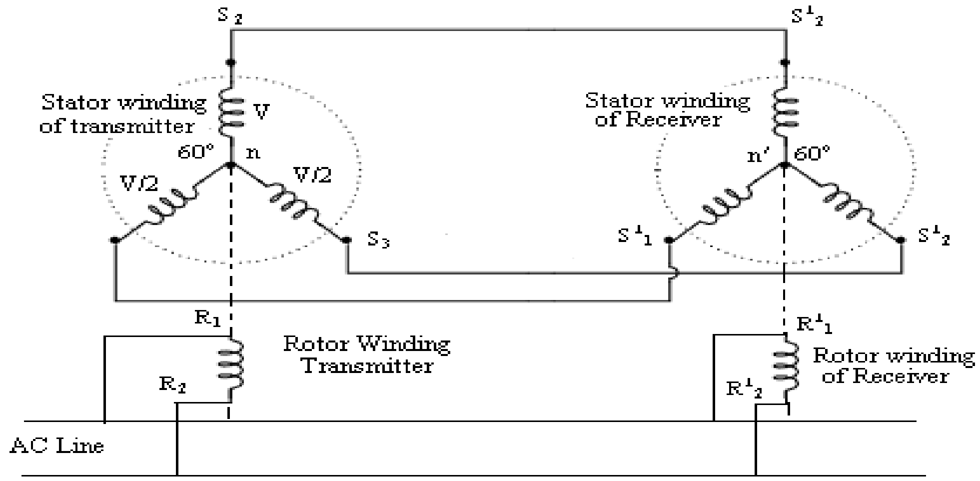


Fig. 3: Torque Transmission using Synchro Transmitter

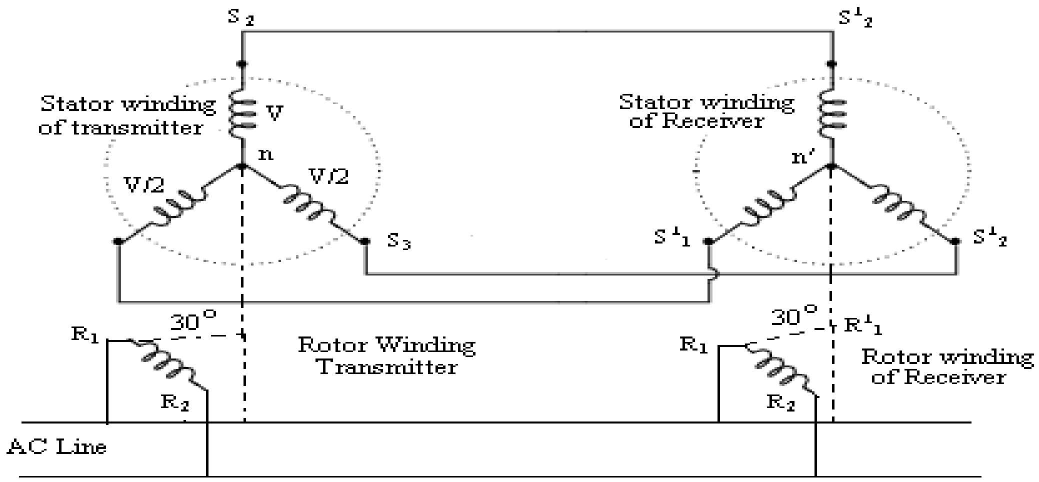


Fig. 4: Synchro Transmitter and Receiver

PROCEDURE:

1. Connect the mains supply to system with the help of cable provided.
2. Connect patch cords to terminal marked S1, S2, S3 and R1, R2 (Tx) to S1, S2, S3 and R1, R2 (Rx).
3. Switch on the main supply.
4. Set the dial Tx motor in zero position.
5. Starting from Zero position, note down the voltage between stator winding terminals i.e., V_{s1s2}, V_{s2s3} and V_{s3s1} with the help of AC voltmeter in a sequential manner. Enter readings in a tabular form and plot a graph of angular position of rotor voltages for all three coils.
6. Move the pointer i.e., rotor position of synchro transmitter in steps of 30 degrees and observe the new rotor position. Observe that whenever rotor is rotated, the Rx rotor follows it for both the direction of rotations and their positions are in good agreement.
7. Enter the input angular position and output angular position in the tabular form and plot a graph.

OBSERVATION TABLE:

1. Synchro Transmitter Rotor Position versus Stator Voltage

SL. NO.	Input angle	Rms voltage for stator terminal (V_{s1s2})	Rms voltage for stator terminal (V_{s2s3})	Rms voltage for stator terminal (V_{s1s3})

2. Typical results for study of Synchro Transmitter and Receiver

SL. NO.	Angular position in degrees (synchro transmitter) or input	Angular position in degrees (synchro receiver) or output

QUESTIONS FOR STUDENTS:

(1) What is Synchro?
(2) What is the application of synchro transmitter & receiver?
(3) Why does synchro work only in AC?
(4) What is the difference between potentiometer and Synchro?

Fig.5 : Synchro Transmitter & Receiver kit and DSO.

EXPERIMENT NO.: 05

TITLE: To study the effect of PID controller gains.

OBJECTIVE: To apply the proportional (P), integral (I) and derivative (D) gains for first and second order systems.

OUTCOME:

The nature of response curves for square and triangular wave signals is studied. The difference in nature of the responses for open-loop and closed-loop feedback systems is observed.

SAFETY PRACTICES AND DO's & DON'Ts:

(f) When plugging/unplugging a power cord from the supply mains make sure that switch is in OFF condition.
(g) Do not touch uninsulated live wires with bare hands.
(h) Avoid loose wires, cables, and connections.
(i) Rotate the gain knobs carefully.

APPARATUS REQUIRED:

S. No	APPARATUS	SPECIFICATION	MAKE
1.	PID controller kit	1. Supply requirement: 1-ϕ, 240V, 50Hz 2. Blocks: Adder, PID Gains, Integrator, Time Constant and Delay. 3. Signal Sources: Square wave, Triangular wave	Geotech Instruments
2.	Digital Storage Oscilloscope (DSO)	1. Supply requirement: 1-ϕ, 240V, 50Hz 2. Input Channels: Four 3. Divisions: Volt/Division ……& Time/Division …… 4. Frequency: 200 MHz	SIGLENT

Fig. 1: PID control kit with DSO.

THEORY:

The PID controller provided in the setup has three separate control knobs for each parameter, P for proportional gain, I for integral gain and D for derivative gain. The Three controls are continuously variable potentiometers, with knobs.

First Order Systems: These are characterized by one pole. A first order system is represented in the standard form as:

$$G(s) = \frac{K}{(sT+1)} \text{ and } c(t) = K(1 - e^{\frac{-1}{T}})$$

Second Order System: These system are characterized by two poles. For the purpose of transient response studies, zeros are usually not consideration primarily because of simplicity in calculations and also because the zeros do not affect the internal modes of the systems. This forms the basis of studying higher order systems many of which can be approximated to second order. A second order system is represented in the standard form as:

$$G(s) = \frac{{\omega_n}^2}{s^2 + 2\xi\omega_n + {\omega_n}^2}$$

Where ξ is called the damping ratio and ω_n is called undamped natural frequency. Depending upon the value of ξ, the poles of the system may be real, repeated or complex conjugate which is reflected in the nature of its step response. Results obtained for various cases are:

(i) Underdamped case (0< ξ<1)

$$c(t) = 1 - \frac{e^{-\xi.\omega_n.t}}{\sqrt{1-\xi^2}}.\sin(\omega_d.t + tan^{-1}(\frac{\sqrt{1-\xi^2}}{\xi}))$$

Where $\omega_d = \omega_n.\sqrt{1-\xi^2}$ is termed the damped natural frequency. A sketch of the unit step response for various values of ξ is available in the text books.

(ii) Critically damped case ($\xi = 1$) :

$$\mathrm{c(t)} = 1 - e^{-\omega_n.t}.(1 + \omega_n.t)$$

(iii) Overdamped Case ($\xi > 1$)

$$c(t) = 1 + \frac{\omega_n}{2.\sqrt{\xi^2 - 1}}\left(\frac{e^{-s_1.t}}{s_1} - \frac{e^{-s_2.t}}{s_2}\right)$$

Where s_1=($\xi + \sqrt{\xi^2 - 1}$). ω_n and $s_2 = (\ \xi - \sqrt{\xi^2 - 1}).\ \omega_n$

PROCEDURE:

1. Prepare a control system with the given blocks in the Kit with the help of patch cords.
2. Insert the DSO probe into channel 1.
3. Connect the black probe tip of the DSO to ground of the kit using a patch cord.
4. Connect the red probe tip of the DSO to the function generator (square wave) of the kit.
5. Set peak-to-peak voltage and frequency of input signal using LEVEL and FREQUENCY knob, respectively.
6. Connect the ‘P’ knob and see the response on DSO.
7. Repeat the aforementioned steps for I, D and different combination of these controller gains.

OBSERVATION TABLE:

Graph displayed in the DSO will be drawn on the rough sheet (in the laboratory) and on the graph paper (for report). The measurement of each input and output response will be shown on the same vertical axis of the graph.

Fig. 2: A sample square-wave response.

Questions for students:

(1) What is the effect of time constant in the response of a system?
(2) Differentiate between the effect of Integral controller in open-loop and closed loop condition of a system.
(3) Define second order system and its characteristics.

LIST OF EXPERIMENTS FOR MEASUREMENT LAB

Exp. No.	Title
1	Measurement of Active and Reactive Power in Three-Phase AC Circuit
2	Measurement of Unknown Inductance and Q-factor using Maxwell's Inductance Capacitance Bridge
3	Measurement of Unknown Capacitance using Schering Bridge
4	Study of the Characteristics of Analog to Digital Converter (ADC)
5	Study of the Characteristics of Digital to Analog Converter (DAC)

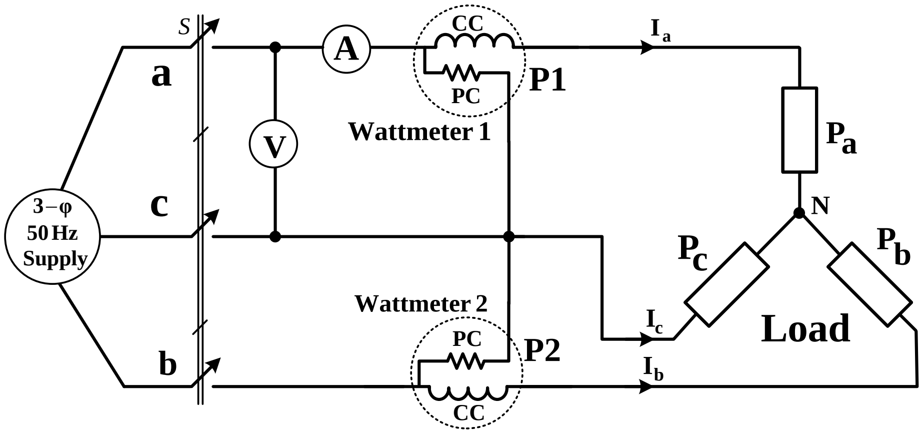
EXPERIMENT NO.: 01

TITLE: Measurement of Active and Reactive Power in Three Phase AC Circuit

OBJECTIVE: Measurement of the power in a three phase AC circuit by two wattmeter method using Resistive (R) and Inductive (R-L) Load.

THEORY: The two-wattmeter method uses two single-phase wattmeters, to measure three-phase power. The sum of the measurement with two single-phase wattmeters becomes three phase power in this measuring setup.

See the figure, measurement of a three-phase three-wire (Y) connection load. The wattmeter 1 is connected to the phase a, c. The wattmeter 2 is connected to the b phase and the c phase. Each measures the single phase power P_1 and P_2, respectively. The sum of the two measured values is equal to the total three-phase power.



$$P_a + P_b + P_c = P1 + P2$$

Fig. 1 Two Wattmeter method

Total power is the algebraic sum of the two readings under all conditions of load and power factor. For three-phase power systems, two watt-meters are connected as shown in Figure (previous). With this configuration, each wattmeter uses the c-phase line as its reference. Although it is possible to use three wattmeters (one in each phase with the neutral as a reference), the neutral is not always available in a three-phase system and the three-wattmeter method cannot determine the reactive power as the two wattmeter method can.

Using the a-phase the mathematical reference, the line-to neutral voltages, a- to b-phase voltage, and a-phase current are given by

$V_a = V_{rms} \angle 0^0$

$V_b = V_{rms} \angle -120^0$

$V_c = V_{rms} \angle 120^0$

And,

$V_{ab} = V_{l\text{-}l} \angle 30^0$

$I_a = I_{rms} \angle \phi$

Where $V_{l\text{-}l}$ is the RMS value of the line-to-line voltage which is related to the line-to-neutral voltage by

$V_{l\text{-}l} = \sqrt{3} V_{rms}$

These phasors are plotted in the figure given below.

The watt-meters output

$P_1 = | V_{ac} || I_a | \cos(\angle V_{ac} - \angle I_a)$ and $P_2 = | V_{bc} || I_b | \cos(\angle V_{bc} - \angle I_b)$

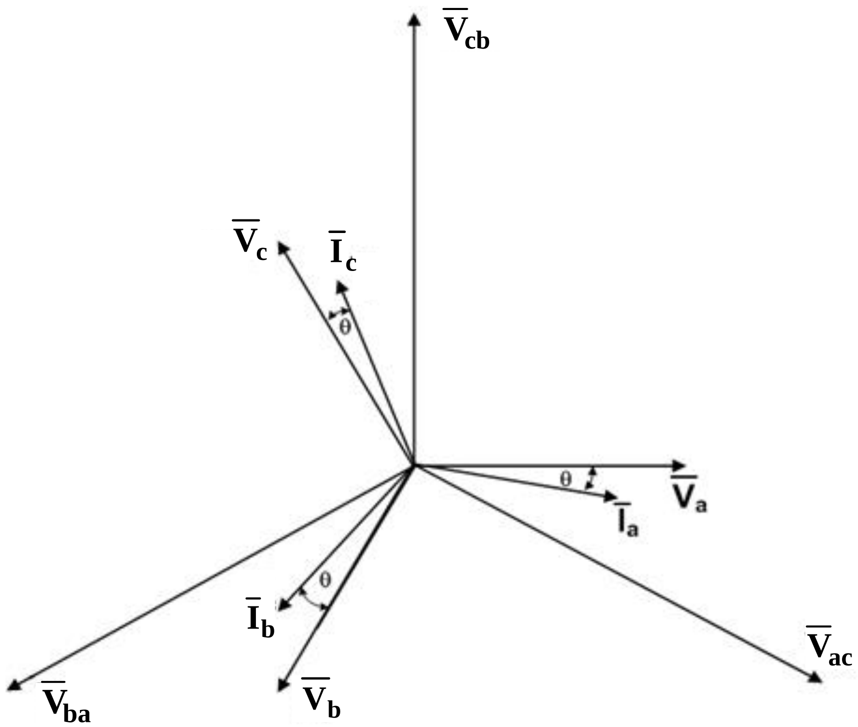


Fig. 2 Voltage and Current Phasors in a Three-Phase Power System

As can be seen from figure, and determined by combining

$P_1 = V_{l\text{-}l} I_{rms} \cos(\theta + 30°)$

Similarly,

$P_2 = V_{l\text{-}l} I_{rms} \cos(\theta - 30°)$

Adding the two wattmeter readings yields

$P_1 + P_2 = V_{l\text{-}l} I_{rms} [\cos(\theta + 30°) + \cos(\theta - 30°)] = \sqrt{3} V_{l\text{-}l} I_{rms} \cos(\theta)$

Taking the difference of the wattmeter readings yields

$P_2 - P_1 = V_{l\text{-}l} I_{rms} [\cos(\theta - 30°) - \cos(\theta + 30°)] = V_{l\text{-}l} I_{rms} \sin(\theta)$

Recalling that three-phase real and reactive power are given by

$P = \sqrt{3} V_{l\text{-}l} I_{rms} \cos(\theta)$ and $Q = \sqrt{3} V_{l\text{-}l} I_{rms} \sin(\theta)$

It can be seen that $P = P_1 + P_2$ and $Q = \sqrt{3} (P_2 \sim P_1)$

From this information, the apparent power and load impedance angle can be found using

$S = \sqrt{\ } P_2 + Q_2$

$\phi = tan^{-1}\left(\frac{Q}{P}\right)$

It should be noted that a-b-c phase sequence is assumed for this derivation. If the phase sequence is a-c-b, then the wattmeter readings should be reversed.

APPARATUS REQUIRED:

1. Nvis 7005 (Technical specifications are given below)
2. Patch cords (4 mm)
3. 100 W, 250 V bulbs (3 Nos.)

TECHNICAL SPECIFICATIONS OF NVIS 7005:

Mains Supply: 415 V ±10%, 50 Hz

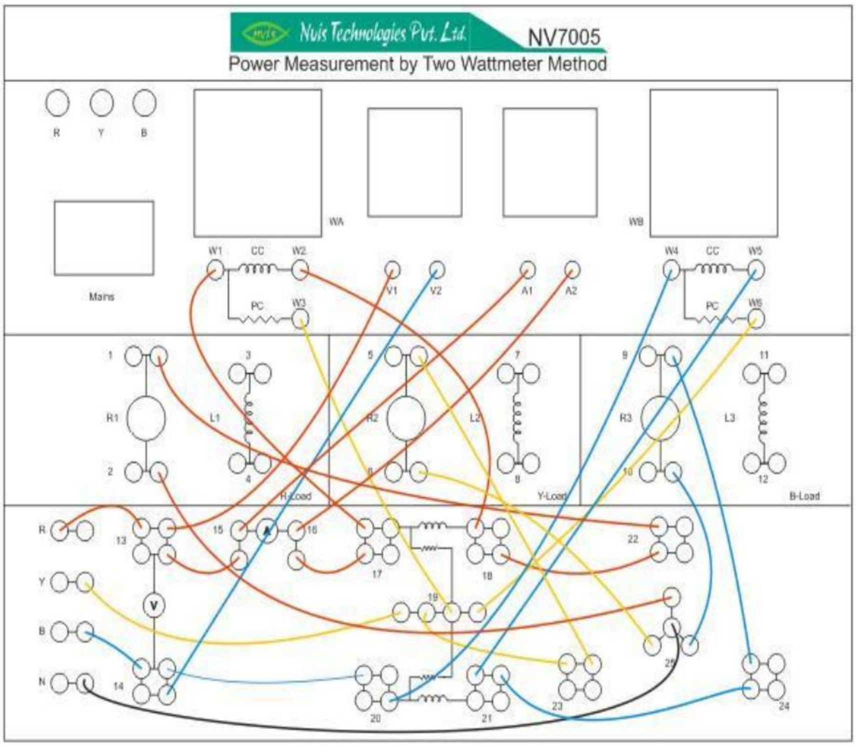
Load: R – L [**Bulb :** 100 W (3 Nos.), **Inductor Coil :** 0.8 H, 2A]

Meters Used

Wattmeter: 500W (2 Nos.), **Voltmeter (MI) :** 500V and **Ammeter (MI) :** 1A

MCB : 10 A

CONNECTION DIAGRAM: For "R" Load



PROCEDURE:

1. First of all, make sure that the earthing of your laboratory is proper and it is connected to the terminal provided to back side of panel.
2. Make sure that the Three Phase Mains is "Off" and MCB of panel is at "Off" position.
3. Connect single phase cable to the auxiliary socket provided at the back side of the control panel (For digital Meter only).
4. Now connect R terminal to terminal 13 and Y to 19.
5. Connect B to 14 and N to 25.
6. Connect terminal 13 to 15 and 14 to 20.
7. Connect 16 to 17.
8. Connect terminal 18 to 22 and 19 to 23.
9. Connect terminal 21 to 24.

Now insert meters across the circuit

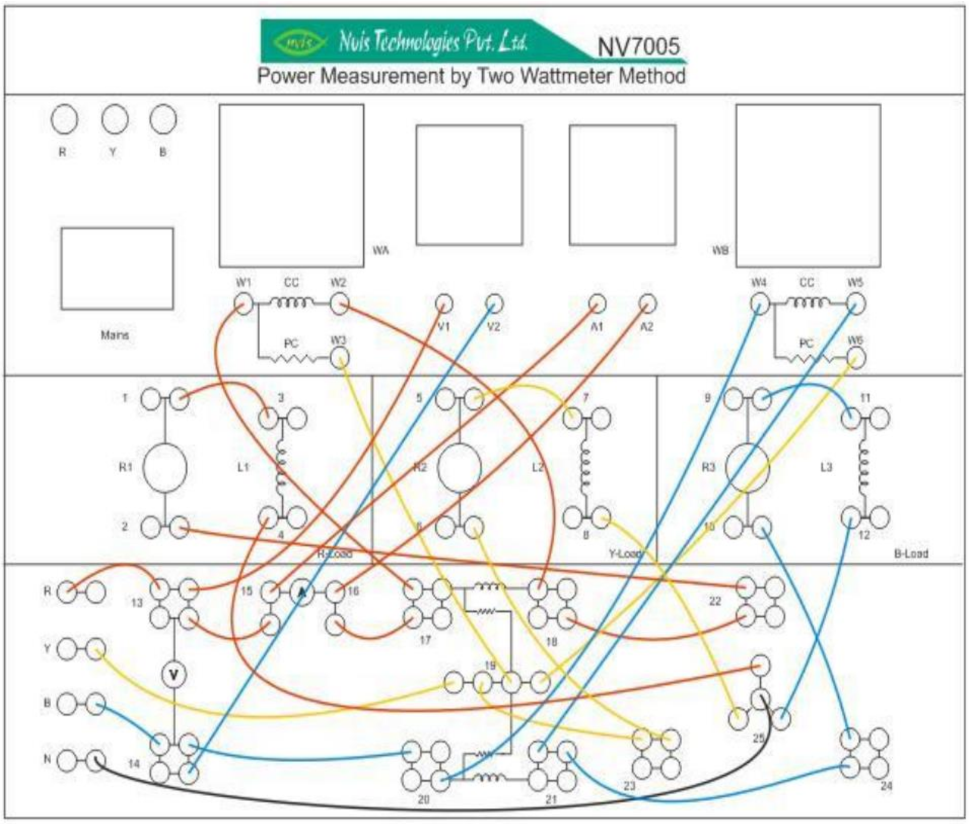
10. Connect voltmeter terminals V1 and V2 across terminals 13 and 14 respectively.
11. Similarly connect ammeter terminals A1 and A2 across terminals 15 and 16 respectively.
12. Connect first wattmeter (terminals W1, W2 and W3) across terminals 17, 18 and 19 respectively.
13. Similarly connect second wattmeter (terminals W4, W5 and W6) to terminals 20, 21 and 19 respectively.

Now insert Resistive load into the circuit

14. Connect R- Load terminal 1 and 2 across terminals 22 and 25 respectively.
15. Connect Y- Load terminal 5 and 6 across terminals 23 and 25 respectively.
16. Connect B- Load terminal 9 and 10 across terminals 24 and 25 respectively.
17. Now recheck the connections whether it is properly connected or not.
18. Connect 100W Bulb externally into the bulb holders provided at the front panel.
19. Switch "On" the Single Phase Supply (For digital Meter only).
20. Then switch "On" the Three Phase Mains as well as the MCB of panel.
21. Observe the readings of voltmeter, ammeter and wattmeter.
22. Record reading of voltmeter as V or V_L, reading of ammeter as I or I_L, reading of first wattmeter W_A as W_1 and that of second as W_2.
23. Switch "Off" the Three Phase Mains as well as the MCB of panel.

POWER MEASUREMENT WITH "R-L" LOAD

CONNECTION DIAGRAM: For "R-L" Load



PROCEDURE:

1. First of all, make sure that the earthing of your laboratory is proper and it is connected to the terminal provided to back side of panel.
2. Make sure that the Three Phase Mains is "Off" and MCB of panel is at "Off" position.
3. Connect single phase cable to the auxiliary socket provided at the back side of the control panel (For digital Meter only).
4. Now connect R terminal to terminal 13 and Y to 19.
5. Connect B to 14 and N to 25.
6. Connect terminal 13 to 15 and 14 to 20.

7. Connect terminal 18 to 22 and 19 to 23.
8. Connect terminal 21 to 24.

Now insert meters across the circuit

9. Connect voltmeter terminals V1 and V2 across terminals 13 and 14 respectively.
10. Similarly connect ammeter terminals A1 and A2 across terminals 15 and 16 respectively.
11. Connect first wattmeter (terminals W1, W2 and W3) across terminals 17, 18 and 19 respectively.
12. Similarly connect second wattmeter (terminals W4, W5 and W6) to terminals 20, 21 and 19 respectively.

Now insert R-L load in the circuit

13. Firstly connect terminals 1 -3, 5-7 and 9-11 of the load so that the bulb (resistive load) and the coil (inductive load) will be in series and form an R-L load.
14. Connect terminals 2 and 4 to terminals 22 and 25 respectively.
15. Connect terminals 6 and 8 to terminals 23 and 25 respectively.
16. Connect terminals 10 and 12 to terminals 24 and 25 respectively.
17. Now recheck the connections whether it is properly connected or not.
18. Connect 100W Bulb externally into the bulb holders provided at the front panel.
19. Switch "On" the Single Phase Supply (For digital Meter only).
20. Then switch "On" the Three Phase Mains as well as the MCB of panel.
21. Observe the readings of voltmeter, ammeter and wattmeter.
22. Record reading of voltmeter as V or V_L, reading of ammeter as I or I_L, reading of first wattmeter W_A as W_1 and that of second as W_2.
23. Switch "Off" the Three Phase Mains as well as the MCB of panel.

OBSERVATION TABLE:

Type of Load	Line Voltage (V)	Line Current (A)	Watt-meter Reading W_1 (Watt)	Watt-Meter Reading W_2 (Watt)	Total Active Power $P = (W_1 + W_2)$ (Watt)	Total Reactive Power $Q = \sqrt{3}(W_1 \sim W_2)$ (Var)	Apparent Power $\sqrt{P^2 + Q^2}$ (VA)	Power Factor $\text{Cos}\Phi = \frac{W_1 + W_2}{\sqrt{3}V_L I_L}$
R								
RL								

CALCULATION:

Active power of the circuit would be $P = \sqrt{3}\ V_L\ I_L \text{ Cos } \Phi = W_1 + W_2$. (In watts)

Reactive power of load would be

$Q = \sqrt{3}\ (W_1 \sim W_2)$.

And, hence apparent power of the circuit would be $S = \sqrt{(P^2 + Q^2)}$

$$\tan\phi = \frac{\sqrt{3}(W_1 \sim W_2)}{(W_1 + W_2)}$$

Power factor would be

Cos Φ = $W_1 + W_2 / \sqrt{3}\, V_L\, I_L$.
where,
V = Voltmeter reading.
I = Ammeter reading. W_1 = Power measure in wattmeter W_A.
W_2 = Power measure in wattmeter W_B.
P = Total power.
Q = Reactive power.
Cos Φ = Power factor.
V_L = Line voltage (voltmeter reading).
I_L = Line current.

RESULT:

1. Total active/ reactive/apparent power and power factor in the three phase ac circuit for R-load are……………………………
2. Total active/ reactive/apparent power and power factor in the three phase ac circuit for R-L load are……………………………

SAMPLE QUESTIONS/QUERIES::

Comment upon the readings of the two wattmeters under following conditions. Support your answer by drawing phasor diagrams:

(i) When pf = 1
(ii) When pf = 0.5
(iii) When pf = 0.3
(iv) When pf = 0.

REFERENCE:

1. Electrical Measurements and Measuring Instruments by E. W. Golding, F. C. Widdis.
2. Modern Electronic Instrumentation and Measurement Techniques by A. D. Helfrick, W. D. Cooper.
3. Elements of Electronic Instrumentation and Measurements by J. J. Carr.
4. A Course in Electrical and Electronic Measurements and Instrumentation by A. K. Sawhney.

Note:

- For better results Line Voltages as well as Phase Voltages of the Input Three Phase Supply must be same.
- It is strongly recommended not to use Inductive Load alone into the circuit or else inductive coil will get damage.

EXPERIMENT NO.: 02

TITLE: Measurement of Unknown Inductance & Q-Factor using Maxwell's Inductance Capacitance Bridge

OBJECTIVE: Determination of unknown inductance and Q-factor using Maxwell's inductance capacitance bridge method.

THEORY:

A **Maxwell Bridge**, also known as the Maxwell-Wien Bridge, is an AC bridge circuit used for measuring an unknown inductance by balancing the loads of its four arms, one of which contains the unknown inductance. Figure below shows a diagram of the Maxwell Bridge.

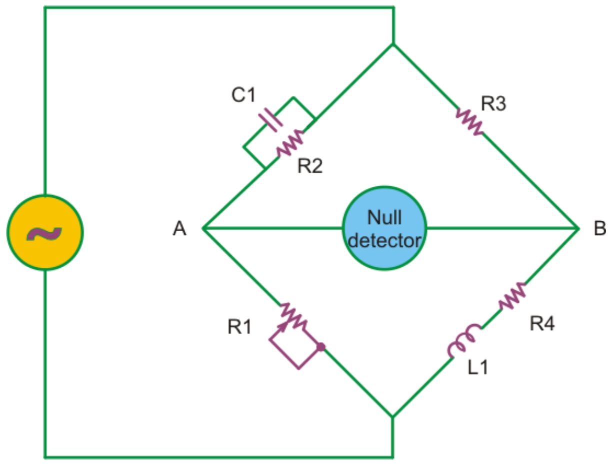


Fig. 1 Maxwell's Inductance Capacitance Bridge

As shown in Figure, one arm of the Maxwell bridge consists of a capacitor in parallel with a resistor (C1 and R2) and another arm consists of an inductor L1 in series with a resistor (L1 and R4). The other two arms just consist of a resistor each (R1 and R3). The values of R1 and R3 are known, and R2 and C1 are both adjustable. The unknown values are those of L1 and R4.

Like other bridge circuits, the measuring ability of a Maxwell Bridge depends on 'balancing' the circuit. Balancing the circuit means adjusting C1 and R2 until the current through the bridge between points A and B becomes zero. This happens when the voltages at points A and B are equal. When the Maxwell Bridge is balanced, it follows that Z1/R1 = R3/Z2, where Z1 is the impedance of C1 in parallel with R2, and Z2 is the impedance of L1 in series with R4. Mathematically,

Z1 = R2/(1+jωC1.R2);

while, **Z2 = R4 + jωL1**

Thus, when the bridge is balanced,

Z1/R1 = R3/Z2

or, [R2/(1+jωC1.R2)][R4+ jωL1]=R1.R3

or, R2(R4+ jωL1)=R1.R3+jω C1.R2.R1.R3

On equating real parts,

R1.R3 = R2.R4,

or, R2=R1.R3/R4

On equating imaginary parts,

L1.R2 = C1.R2.R1.R3

or, L1 = C1.R1.R3

Note that the balancing of a Maxwell Bridge is independent of the source frequency.

APPARATUS REQUIRED:

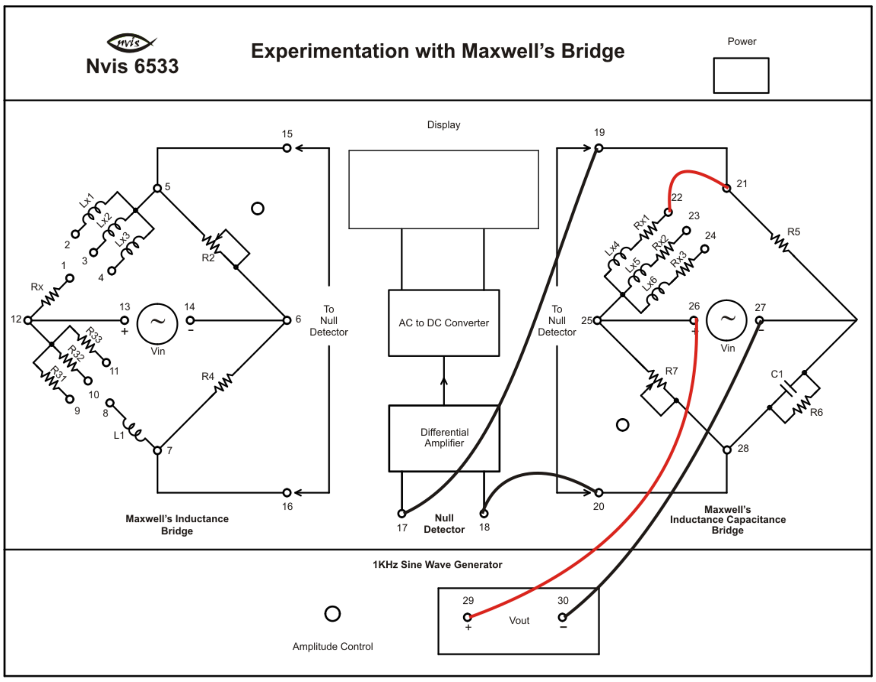
1. Maxwell's bridge Trainer Kit (Nvis 6533)
2. 2 mm patch cords
3. Digital multimeter
4. Oscilloscope

TRAINER KIT'S (NVIS 6533) TECHNICAL SPECIFICATION:

Mains supply	230 V AC ±10%, 50 Hz
DC Power supply **Sine wave generator**	±12 V
Fixed frequency	1 kHz ± 5%
Amplitude control range	Up to $20V_{pp}$
DPM	200 mV
Unknown Inductors	10 mH,20 mH, 30 mH

CIRCUIT DIAGRAM:

Mimic illustration with connections for Maxwell's inductance capacitance bridge method for measurement of unknown inductance is shown in the figure below.



PROCEDURE:

1. Connect a patch cord between socket ‘26’ of Vin terminal of the Maxwell’s inductance capacitance bridge and socket ‘29’of Vout terminals of 1 kHz sine wave generator.
2. Connect a patch cord between socket ‘27’ of Vin terminal of the Maxwell’s inductance capacitance bridge and socket ‘30’of Vout terminals of 1 kHz sine wave generator output.
3. Connect a patch cord between sockets ‘19’ and ‘17’ and another patch cord between sockets ‘20’ and ‘18’ for null detection purpose.
4. Connect the unknown inductor Lx4 with internal resistance Rx1 from socket ‘22’ to arm consisting resistance R5 at socket ‘21’.
5. Set the amplitude at maximum or as per your requirement by rotating amplitude control knob of 1 kHz sine wave generator.
6. Set the potentiometer R7 in fully counter clockwise direction.
7. Switch ‘ON’ the power supply and the Null Detector.
8. Now vary the resistance R7 towards clockwise direction very precisely with the help of pot till the null position is achieved.
9. Now switch off the power supply.
10. Remove the patch cord from socket ‘22’ and ‘21’ measure the resistance R7 across ‘25’ & ‘28’ with the help of multimeter.
11. Calculate the value of unknown inductor using the following equation

    $$\mathbf{Lx = R5 . R7 . C1}$$

    Where, Lx = Lx4, R5=221 Ω, C1=330 nF.

12. Calculate unknown value of internal resistance by using the following equation

    $$\mathbf{Rx = R5 . R7 / R6}$$

    Where Rx = Rx1, R5 = 221 Ω & R6 =1.122 kΩ.

13. Calculate the value for Q factor by using the following equation

    $$\mathbf{Q = \omega Lx / Rx = \omega . C1 . R6}$$

    Where, ω =2 Π f, where f = frequency = 1 kHz and Π = 3.14.

14. Verify the result for calculation of Q factor using both the formulae in the above step.
15. Connect the unknown inductor Lx5 from socket ‘23’ to arm consisting resistance R5 at socket ‘21’.
16. Repeat steps from 5 to 9.
17. Remove the patch cord from socket ‘23’ and ‘21’ measure the resistance R7 across ‘25’ & ‘28’ with the help of multimeter.
18. Calculate the value of unknown inductor using the following equation

    $$\mathbf{Lx = R5 . R7 . C1}$$

    Where, Lx = Lx5, R5=221 Ω, C1=330 nF.

19. Calculate unknown value of internal resistance by using the following equation

    $$\mathbf{Rx = R5 . R7 / R6}$$

    Where Rx = Rx2, R5 = 221 Ω & R6 =1.122 kΩ.

20. Calculate the value for Q factor by using the following equation

$$Q = \omega.Lx / Rx = \omega.C1.R6$$

Where, ω =2 Π f, where f = frequency = 1 kHz and Π = 3.14.

21. Verify the result for calculation of Q factor using both the formulae in the above step.

22. Connect the unknown inductor Lx6 from socket '24'to arm consisting resistance R5 at socket '21'.

23. Repeat steps from 5 to 9.

24. Remove the patch cord from socket '24'and '21'measure the resistance R7 across '25' & '28' with the help of multimeter.

25. Calculate the value of unknown inductor using the following equation

$$Lx = R5 .R7.C1$$

Where, Lx = Lx6, R5=221 Ω, C1=330 nF.

26. Calculate unknown value of internal resistance by using the following equation

$$Rx = R5.R7 / R6$$

Where Rx = Rx3, R5 = 221 Ω & R6 =1.122 kΩ.

27. Calculate the value for Q factor by using the following equation

$$Q = \omega.Lx / Rx = \omega.C1.R6$$

Where, ω =2 Π f, where f = frequency = 1 kHz and Π = 3.14.

28. Verify the result for calculation of Q factor using both the formulae in the above step.

FOR ACCURATE MEASUREMENT USING CRO:

1. Connect a patch cord between socket '26' of Vin terminal of the Maxwell's inductance capacitance bridge and socket '29' of Vout terminals of 1 KHz sine wave generator.
2. Connect a patch cord between socket '27'of Vin terminal of the Maxwell's inductance capacitance bridge and socket '30'of Vout terminals of 1 KHz sine wave generator output.
3. Set the Amplitude Control pot in fully clockwise direction.
4. Connect the unknown inductor Lx4 with internal resistance Rx1 from socket '22'to arm consisting resistance R5 at socket '21'.
5. Set the potentiometer R7 in fully counter clockwise direction.
6. Now connect the CRO test probe across terminal '19'& terminal '20'.
7. Set the Volts/Div knob of CRO at '**2**'position.
8. Switch 'ON'the power supply.
9. Now vary the resistance R7 towards clockwise direction with the help of pot till the null position is achieved i.e. signal is diminished on CRO screen.
10. Now switch off the power supply.
11. Remove the patch cord from socket '22'and '21'measure the resistance R7 across '25' & '28' with the help of multimeter.
12. Calculate the value of unknown inductor & resistance using given above equations.

13. Similarly we can measure unknown inductor Lx2 and Lx3 with the help of this process.

OBSERVATION TABLE:

Sl. No.	R7 (Ω)	R5 (Ω)	R6 (Ω)	C1 (nF)	Lx =R5.R7.C1 (mH)	% Error	Rx = R5.R7/R6 (Ω)	% Error	Q = ω.Lx / Rx =ω.C1.R6
1									
2									
3									

CALCULATION:

Measured value of R7 is. ……………….. Ω.

Now measure the value of Lx by the formula: **Lx =R5.R7.C1**

Now measure the values of Rx by the formula: **Rx =R5.R7/R6**

Now measure values of Q factor by the formula: **Q = ω.Lx / Rx = ω.C1.R6**

where, $\omega = 2\pi f$ and frequency f = 1 kHz and $\pi = 3.14$.

RESULT:

The unknown value of Inductor Lx4, Resistance Rx1 and Q factor are …….
The unknown value of Inductor Lx5, Resistance Rx2 and Q factor are …….
The unknown value of Inductor Lx6, Resistance Rx3 and Q factor are …….

Note:

1. The actual values of inductor Lx4, Lx5 and Lx6 are 10mH, 20mH and 30mH.
2. The actual value of resistor Rx1, Rx2, Rx3 is 27 Ω, 54 Ω and 81 Ω.
3. Small amount of error would be there due to component variations and also due to human error.

SAMPLE QUESTIONS/QUERIES:

1. Which measurements can carried out by Maxwell's Bridge?
2. Note down the advantages and disadvantages of Maxwell's Bridge.
3. Name two AC Bridges which are frequency independent?
4. What is Q factor of a coil? Drive the measurement equation of Q factor by using Maxwell's bridge.

REFERENCES:

1. Electrical Measurements and Measuring Instruments by E. W. Golding, F. C. Widdis.
2. Modern Electronic Instrumentation and Measurement Techniques by A. D. Helfrick, W. D. Cooper.
3. Elements of Electronic Instrumentation and Measurements by J. J. Carr.
4. A Course in Electrical and Electronic Measurements and Instrumentation by A. K. Sawhney.

EXPERIMENT NO.: 03

TITLE: Measurement of Unknown Capacitance using Schering Bridge

OBJECTIVE: Determination of unknown capacitance using Schering Bridge method.

THEORY:

A Schering Bridge is a bridge circuit used for measuring an unknown electrical capacitance and its dissipation factor. The dissipation factor of a capacitor is the ratio of its resistance to its capacitive reactance. The Schering Bridge is basically a four-arm alternating current (AC) bridge circuit whose measurement depends on balancing the loads on its arms. Figure below shows a diagram of the Schering Bridge.

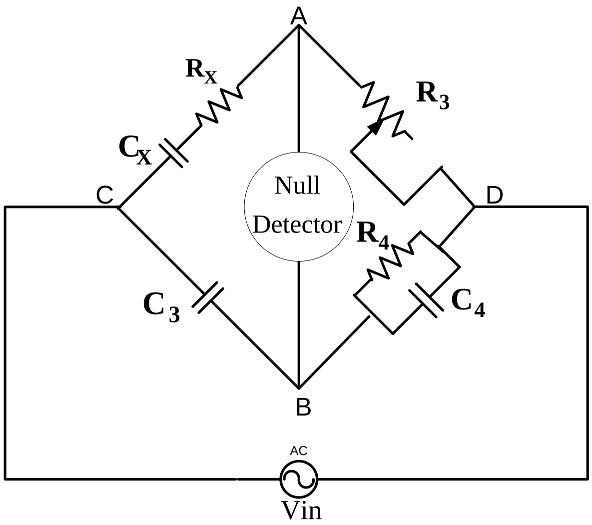


Fig. 1 Schering Bridge

In the Schering Bridge above, the resistance values of resistor R_4 is known, while the resistance value of resistor R_3 is unknown. The capacitance values of C_3 and C_4 are also known, while the capacitance of C_x is the value being measured. To measure the C_x, the values of C_3, C_4 and R_4 are fixed, while the values of R_3 is adjusted until the current through the ammeter between points A and B becomes zero. This happens when the voltages at points A and B are equal, in which case the bridge is said to be 'balanced'.

When the bridge is balanced.

Mathematically,

$$\left(R_x + \frac{1}{j\omega C_x}\right)\left(\frac{R_4}{j\omega C_4\left(R_4 + \frac{1}{j\omega C_4}\right)}\right) = \frac{R_3}{j\omega C_3}$$

$$\Rightarrow \left(R_x + \frac{1}{j\omega C_x}\right)\left(\frac{R_4}{j\omega C_4}\right) = \frac{R_3}{j\omega c_3}\left(R_4 + \frac{1}{j\omega C_4}\right)$$

$$\Rightarrow \frac{R_x R_4}{C_4} - j\frac{R_4}{\omega C_x C_4} = \frac{R_3 R_4}{C_3} - j\frac{R_3}{\omega C_4 C_3}$$

Equating real and imaginary part, we get

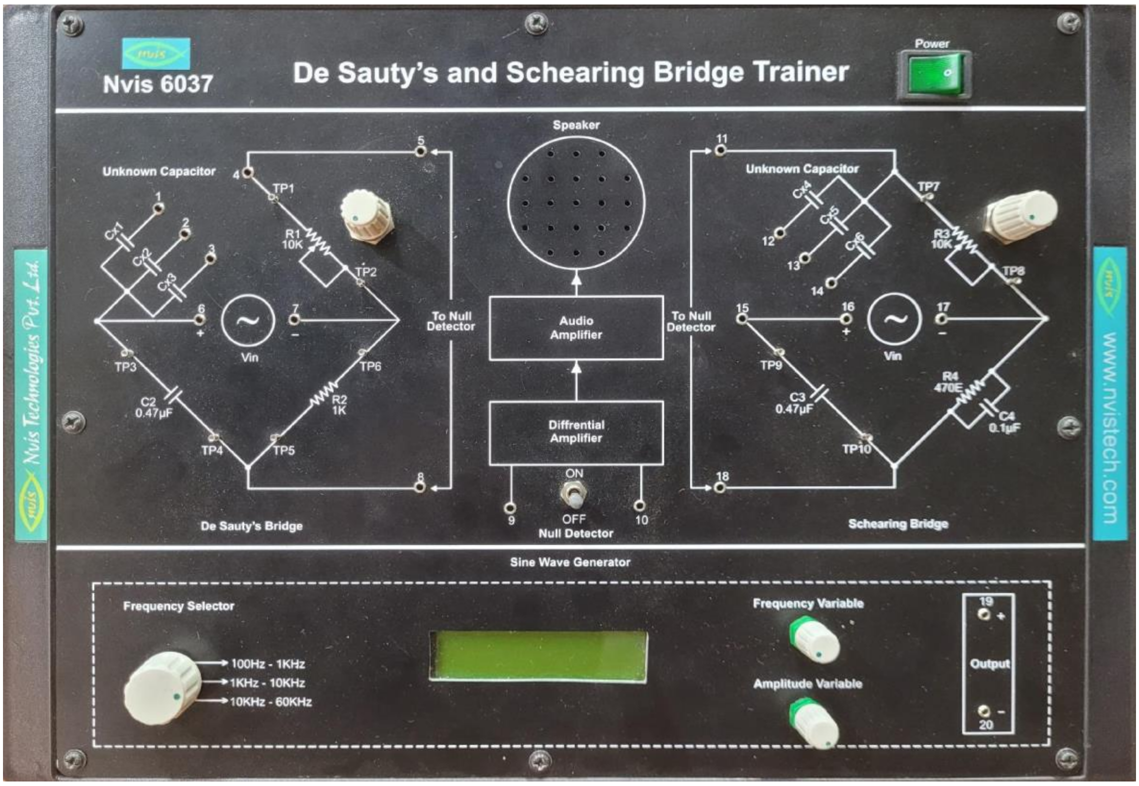
$$R_x = \frac{R_3 C_4}{C_3} \qquad C_x = \frac{R_4 C_3}{R_3}$$

APPARATUS REQUIRED:

- Schearing Bridge Trainer (Nvis 6037)
- Multimeter
- 2mm Patch cords

CIRCUIT DIAGRAM:

Mimic illustration with connections for Shearing bridge method for measurement of unknown capacitance is shown in the below figure.



Trainer Kit's (Nvis 6037) Technical Specification:

Sine Wave Generator

Frequency Range	:	**Selectable**
		100Hz to 1kHz
		1kHz to 10kHz
		10kHz to 60 kHz
Amplitude Control Range	:	Up to 5 Vpp
Mains	:	230 V AC ±10%, 50 Hz
Unknown Capacitor	:	0.1μF, 0.22μF, 0.47μF

PROCEDURE:

1. Connect mains cord to the trainer
2. Connect terminal 15 to 4 (for evaluating unknown capacitance C_{X1}).
3. Rotate variable resistances towards anticlockwise direction.
4. Connect null detector (terminal 9 to 11 and 10 to 18).
5. Connect terminal 19 to 16 and 20 to17.

6. Now switch „On' the power supply.
7. Set Amplitude Control knob in fully clockwise direction.
8. Now vary the variable resistance towards clockwise direction very precisely until the Null Point is detected
9. Now remove the patch cord between terminal 12 &15 and record the value of variable resistance in the observation table using multimeter.
10. Repeat above procedure for different value of unknown capacitors (i.e. Cx5 and Cx6)
11. Tabulate all the retrieved data in observation table below

OBSERVATION TABLE:

Sl. No.	Unknown Capacitor	Frequency (kHz)	Resistance $\mathbf{R_3}$ (Ohm)	Resistance $\mathbf{R_4}$ (Ohm)	Capacitor $\mathbf{C_3}$ (μF)	$\mathbf{C_x = R_4 \times \frac{C_3}{R_3}}$ (μF)	Theoretical Value
1.	C_{X4}						
2.	C_{X5}						
3.	C_{X6}						

CALCULATIONS:

1. **For unknown Capacitance** C_{X4} **on frequency f**

$$\mathbf{C_{X4} = R_4 \times \frac{C_3}{R_3}}$$

=…………….. μF

2. **For unknown Capacitance** C_{X5} **on frequency** f

$$\mathbf{C_{X5} = R_4 \times \frac{C_3}{R_3}}$$

=…………….. μF

3. **For unknown Capacitance** C_{X6} **on frequency** f

$$\mathbf{C_{X6} = R_4 \times \frac{C_3}{R_3}}$$

=…………….. μF .

RESULT:

The unknown value of Capacitor C_{X4} for frequency f is…….

The unknown value of Capacitor C_{X5}, for frequency f is …….

The unknown value of Capacitor C_{X6}, for frequency f is …….

SAMPLE QUESTIONS/QUERIES:

1. Which measurements can carried out by Schearing Bridge?
2. Note down the advantages and disadvantages of Schearing Bridge.
3. Name of two other Bridge by which we can find the value of unknown capacitance.

REFERENCE:

1. Electrical Measurements and Measuring Instruments by E. W. Golding, F. C. Widdis.
2. Modern Electronic Instrumentation and Measurement Techniques by A. D. Helfrick, W. D. Cooper.
3. Elements of Electronic Instrumentation and Measurements by J. J. Carr.
4. A Course in Electrical and Electronic Measurements and Instrumentation by A. K. Sawhney.

EXPERIMENT NO.: 04

TITLE: Study of the Characteristics of Analog to Digital Converter (ADC)

OBJECTIVE:

- Performance analysis of 4-bit Staircase Ramp Type A/D Converters and
- Performance analysis of 8-bit Successive Approximation Type A/D Converters

THEORY:

Analog to digital converters (ADCs) are electrical devices that convert continuous signals such as voltages from analog domain to the digital domain. In digital domain the signals are represented by binary numbers. A process of converting an analog signal into digital signal compulsory measuring the amplitude of the analog signal at consistent time intervals and producing a set of signals representing the measured digital value.

There are two major steps that involved in conversion of analog signal to digital signal

- **Quantizing-** It is the process of mapping a large set of input values to a (countable) smaller set. Rounding and truncation are typical examples of quantization processes.
- **Encoding**- In the encoding, when numbers, letters or words are represented by a specific group of symbols, it is said that the number, letter or word is being encoded. The group of symbols is called as a code. The digital data is represented, stored and transmitted as group of binary bits. This group is also called as binary code.

There are following types of A/D converters:

Flash A/D Converters, Sub-ranging A/D Converters, Successive Approximation type A/D Converts, Integrating/Dual-Slope type A/D Converters, Staircase Ramp/Ladder Network/Counter Type A/D Converters.

Staircase Ramp/Ladder Network/Counter Type A/D Converters: The basic idea is to connect the output of a free-running binary counter to the input of a DAC, then compare the analog output of the DAC with the analog input signal to be digitized and use the comparator's output to tell the counter when to stop counting and reset.
As the counter counts up with each clock pulse, the DAC outputs a slightly higher (more positive) voltage. This voltage is compared against the input voltage by the comparator. If the input voltage is greater than the DAC output, the comparator's output will be high and the counter will continue counting normally. Eventually, though, the DAC output will exceed the input voltage, causing the comparator's output to go low. This will cause two things to happen: first, the high-to-low transition of the comparator's output will cause the shift register to "load" whatever binary count is being output by the counter, thus updating the ADC circuit's output; secondly, the counter will receive a low signal on the active-low LOAD input, causing it to reset to 00000000 on the next clock pulse. Figure-1 depicts the 4-bit staircase ramp A/D converter (ADC).

Successive Approximation Type A/D Converters: Successive approximation ADC is the advanced version of Digital ramp type ADC which is designed to reduce the conversion and to increase speed of operation. The major draw of digital ramp ADC is the counter used to produce the digital output will be reset after every sampling interval. The normal counter starts counting from 0 and increments by one LSB in each count, this result in 2N clock pulses to reach its maximum value**.** In successive approximation ADC the normal counter is replaced with successive approximation register. The successive approximation register counts by changing the bits from MSB to LSB according to input. The output of SAR is converted to analog out by the DAC and this analog output is compared with the input analog sampled value in the Opamp comparator. This Opamp provides a high or low clock pulse based on the difference through the logic circuit. In very first case the SAR enables its MSB bit as high i.e. '1' and the result will be "100000....". This digital output is converted to analog value and compared with input sampled voltage (Vin). If the deference is positive i.e. if the sampled input is high then the SAR enables the next bit from MSB and result will be "1100000...". Now if the output is negative i.e. if the input sampled voltage is less than the SAR resets the last set bit and sets the next bit thus definitely approximately equal to the input analog value**.** Figure-2 shows the 8- bit successive approximation A/D converter (ADC).

CIRCUIT DIAGRAMS:

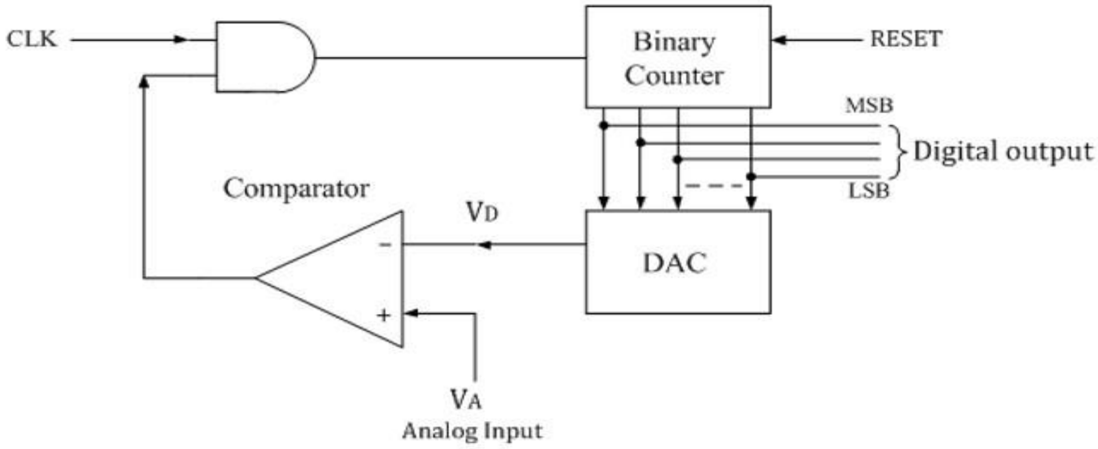


Fig. 1 4-bit staircase Ramp A/D Converter

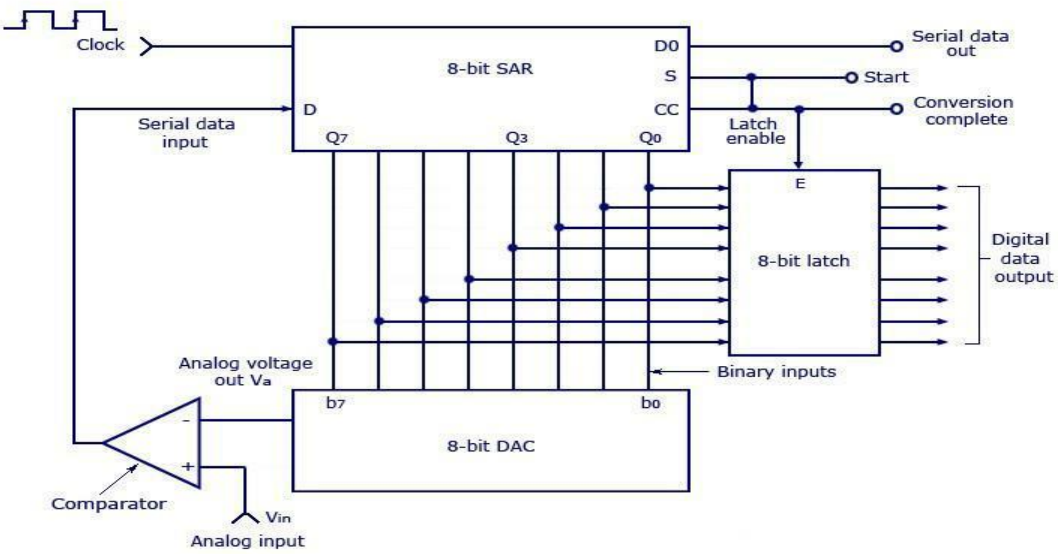


Fig. 2 8-bit Successive Approximation A/D Converter

PROCEDURE:

1. Power supply is connected to scientech
2. DC supply is provided to Vin of the converter through connecting wire
3. DC potentiometer was kept in counter clockwise position
4. Bring Reset/Count switch in Reset position
5. Switch ON the power supply
6. Keep the switch into count position to conversion process. Thus, LED's will light according to binary sequence.

OBSERVATIONS:

1. **For 4-bit staircase A/D Converter**

Analog Inputs in Volts	**Digital Outputs**			
	D_3	**D_2**	**D_1**	**D_0**

2. **For 8-bit Successive Approximation A/D Converter**

Analog Inputs in Volts	**Digital Outputs**							
	D_7	**D_6**	**D_5**	**D_4**	**D_3**	**D_2**	**D_1**	**D_0**

SAMPLE QUESTIONS/QUERIES::

1. What is A/D Converter?
2. What is the major disadvantage of the digital ramp type ADC?

REFERENCES:

1. ADC and DAC circuits notes by M. B. Patil
2. Analog-to-Digital Conversion by Pelgrom, Marc

PRECAUTIONS:

1. Use only the mains cord designed for the instrument.
2. Observe all ratings and marks on the instrument to avoid fire or shock hazards.
3. Do not operate in wet/ damp conditions.
4. Do not operate in explosive atmosphere.
5. Keep the product dust free, clean and dry.

EXPERIMENT NO.: 05

TITLE: Study of the Characteristics of Digital to Analog Converter (DAC)

OBJECTIVE:

- Performance analysis of 4-bit weighted resistor type DAC
- Performance analysis of 4-bit R-2R Ladder network type DAC
- Performance analysis of 8-bit monolithic DAC

THEORY:

The ideal characteristic of a 3 bit DAC is shown in figure 1 and it is represented by the straight line that connects the output discrete values corresponding to the single input digital data.

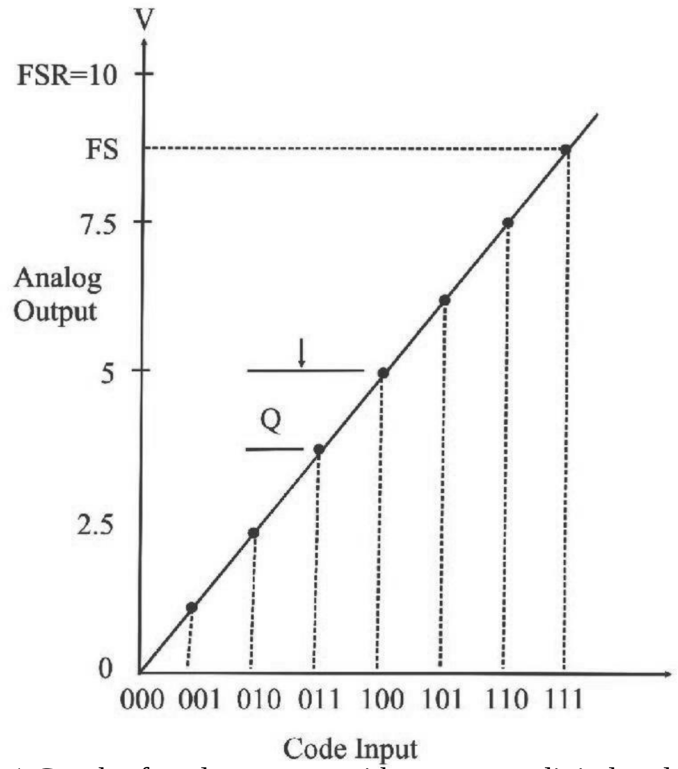


Fig. 1 Graph of analog output with respect to digital code input

An output voltage value depending on the converter full-scale range corresponds to every one of the 8 input stages, normally indicated with FSR (Full Scale Range).

If we define "quantum" Q the smallest variation of the output voltage, it results $Q = FSR / 2^n$
Where, n is the bit number composing the input code: it is therefore evident that the resolution of the digital number conversion depends on the n value.

The maximum FS (Full Scale) value of the output voltage is: $FS = (2^n-1)\ Q$
In figure 1, in the hypothesis of FSR 10V, it results therefore Q = 10 / 8 = 1.25V
FS = (8 - 1) * 1.25 = 8.75V

1. **Weighted Resistor D/A Converter:**

The simplest D/A converter is obtained by means of a summing circuit with input resistances whose value depends on the bit weight that are associated to. We obtain in this way the weighted resistors converter whose diagram is shown in figure 2 for the 4 bit case, where the switches S 3-S0 are driven from the digital information so that every resistance is connected to the reference voltage VREF or to ground in accordance with the fact that the corresponding bit is at logical level 1 or 0.

Let's consider now the possibility where only the most significant bit (MSB) S3 is at level 1:

In the R resistance the current I3 = VREF/R will flow and therefore at the operational amplifier output we will have the voltage

$$V_{03} = - I_3 (R / 2) = - V_{REF} / 2$$

Analogously the contribution to the output voltage provided by the immediately less significant digit will result

$$V_{02} = - I_2 (R/ 2) = - (V_{REF} /2R) (R/2) = - V_{REF} /4 \text{ and so on}$$

$$V_{01} = -I_1 (R/2) = - (V_{REF} /4R) (R/2) = - V_{REF} /8$$

$$V_{00} = I_0 (R/2) = - (V_{REF} /8R) (R/2) = - V_{REF} /16$$

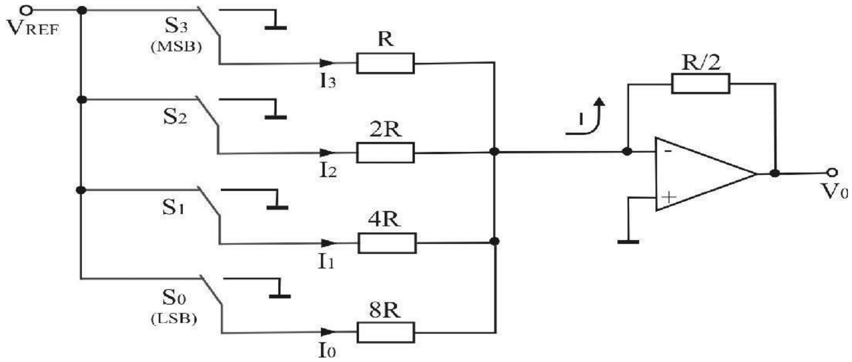


Fig. 2 Weighted Resistor D/A Converter

The operational amplifier works as current to voltage converter, by summing the currents in the branches where the switch Si = 1, and it provides in output a voltage proportional to the total current and therefore to the binary value of the input signal

$$V_0 = -V_{REF} (8.S_3 + 4.S_2 + 2.S_1 + 1.S_1)/16$$

When all the bits are at logical level 1 the output voltage assumes the maximum full-scale value $V_{OFS} = - 0.9375\ V_{REF}$

While the quantum, which represents the minimum increase of the output voltage in correspondence to the least significant bit (LSB) results

$$Q = - 0.0625\ V_{RE}$$

The main disadvantage of this converter is that resistances of different value in a very wide field are demanded, above all at the increasing of the bit number, and therefore that can be carried out with limited accuracy.

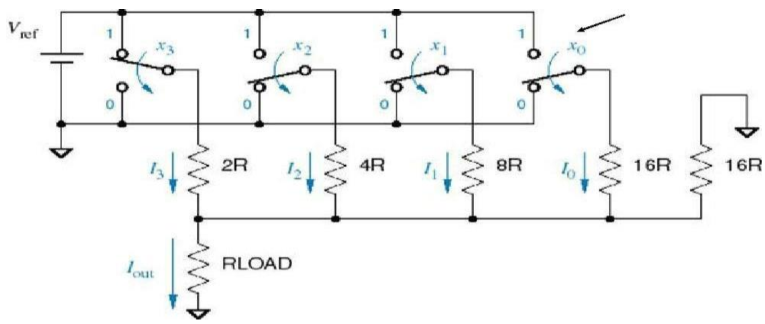


Fig. 3 Weighted Resistor D/A Converter Network

2. 4 bit R-2R ladder discrete D/A converter:

The weighted resistances converter has been among the first ones studied and carried out but it has been then abandoned in favor of the configuration with ladder network that uses only resistances of two values, one the double of the other. The converter with ladder network (R-2R ladder) eliminates the disadvantages of the weighted resistances converter since it is characterized by the presence of only two types of resistances, even if the resistance number, with bit equality, now results double, as it is shown in figure 4 for the 4 bit possibility, where the switches S3- S0 connect the corresponding resistance to the reference voltage VREF or to ground in accordance with the fact that the corresponding bit finds itself to logic level 1 or 0.

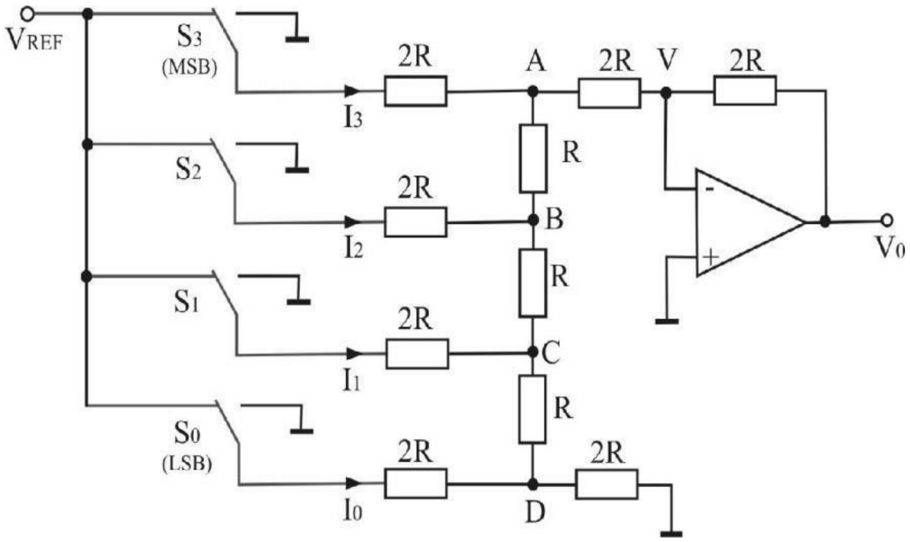


Fig. 4 R-2R ladder discrete D/A converter

If we suppose at first that all the input bits are at low level (S_3 S_2 S_1, S_0 = 0000) every switch ground the respective resistance 2R.

Let's consider now the possibility where only the most significant bit S_3 is at level 1: the current I_3, delivered from the reference voltage V_{REF}, will divide in node A into two identical currents but equal to the half of the incoming one, as it is shown in figure 5.

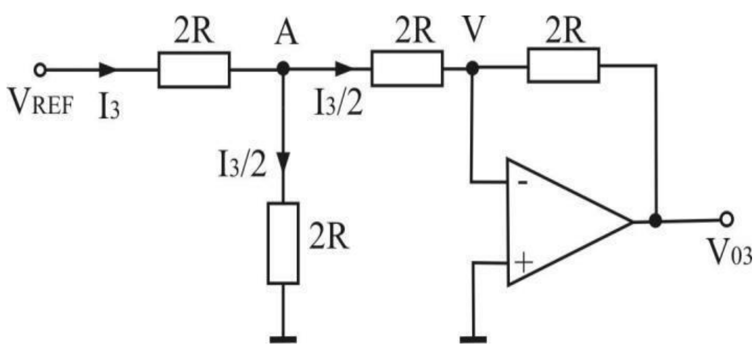


Fig. 5 Inverting buffer circuit using Op-Amp

Being

$$I_3 = V_{REF} / 2R + (2R// 2R) = V_{REF}/ 3R$$

The potential of node A against ground is equal to

$$V_{A3} = 2R.\ I_3 / 2 = (1 / 3)\ V_{REF}$$

And therefore, at the operational amplifier output the voltage results

$$V_{03} = - 2R / 2R (1 / 3) V_{REF} = - V_{REF} /3$$

Analogously the contribution to the output voltage of the immediately less significant digit is determined by noticing that the current delivered from the reference voltage VREF is equal to

$$I_2 = V_{REF} / 2R + (2R // 2R) = V_{REF} / 3R = I3$$

And it divides itself in node B into two identical currents of value I2/2: this now current will split equally at node A so the potential of node A against ground is now equal to:

$$V_{A2} = 2R. (I_2/4) = (1/6) V_{REF}$$

And therefore, at the operational amplifier output the voltage results

$$V_{02} = -2R/2R. 1/6 V_{REF} = - V_{REF} /6$$

With analog reasoning, we obtain

$$I_1 = V_{REF} /3R$$

$$V_{Al} = 2R. (I_1/8) = (1/12) V_{REF}$$

$$V_{01} = - V_{REF} /1_2$$

And at the end

$$I_0 = V_{REF} /3R$$

$$V_{AO} = 2R (I_0/ 16) = (1/ 24) V_{REF}$$

$$V_{00} = - V_{REF} /24$$

By applying the principle of effect superposition, the output voltage results at the end

$$V_0 = - V_{REF} (8.S_3 + 4.S_2 + 2.S_1 + 1.S_0)/24$$

When all the bits are at logic level 1 the output voltage assumes the maximum full-scale value:

$$V_{OFS} = -0.625 V_{REF}$$

While the quantum that represents the minimum increase of the output voltage in correspondence of the least significant bit (LSB), results

$$Q = -0.04167 V_{REF}$$

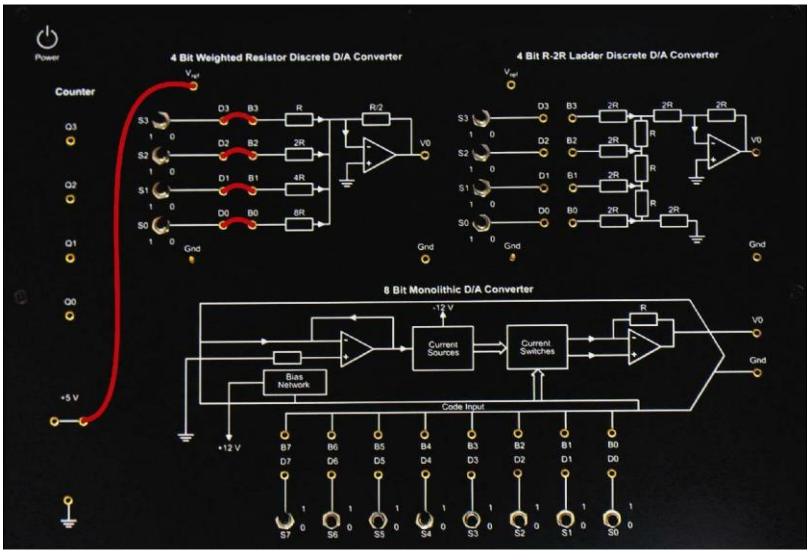
EXPERIMENT A

The purpose of this experiment is to analyse the operation of weighted resistor D/A converter according to the binary system.

CONNECTION DIAGRAM:

PROCEDURE:

- Connect the Power Supply to the board.



- Connect the D0- D3 of the logic switches to the corresponding jacks B0-B3 of the converter.
- Set the switches S0-S3 to logic level 0.
- Connect the VREF socket to +5V.
- Connect a Multi meter as voltmeter for DC, to the output V0 of the converter.
- Switch the logic switches in binary progression & measure & record the output voltage in correspondence of every combination of the input code.
- With input code S3 S2 S1 S0 = 0000 the output voltage VO has to be null: eventual little deviations against zero are due to the operational amplifier offset.
- Switch off the Power Supply.

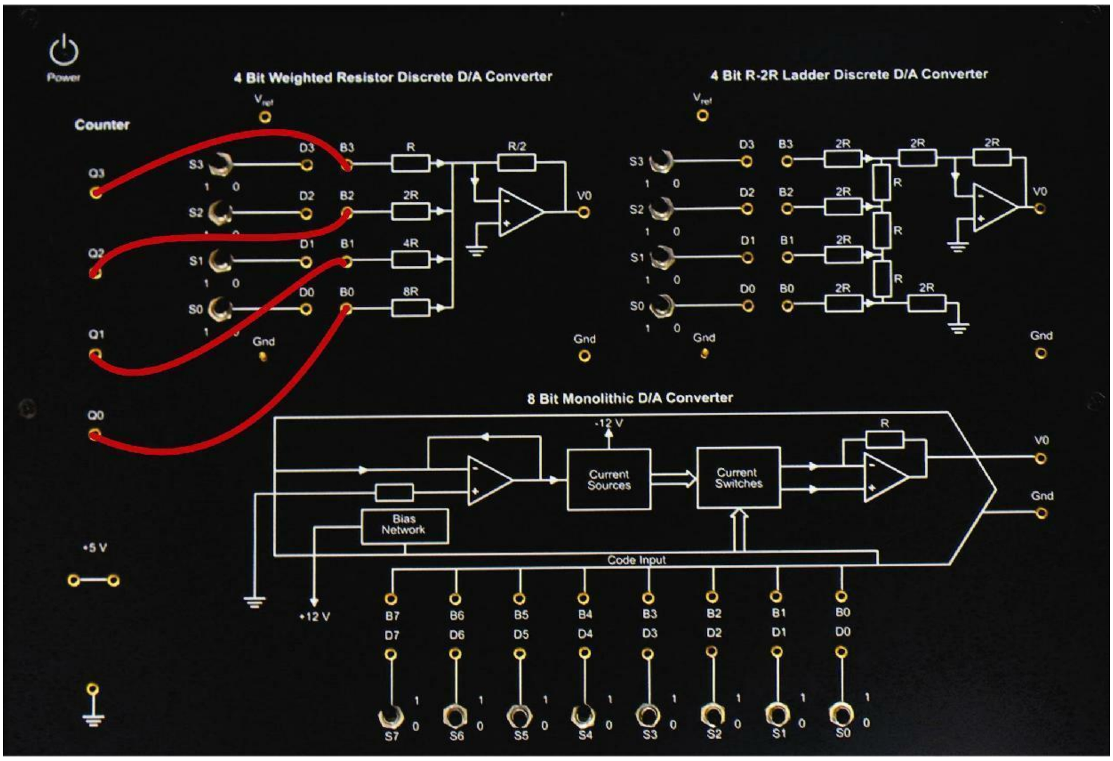
OBSERVATIONS

S_3	S_2	S_1	S_0	V_0(Volt)

EXPERIMENT B

The purpose of this experiment is to record the transfer characteristic of 4 bit weighted resistor D/A converter

CONNECTION DIAGRAM:



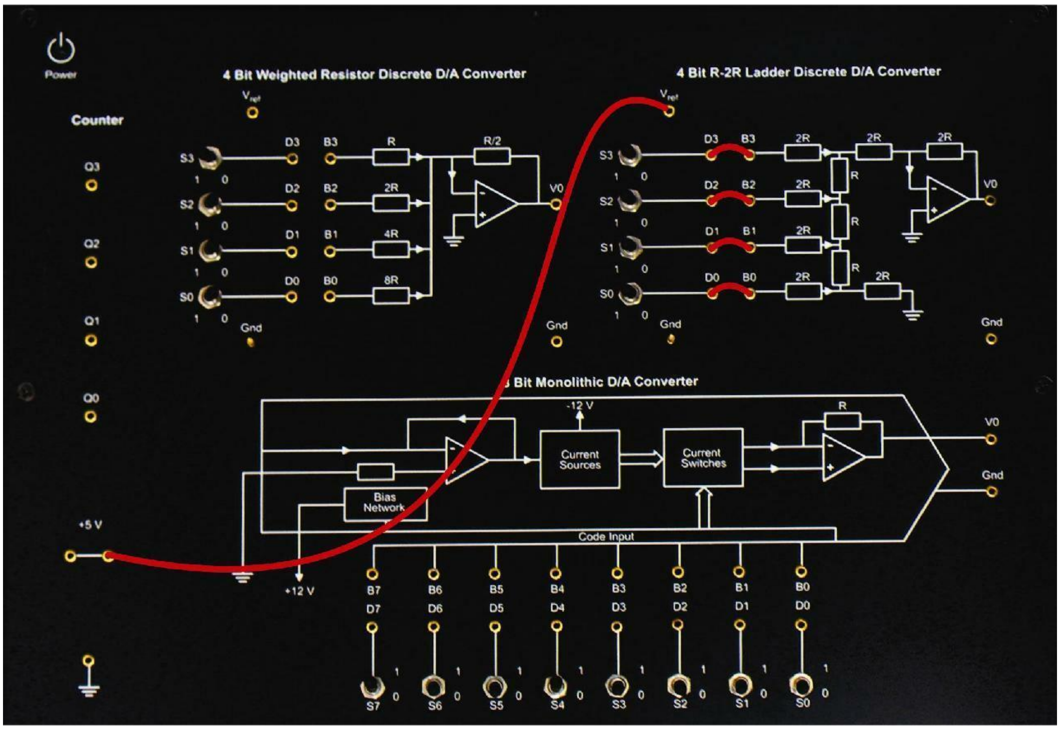
PROCEDURE:

- Connect the o/p of counter Q3-Q0 respectively to input B3-B0 of the converter.
- Switch ‘On’ the Power Supply.
- On the Oscilloscope observe the staircase of the transfer function of the generator.

EXPERIMENT C

The purpose of this experiment is to functional verification of 4-bit D/A converter with ladder network.

CONNECTION DIAGRAM:



PROCEDURE:

- Connect the D0-D3 of the logic switches respectively to the B0-B3 of the converter.
- Switch 'On' the Power Supply.
- Connect the multi meter as a voltmeter for DC, to the output V0 of the converter.
- Connect the VREF to +5V.
- Switch the logic switches in binary progression and measure & record the output voltage in correspondence of every combination of the input code.
- With input code S3 S2 S1 S0 = 0000 the output voltage V0 has to be null: eventual little deviations against zero are due to the operational amplifier offset.
- Switch off the Power Supply.

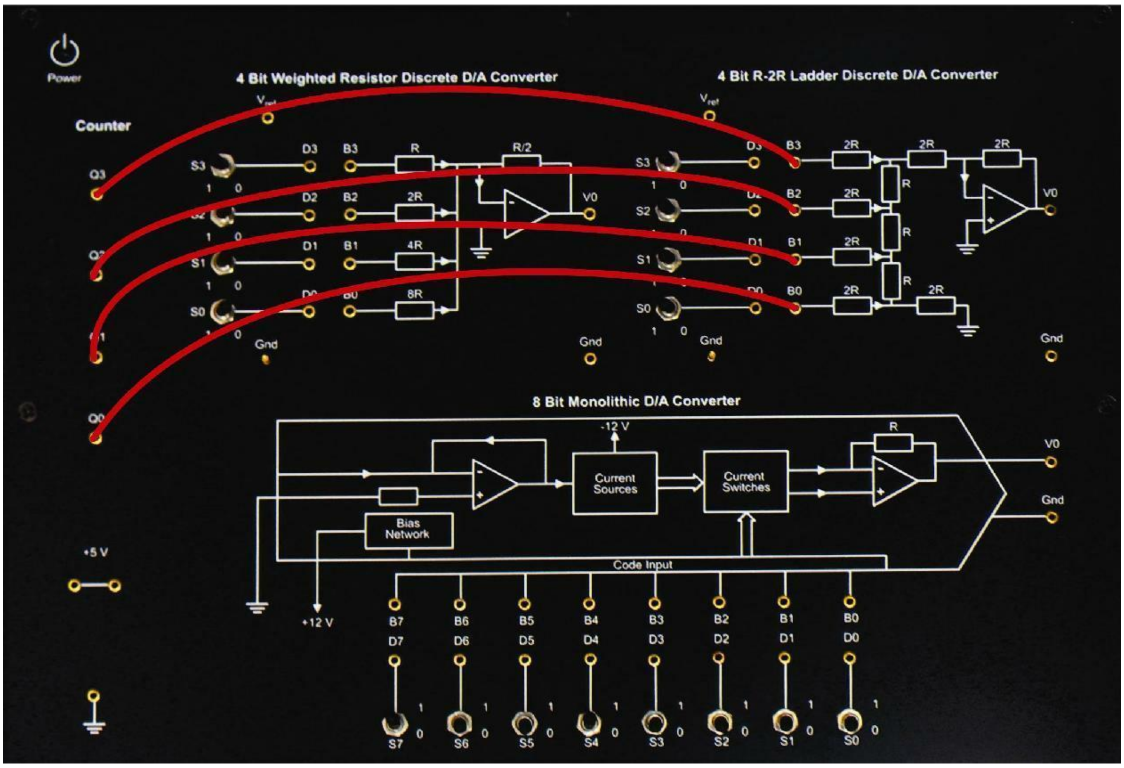
OBSERVATIONS:

S_3	S_2	S_1	S_0	V_0(Volt)

EXPERIMENT D

The purpose of this experiment is to record of transfer characteristic of the 4 bit ladder network D/A converter.

CONNECTION DIAGRAM:



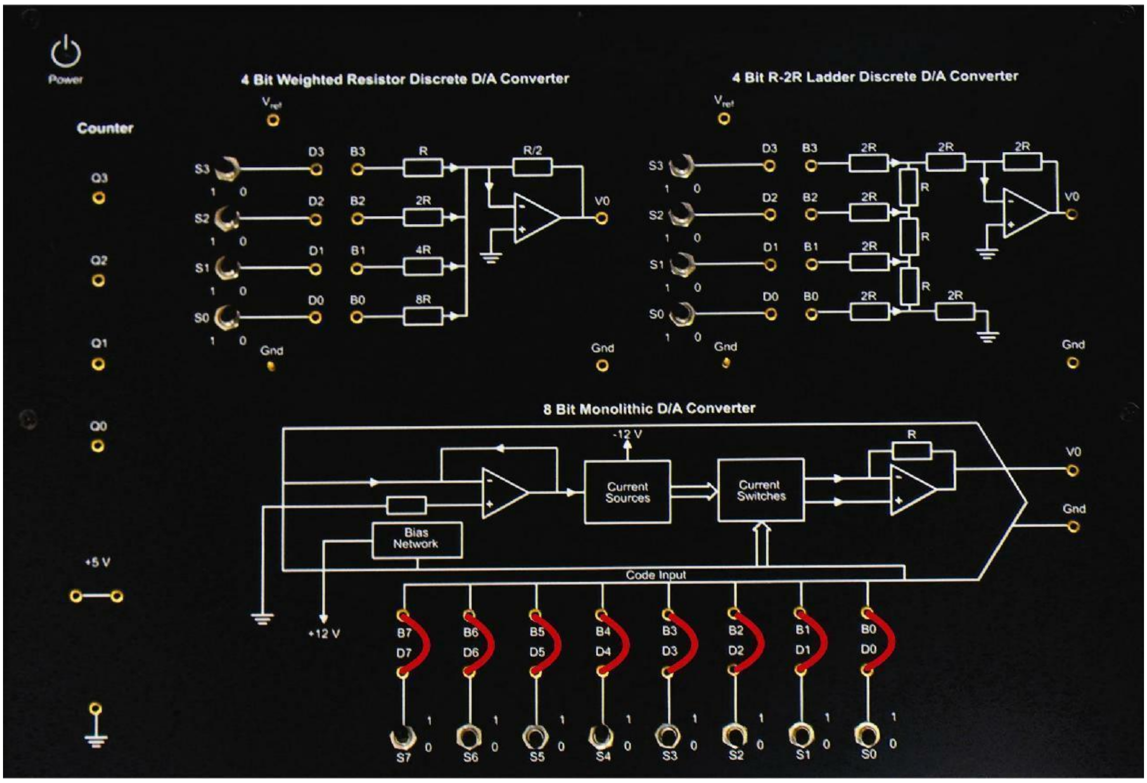
PROCEDURE:

- Connect the outputs of the counter Q_0-Q_3 respectively to B_0-B_3 of the converter.
- Switch 'On' the Power Supply.
- Observe on the Oscilloscope the typical staircase of the transfer function of the converter.

EXPERIMENT E

The purpose of this experiment is to functional verification of an 8-bit monolithic D/A converter

CONNECTION DIAGRAM:



PROCEDURE:

- Connect the outputs D0-D7 of the logic switches to the corresponding digital inputs B0-B7 of the DAC.
- Set all the switches S0-S7 to the logic level 0.
- Connect the multi meter as a voltmeter for DC, to the output VO of the DAC.
- Switch 'On' the Power Supply.
- Measure the quantum value in correspondence with every combination of input code.

REPORT:

3. What is D/A Converter?
4. Discuss some of the DAC applications.
5. Describe offset error and its effect on a DAC output.
6. What is the advantage of R/2R ladder DACs over those that use binary weighted resistors?

REFERENCES:

3. ADC and DAC circuits notes by M. B. Patil
4. Integrated Analog-To-Digital and Digital-To-Analog Converters by van de Plassche, Rudy J.