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VISVESVARAYA TECHNOLOGICAL UNIVERSITY

BELGAUM – 590 014

A PROJECT REPORT ON

"MEASUREMENT OF PHASE ANGLE USING PLL"

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ABSTRACT

This project aims at measuring the phase angle between two signals of same frequency. This is incorporated using a Phase Locked Loop (PLL).The PLL used is an analog PLL. Suitable input signals are generated for testing the circuit and are conditioned as demanded by the network and fed into the PLL. The phase detector in the PLL produces an output waveform whose frequency is proportional to the phase difference between the two inputs. A negative edge triggered J-K flip flop is used for “lead” or “lag” indication.

In the next stage a frequency to voltage converter is used to get a DC voltage proportional to the frequency of the PLL output, which in turn is proportional to the phase difference between two input signals.

The network used also takes into consideration the difference in lagging and leading signals which highlights the implementation of this project for the purpose. The DC voltage in the analog form is then calibrated to display the phase difference on the digital panel meter.

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INTRODUCTION

The **phase of an oscillation or wave** is the fraction of a complete cycle corresponding to an offset in the displacement from a specified reference point at time t = 0. The **phase angle** of a periodic wave is the number of suitable units of angular measure between a point on the wave and a reference point. The reference point may also be a point on another periodic wave.

The phase angle can be considered as a measure of the time delay between two periodic signals expressed as a fraction of the wave period. This fraction is normally expressed in units of angle, with a full cycle corresponding to 360°. Phase angle is usually defined from the fundamental component of each waveform; therefore distortion of either or both signals can give rise to errors, the extent of which depends on the nature of the distortion and the method of measurement.

The instrument which measures the phase difference between two periodic waveforms having same frequency is known as a **phase angle meter**. A simple cathode ray oscilloscope available in any basic electrical lab can be used to measure the phase of a signal using a reference or the phases of two signals can be compared by giving two signal inputs.

The phase angle meters are of two types:

- Analog type
- Digital type

Digital phase angle meters have almost replaced the analog type because of its simplicity, portability, higher accuracy and compactness.

NEED FOR PHASE ANGLE MEASUREMENT

- Phase angle meters are used to **verify the correct connection of three-phase transformer banks** which must be paralleled with an existing electrical bus or high voltage line. The process of making these measurements is known as "phasing-out" and is performed before the tie-in is made.

- Phase angle measurement is also employed to **analyze the operation of AC synchronous generators and synchronous motors** to verify the proper operation of field regulators and synchronizing equipment.

- The Phase angle measurement is used for verifying the proper installation of medium and high-voltage primary metering equipment and sophisticated protective relays that receive input from Potential and Current Transformers (PTs & CTs).

- **Phase Angle Measurement for Power Factor Determination:**
  The most important application of the equipment which measures phase angle is the **determination of power factor for conducting electrical system load studies and power factor correction studies**.

  The system power factor is equal to the cosine of the phase angle that exists between the system voltage and current. In the ideal AC electrical system the voltage and current are in phase. This condition only occurs on systems where the entire load is resistive, such as electric heat, incandescent lighting, or fluorescent lighting with power factor corrected ballasts. Electrical utilization equipment such as motors and welders has a considerable amount of inductance and the inductive reactance (X_L which is measured in ohms) causes the circuit current to lag the applied voltage. The actual amount, or number of degrees of lag, depends on the ratio of the Inductive Reactance (X_L) in ohms to the ohmic value of Resistance (R) of the system. Once the system power factor is known, power factor correction, if desired, can be applied to the system using power factor correction capacitors or by using synchronous motors, either of which can supply leading Volt Amperes Reactive (VARs) to the system to compensate for the lagging power factor. Most electric utilities charge a penalty for poor system power factor, so keeping the power bove the required minimum value will result in a lower utility bill and will also improve the voltage drop on the system.

Although both the current and the voltage oscillate sinusoidally in an AC circuit they will not necessarily rise and fall simultaneously with each other in each circuit element or the circuit as a whole. The current and voltage will oscillate with the same frequency but they will (in general) be out of phase with each other. The exception being when the circuit is in resonance or if there is only resistor in the circuit.

The phase difference between two sinusoidal waveforms that have the same frequency and are free of a dc component can be conveniently described as shown in figure 1. It can be seen that the phase angle can be considered as a measure of the time delay between two periodic signals expressed as a fraction of the wave period. This fraction is normally expressed in units of angle, with a full cycle corresponding to 360°. For example, in figure 1, where the voltage v_1 passes through zero one-eighth cycles before a second voltage v_2, it leads v_2 by (360°/8) or 45°.

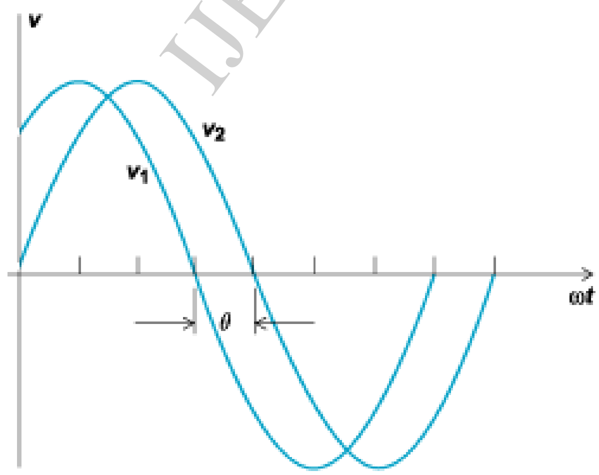

Figure 1: Phase angle θ¸ between voltages v_1 and v_2.

PRINCIPLE OF OPERATION

The phase difference between two sinusoidal voltage waveforms is a physical quantity. Measurement of any such physical quantity involves two steps:

1. Conversion of the physical quantity into an electrical quantity.
2. Calibration of a panel meter to display the physical quantity.

The principle employed to convert the phase difference between two input sine waves into voltage is illustrated in the functional block diagram shown below.

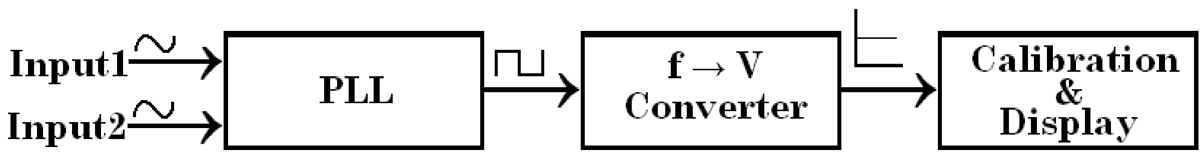

Figure 2: Block diagram of Phase Angle Meter

The two sinusoidal input voltages whose phase difference is to be measured are applied to the Phase Locked Loop (PLL) which is operated in open loop. The PLL generates a square waveform whose frequency is proportional to the phase difference. This square wave is fed to a frequency to voltage converter yielding a DC voltage proportional to the input frequency. The voltage thus obtained is fed to a suitably calibrated panel meter to display the corresponding phase difference.

PHASE LOCKED LOOP (PLL)

A phase-locked loop (PLL) is a control system that generates a signal that has a fixed relation to the phase of a "reference" signal. A phase-locked loop circuit responds to both the frequency and the phase of the input signals, automatically raising or lowering the frequency of a controlled oscillator until it is matched to the reference in both frequency and phase.

A PLL is a control loop consisting of three fundamental components, as shown in figure3. These are a phase detector or phase comparator (PD), a loop filter (LF) and a voltage controlled oscillator (VCO). The phase detector compares the phase of a periodic input signal against the phase of the fed-back output signal. The phase detector output is a measure of phase error between its two applied inputs. The error voltage is then filtered by the loop filter, whose control output is then applied to the VCO. The control voltage changes the VCO frequency in a direction that reduces the phase error between the input signal and the VCO.

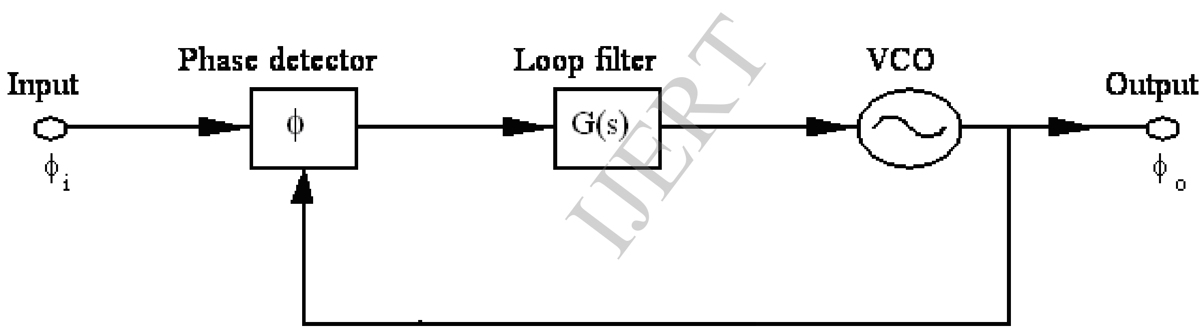

Figure 3: Functional Block Diagram of PLL

Usually the PLLs are operated in closed loop but for the measurement of phase angle it is operated in open loop and the corresponding block diagram is shown in figure 4.

Figure 4: Block diagram of PLL used to measure Phase Angle

Phase Detector

Phase detectors are a form of comparator providing a DC output signal proportional to the difference in phase between two input signals. This may be written as

$$V_p = K_P (\varphi_{i1} - \varphi_{i2})$$

where V_p is the output voltage, φ_{i1} and $\varphi_{i2}$are the phases of the input signals and K_p is the phase detector gain in Volts per radian. In general, the response of phase detectors is non-linear and repeats over a limited phase range. However the response is usually very nearly linear in a narrow phase range close to the point at which the loop would lock and the value of phase detector gain is only of real interest at this point.

Various types of phase detectors are used in PLLs. The simplest and widely used is the analog multiplier type phase detector shown in figure 5. This is basically a double-balanced mixer (or four quadrant multiplier) with a DC coupled output port, that is used to produce the product of two input signals V_1 (t) and V_2 (t).

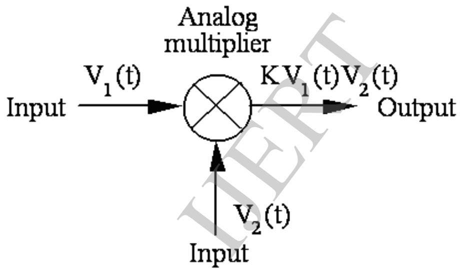

Figure 5: Analog multiplier phase detector

Operation can be easily understood by considering sinusoidal input signals, V_1 (t) = V_1coswt and V_2 (t) = $V_2\cos(\omega t - \varphi)$, the phase detector output being proportional to the product of these signals,

$$V_p(t) = KV_1(t)V_2(t) = \frac{KV_1V_2}{2}\left[\cos(2\omega t - \phi) + \cos\phi\right]$$

Thus, the output consists of a DC term and a double-frequency component. The double-frequency component is filtered out by the action of the loop filter and is of no significance, leaving

$$V_p = \frac{KV_1V_2}{2}\cos\phi$$

Loop Filter

The output signal of the phase detector consists of a number of terms in the locked state of the PLL. The first of these is a "dc" component and is roughly proportional to the phase error and the remaining terms are "ac" components having frequencies 2ω,4ω… As these higher frequencies are unwanted signals, they are filtered out by the loop filter. Because the loop filter must pass the lower frequencies and suppress the higher, it must be low pass filter. In most PLL designs a first order low-pass filters are used.

Voltage Controlled Oscillator

VCOs are electronically tuneable oscillators in which the output frequency is dependent on the value of an applied tuning voltage. They are realised in many forms from RC multivibrators at low frequencies to varactor and tuned oscillators at higher frequencies. Crystal oscillators may also be used.

LAG- LEAD IDENTIFICATION

Out of the two input signals, one is considered as the reference input. The second input may "lead" or "lag" the reference input. This is determined using a negative edge triggered J-K flip flop.

FREQUENCY TO VOLTAGE CONVERSION

A frequency to voltage converter produces an analog output signal having a magnitude linearly proportional to the frequency of an alternating input signal. In many applications, such as frequency-locked-loop circuits or tachometers, a dc voltage proportional to an input frequency is required.

They include an operational amplifier for simple linear signal processing and a small resistor-capacitor (RC) network for removing frequency-dependent ripples. Frequency-to-voltage converters can receive AC and DC voltages, frequencies and pulses, and other specialized waveforms from devices such as encoders, tachometers, timers, relays and switches. Devices with integral filters allow some signal frequencies to pass while attenuating others. Devices with low pass filters allow signals that are below a cutoff frequency to pass while blocking signals that exceed the threshold. Frequency-to-voltage converters with programmable filters are also available.

Frequency-to-voltage converters are available in a variety of form factors. Some devices mount on integrated circuits (ICs), standard DIN rails, or printed circuit boards (PCBs) that attach to enclosures or plug into computer backplanes. Others bolt into walls, cabinets, enclosures, or panels. Some special ICs are specifically designed for a highly linear frequency-to-voltage conversion.

Device specifications for frequency-to-voltage converters include maximum output voltage, accuracy, and signal isolation. Accuracy, which is represented as a percentage of a full measurement range, depends on factors such as signal conditioning linearity, hysteresis, and temperature. Signal isolation can be achieved through optical isolation, magnetic induction, or the use of capacitors.

Frequency-to-voltage converters are used in a variety of industries and applications. For example, vehicle-monitoring applications use frequency-to-voltage converters to evaluate the response times of clutches, air-conditioning compressors, and anti-lock braking systems. Frequency-to-voltage converters are also used in driveline analysis and to monitor and control engine speeds. Other applications for frequency-to-voltage converters include flow meter monitoring, machine analysis and control, and response time evaluation.

CALIBRATION

Calibration is the process of establishing the relationship between a measuring device and the units of measure. This is done by comparing a device or the output of an instrument to a standard having known measurement characteristics.

In non-specialized use, calibration is often regarded as including the process of **adjusting** the output or indication on a measurement instrument to agree with value of the applied standard, within a specified accuracy.

Calibration can be called for:

- with a new instrument
- when a specified time period is elapsed
- when a specified usage (operating hours) has elapsed
- when an instrument has had a shock or vibration which potentially may have put it out of calibration
- whenever observations appear questionable

The phase angle meter is calibrated using a differential amplifier. The differential amplifier amplifies input difference voltage. The working of the differential amplifier can be explained using the principle of superposition. When the input at the non-inverting input terminal is zero, the differential amplifier behaves like an inverting amplifier and as a non-inverting amplifier when the input to the inverting input terminal is zero. The gain of the differential amplifier is same as that of the inverting amplifier.

REGULATED POWER SUPPLY

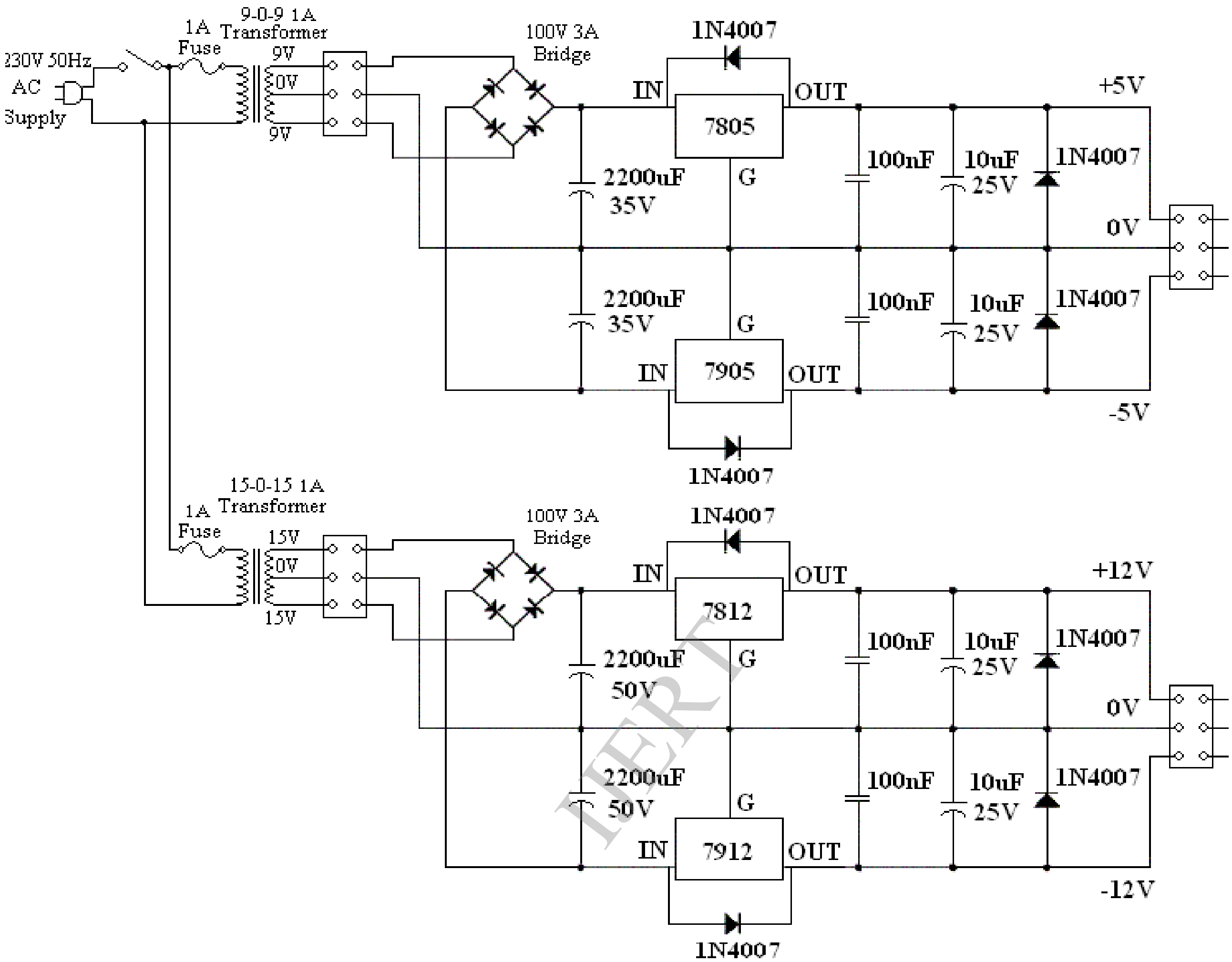

Figure 6: DC regulated power supply

The phase angle meter demands a DC power supply of +12V, -12V and +5V.This demand is met by the circuit shown in figure 6. It consists of two units, one for ± 12V and other for ±5V.Each unit comprises of a center tapped transformer, bridge rectifier with capacitor filter. Positive and negative voltage regulators are used to get a constant DC output. The diodes are used for protection against reverse polarity.

PHASE SHIFTER - TEST CIRCUIT

The phase shifter produces an output voltage with the same magnitude as the input voltage, but with a phase angle that can be varied continuously between 0° and -180°. Figure 7 shows such a phase shifter that can ideally produce a phase shift of 0° to 180°.The non-inverting channel has an RC lag circuit, and the inverting channel has two equal resistors with a value of R´. Therefore the voltage gain of the inverting channel is always unity. But the voltage gain of the non-inverting channel depends on the cutoff frequency of RC lag circuit.

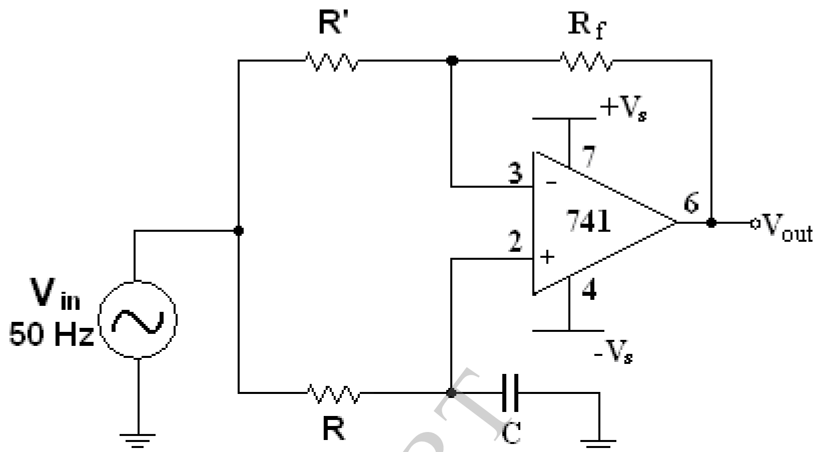

Figure 7: Phase shifter circuit employing an operational amplifier

$$A_v = 1 \text{ (MAGNITUDE)}$$
$$f_c = (1/2\Pi RC)$$
$$\Phi = -2\tan^{-1}(f/f_c)$$

When the input frequency is much lower than the cutoff frequency ($f<<f_c$), the capacitor appears open and:

$$A_{non} = 2 \quad ; \quad A_{inv} = -1 \quad ; \quad A_v = A_{non} + A_{inv} = 1$$

This means that the output signal has the same magnitude as the input signal and the phase shift is 0°, well below the cutoff frequency of the lag network.

When the input frequency is much greater than the cutoff frequency ($f>>f_c$), the capacitor appears shorted. In this case, the non-inverting channel has a voltage gain of zero. The overall gain therefore equals the gain of inverting channel, which is -1, equivalent to a phase shift of 180°.

PHASE ANGLE METER→ HARDWARE DESCRIPTION

The phase angle meter involves phase detection using PLL, frequency to voltage conversion, calibration and display. Each of these is explained below.

PHASE DETECTION USING PLL

The phase difference between the two input signals is determined using an analog phase locked loop (PLL) IC LM565. The circuit connections are as shown in the circuit diagram below.

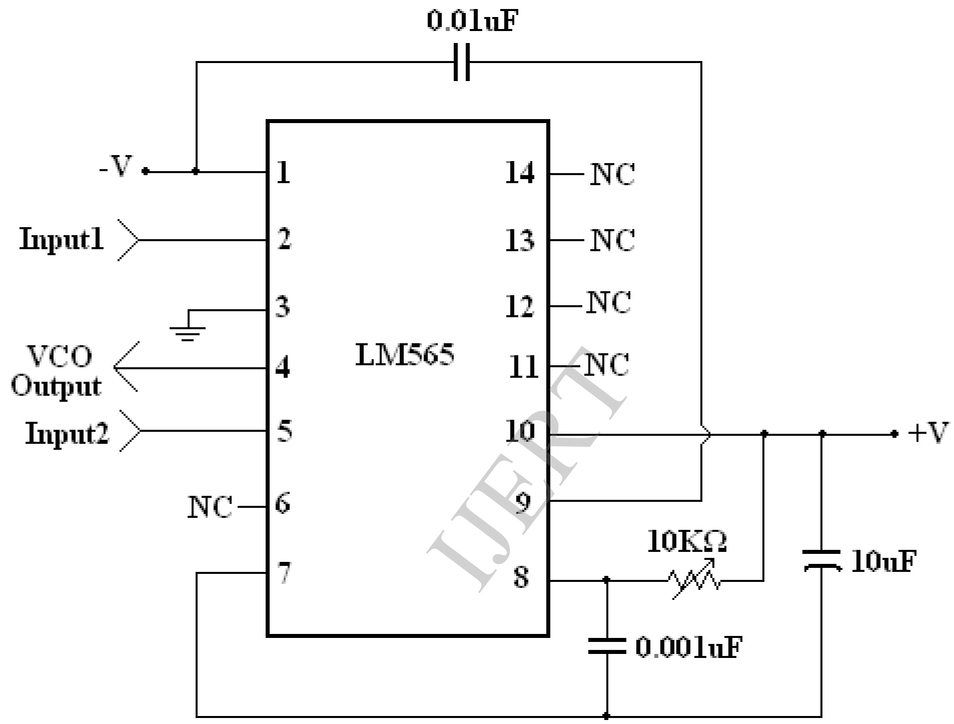

Figure 8: Circuit diagram for of PLL used for Phase Angle Measurement

The input signals whose phase difference is to be measured are applied to the phase detector (pin 2 & pin 5). The output of the phase detector consists of a useful DC component and many unwanted high frequency components. The high frequency components are therefore filtered out using a low pass filter. The capacitor connected between pin 7 and the positive supply (pin 10) forms a first-order low pass filter with an internal resistance of 3.6 kΩ. The output of the low pass filter thus obtained is a pure DC control voltage applied to the voltage controlled oscillator (VCO). The free running frequency of the voltage controlled oscillator is determined by the resistor connected between pin 8 and the positive supply. The VCO output obtained at pin 4 is a square wave whose frequency is proportional to the phase difference between the input signals.

PLL input signals with a phase difference Φ and the corresponding PLL output waveform are illustrated in figure 9.

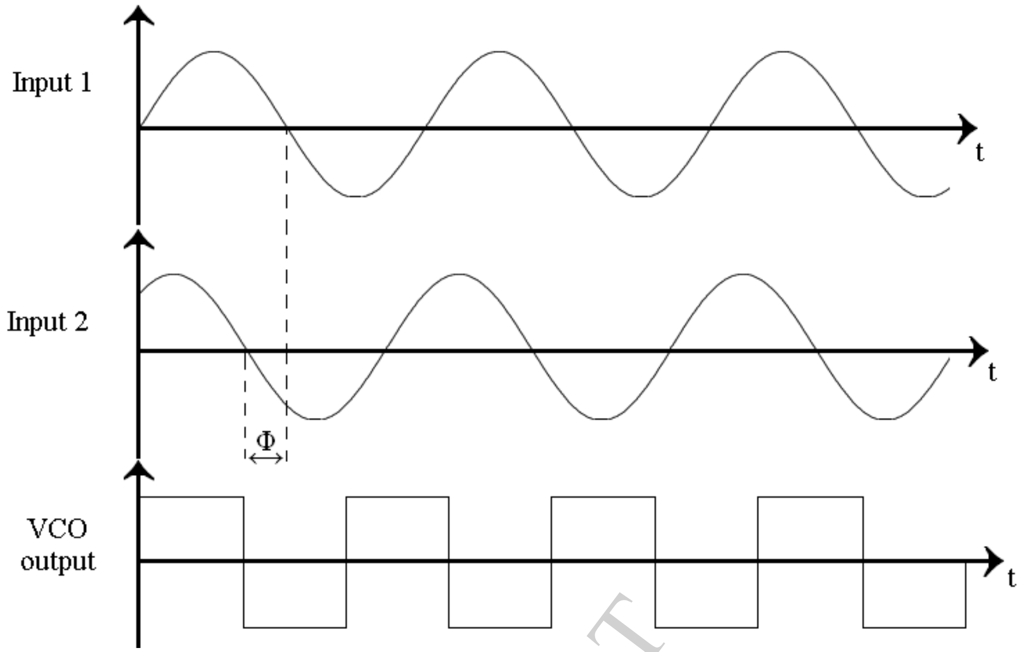

Figure 9: Input and output voltage waveforms of the Phase Locked Loop

FREQUENCY TO VOLTAGE CONVERSION

The circuit diagram of precision frequency to voltage converter using IC LM331 is shown in figure 10. Output of the VCO of the PLL is applied to pin 6 of the precision frequency to voltage converter. In F-V converter, a pulse input at f_{in} is differentiated by a R-C network and the negative-going edge at pin 6 causes the input comparator to trigger the timer circuit. LM 331 generates a DC voltage at pin 1 proportional to the input signal frequency. The input-output relation is given by

$$V_{out} = -f_{in}*2.09V*R_f/R_s*R_tC_t$$

The resistor R_x shown in the circuit diagram is given by

$$R_x = (V_s - 2V)/0.2mA$$

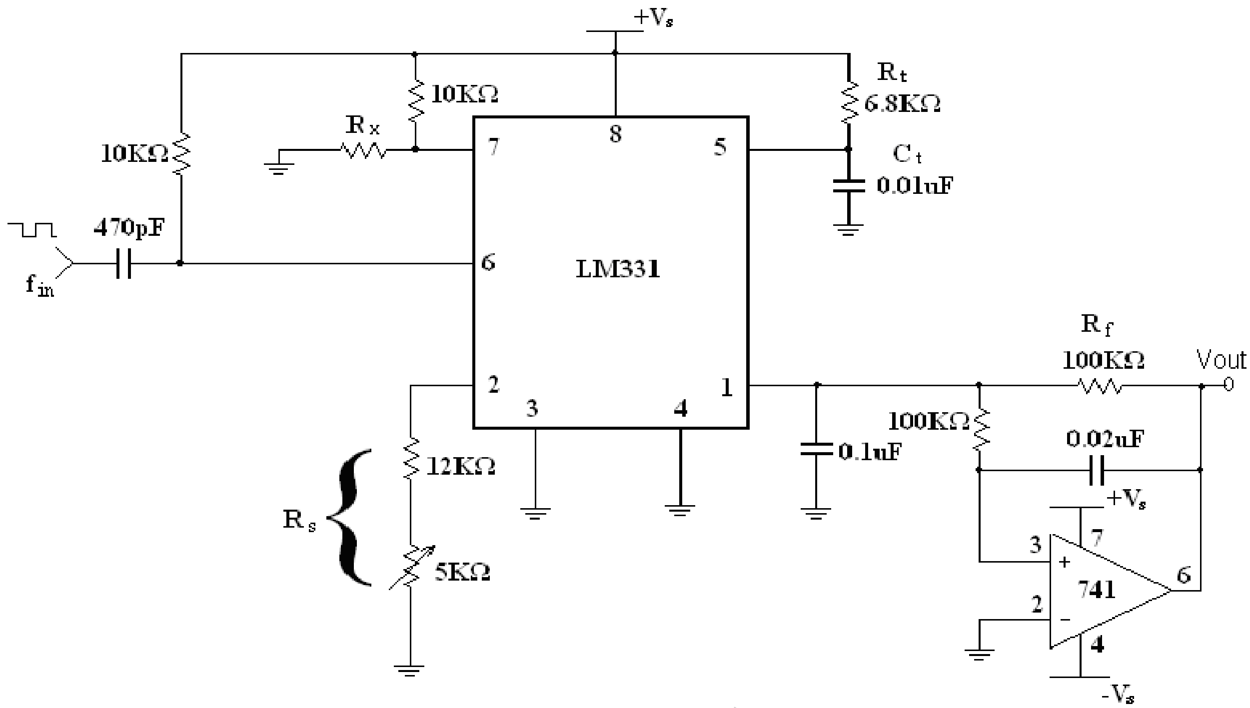

Figure 10: Circuit diagram of precision frequency to voltage converter

In the above precision circuit, the operational amplifier provides a buffered output and also acts as a two-pole filter. The ripple will be less than 5 mV peak for all frequencies above 1 kHz, and the response time will be much quicker. LM331 has very high output impedance which will result in loading. This necessitates the use of buffer. LM331 frequency to voltage converter exhibits very good linearity with a maximum non linearity of ±0.01%.

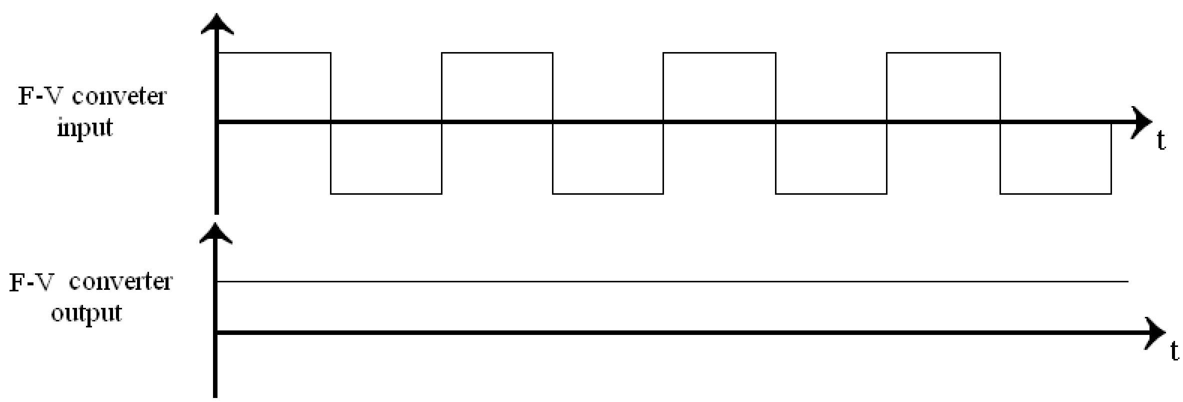

Figure 11: Input and output voltage waveforms of frequency to voltage converter

LINEAR OPERATION

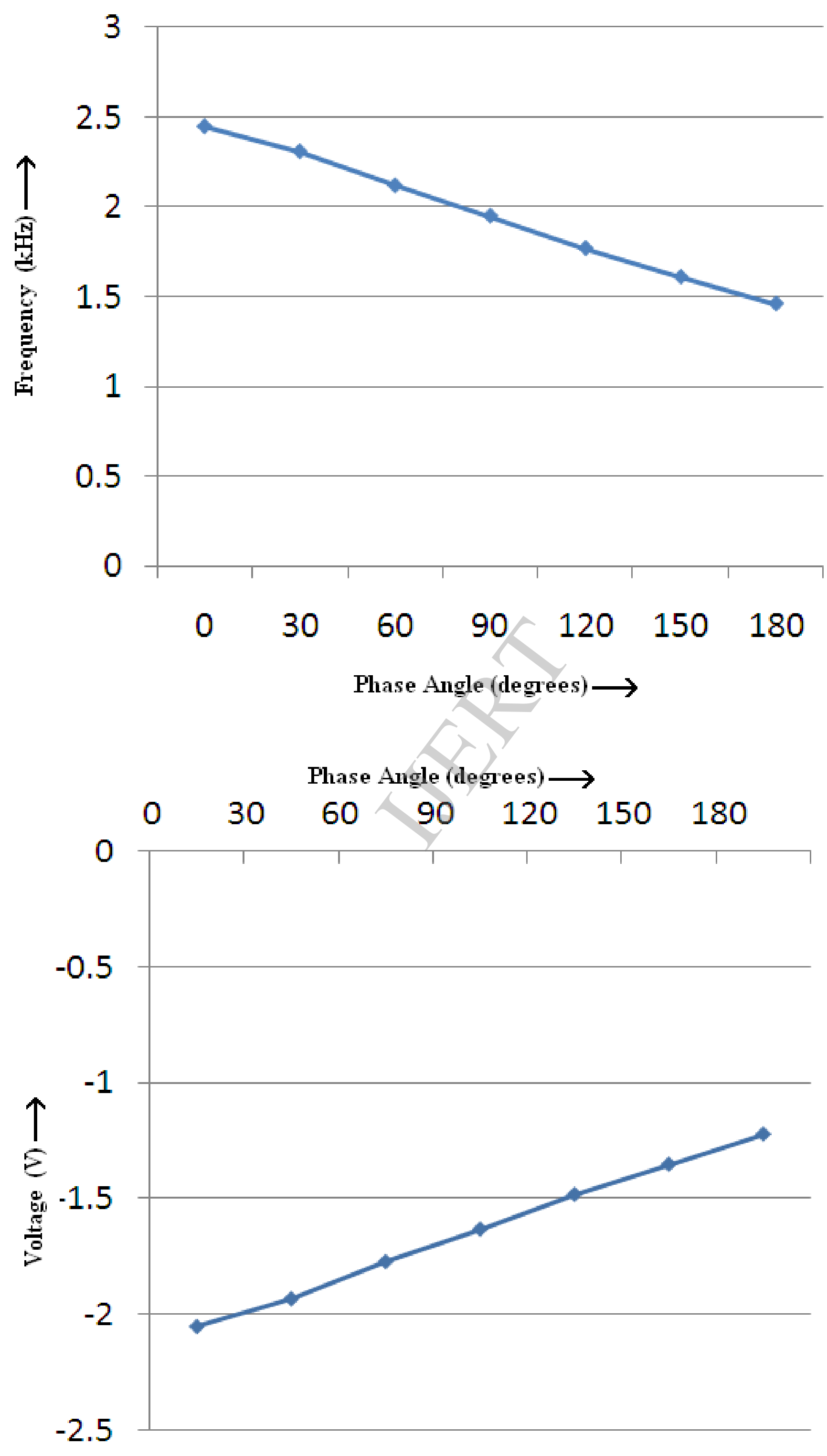

Figure 12: Linear characteristics of PLL and Frequency to Voltage converter

The graphs shown in figure 12 indicate that the output of PLL and frequency to voltage converter vary linearly with the phase difference. Hence calibration is rendered easy.

LEAD-LAG IDENTIFICATION

In many situations, an output is to be activated only when the inputs are activated in a certain sequence. This cannot be accomplished using pure combinational logic but requires the storage characteristics of flip-flops. For example, an AND gate can be used to determine when two inputs A and B are both high, but its output will respond the same regardless of which input goes HIGH first. But if we want to generate a HIGH output only if A goes HIGH and then B goes HIGH some time later, then a flip-flop which can detect the input sequence has to be used.

The J-K flip flop used to detect the input sequence is as shown in Figure 13.

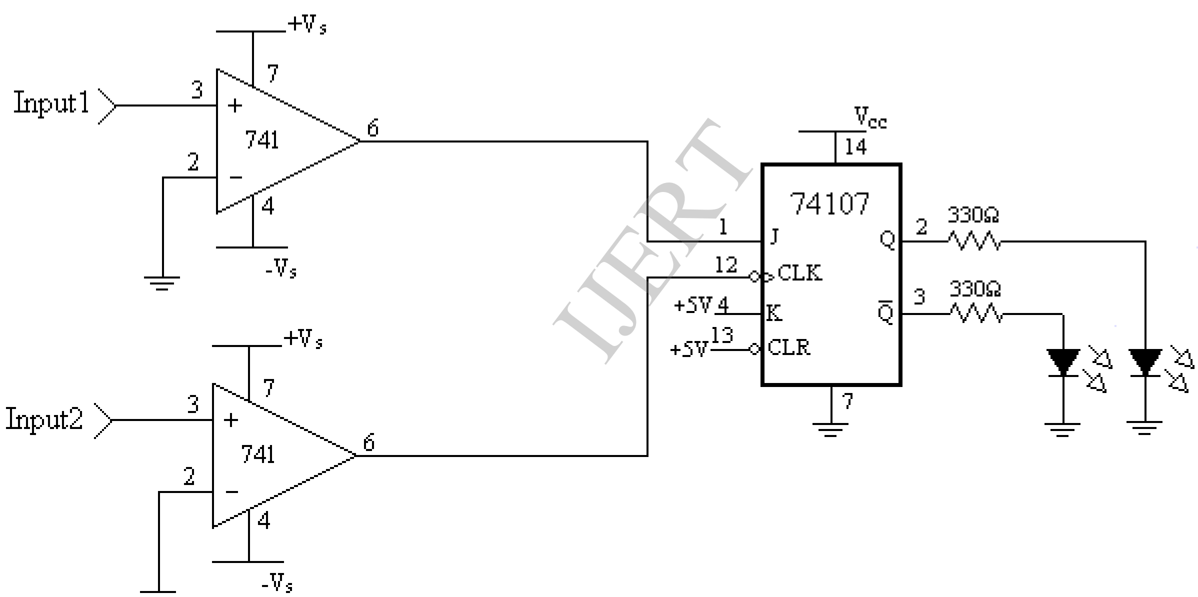

Figure 13: Lag lead detection circuit using ZCD and J-K flip flop

The sinusoidal input signals whose phase difference has to be measured are converted into square wave using zero crossing detectors. The corresponding waveforms are as shown in figure. The square waves thus obtained are applied to the J and CLOCK inputs of the negative edge triggered J-K flip-flop as shown in figure 13.

The circuit operation is as follows:

- Q will go HIGH only if J input leads CLK input. This is because J input must be HIGH in order for Q to go HIGH on the Negative Edge of CLK INPUT.
- Q will go LOW when CLK input leads J input. This is because J input will be LOW by the time the Negative Edge of CLK INPUT arrives.

The corresponding waveforms are shown in figure 14.

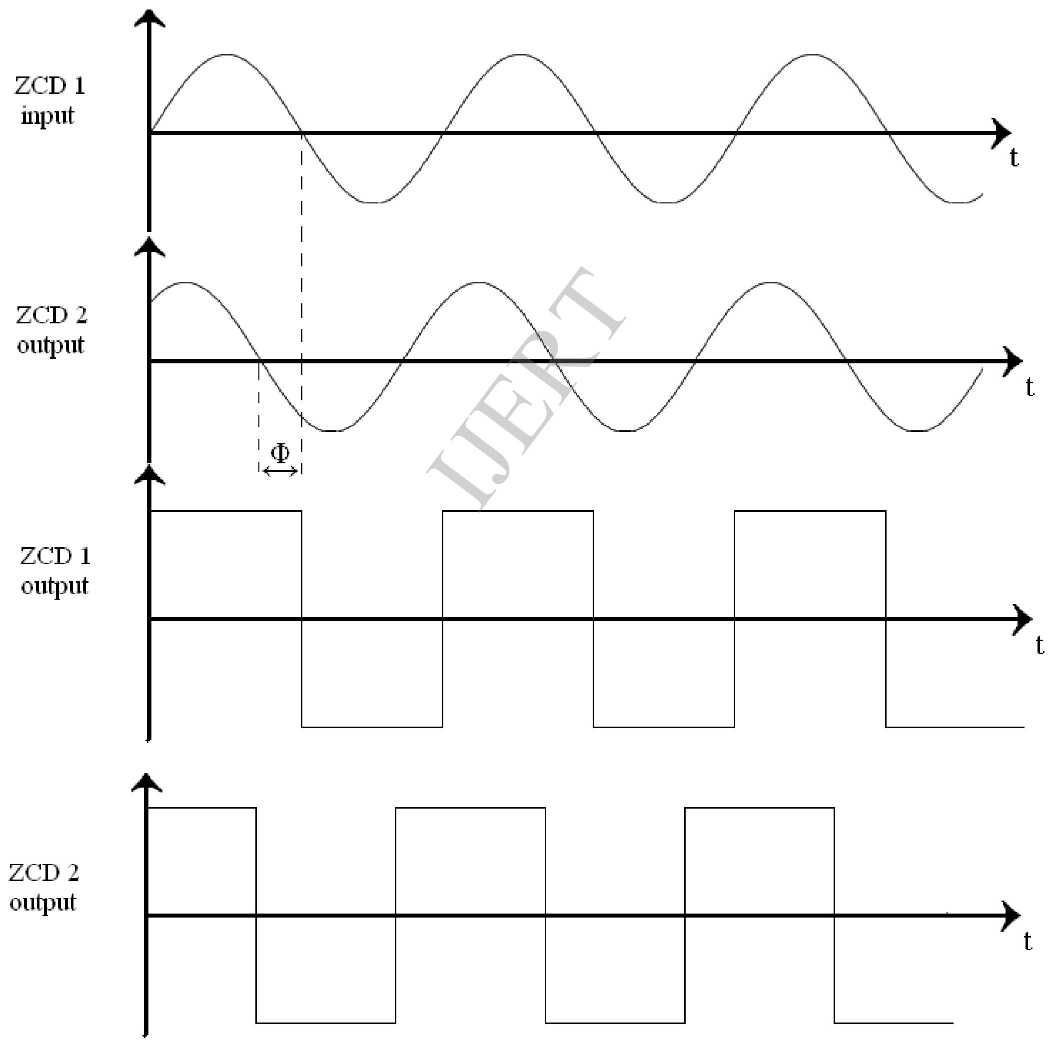

Figure 14: Input-output waveforms of Zero Crossing Detector (ZCD)

CALIBRATION

The F-V converter output voltage corresponding to zero degree phase difference is a non-zero value, so a differential amplifier is used to calibrate a digital panel meter appropriately to read the phase difference between the two inputs (in degrees).

A difference amplifier or a differential amplifier amplifies the difference between two input signals. The relation between input and output is given by

$$V_{out} = -(R_2 / R_1) * (V_1 - V_2)$$

The gain is set to unity by making $R_1 = R_2$. The differential amplifier circuit is as shown below.

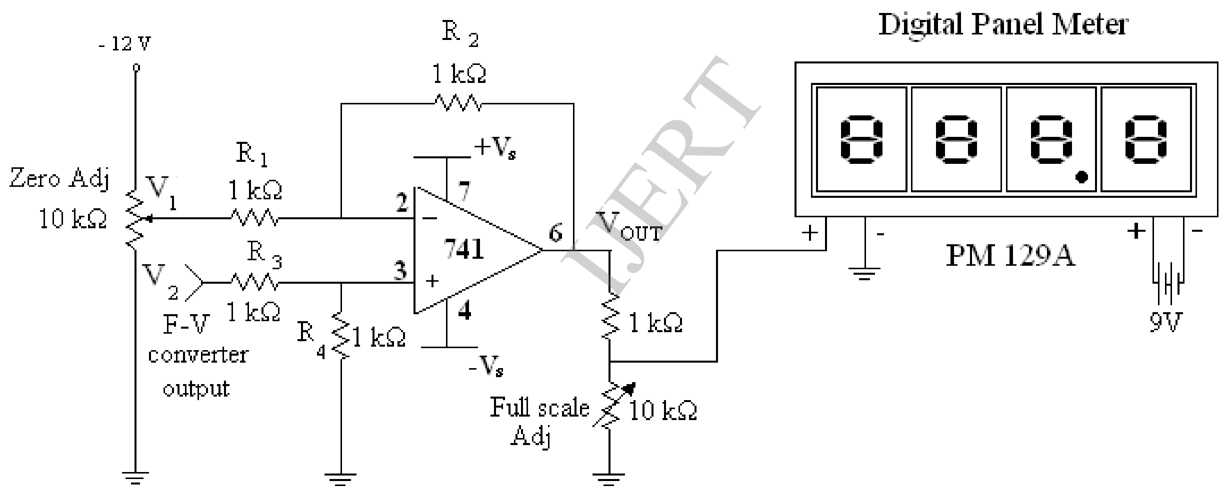

Figure 15: Calibration and Display circuit

Calibration Procedure:

Input signals with zero phase difference are applied to PLL and the corresponding F-V output is given to the non-inverting terminal of the differential amplifier.

- The zero adjuster is varied till the DPM reads 000.0. This sets the lower limit of the Phase angle meter.

- To set the upper limit of the Phase angle meter, input signals with 180° phase difference are applied to PLL and the corresponding F-V output is given to the non-inverting terminal of the differential amplifier.
- The full scale adjuster is then varied till the DPM reads 180.0.

Digital Display using 3½ Digit LED Digital Panel Meter PM 129A

1. FEATURES

200mV full scale input sensitivity

Single 9V DC operation

Decimal point selectable

13mm figure height

Automatic polarity indication

Guaranteed zero reading for 0V input

High input impedance (>100MΩ)

2. APPLICATIONS

Voltmeter

Current meter

Thermometer

Capacitance meter

PH meter

Lux meter

dB meter

LCR meter

Wattmeter & other industrial and domestic uses.

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3. SPECIFICATIONS

Maximum input	: 199.9mV DC
Maximum Display	: 1999 counts (3½ Digits) with automatic polarity indication
Indication method	: LCD display
Measuring Method	: Dual slope integration A-D converter system
Over range Indication	: ″1″ shown in the display
Reading rate time	: 2 to 3 readings per second
Input impedance	: >100MΩ
Accuracy	: ±0.5 %(23º ± 5º, <80%RH)
Power Dissipation	: 1mA DC
Decimal points	: Selectable with wire jumper
Supply voltage	: 7-11V DC
Size	: 68mm x 44mm

SCOPE FOR IMPROVEMENT

- The system designed can be improved to operate at higher input frequencies and higher input amplitudes.
- An analog to digital converter followed by a microprocessor or a microcontroller can be suitably programmed and can be connected prior to the display unit. The program fed should be able to display the phase difference in degrees depending upon the output voltage of the frequency to voltage converter. A look-up table technique can be used in the above case and accurate readings up to 0.01º can be obtained.
- Also the accuracy can be improved by using 4½ digit and 5½ digit LED displays.
- The instrument can be made to read the phase angle between the two inputs irrespective of the difference in peak values of the two waveforms. This is a characteristic of an ideal phase angle meter.
- The instrument can also be made to read phase angle between two current waveforms or between a voltage and a current waveform by designing suitable replica impedance to convert current waveforms into proportional voltage waveforms.

COST SHEET

Sl NO	Component	Unit	Qty	Rate (Rs)	Amount (Rs)
I	ICs				
	1. 7805	No	1	6.00	6.00
	2. 7905	No	1	6.00	6.00
	3. 7812	No	1	6.00	6.00
	4. 7912	No	1	6.00	6.00
	5. UA741	No	4	5.00	20.00
	6. LM565	No	1	40.00	40.00
	7. LM331	No	1	30.00	30.00
	8. 74LS107	No	1	5.00	5.00
II	Transformers				
	1. 15-0-15,1A	No	1	120.00	120.00
	2. 9-0-9,1A	No	1	70.00	70.00
III	Resistors				
	1. Fixed, ½ watt	No	16	0.25	4.00
	2. Variable	No	4	10.00	40.00
IV	Capacitors				
	2200µF,50V	No	2	12.00	24.00
	2200µF,35V	No	2	10.00	20.00
	10µF,63V	No	5	1.00	5.00
	0.1µF	No	6	0.50	3.00
	0.01µF	No	4	0.25	1.00
	0.001µF	No	2	0.50	1.00
	220nF	No	1	4.00	4.00
V	Diode				
	Bridge 100V,3A	No	2	8.00	16.00
	1N4007	No	8	0.50	4.00
	LED	No	2	1.00	2.00
VI	General PCB	No	1	20.00	20.00
VII	Connector,12 pin	No	1	12.00	12.00
VIII	Digital Panel Meter, PM129A	No	1	190.00	190.00
IX	Battery, 9V	No	1	10.00	10.00
X	Fuse with holder, 1A	No	2	10.00	20.00

XI	**Miscellaneous →** IC holder ,Battery holder, Wire, Soldering lead, Heat Sink,				75.00
	Total				860.00

APPLICATIONS OF PHASE ANGLE METER

Phase angle measurement is commonly used with AC power from 50 Hz to 400 Hz. Synchronization of two generators requires the two frequencies to be identical, the lines to be in phase, and the line voltages to be close to each other. It also applies to the triggering of SCRs and Triacs for power control. The phase angle between AC current and voltage determines power factor.

- Calibration laboratories
- Phase angle indicators – Single phase & Three phase
- **Power factor meters**: Power factor in a single-phase circuit (or balanced three-phase circuit) can be measured with the wattmeter-ammeter-voltmeter method, where the power in watts is divided by the product of measured voltage and current.
- Watt meters
- Multifunction watt transducers
- Phase protection relays
- Power meters
- **Energy meters**: An electric meter or energy meter is a device that measures the amount of electrical energy supplied to or produced by a residence, business or machine. The most common type is more properly known as a kilowatt hour meter or a joule meter.
- Current transformer calibration
- Current probe phase delay
- Transformer phasing
- **Synchro**: A synchro or "selsyn" is a type of rotary electrical transformer that is used for measuring the angle of a rotating machine such as an antenna platform.
- **Resolver** : A resolver is a type of rotary electrical transformer used for measuring degrees of rotation. It is considered an analog device, and has a digital counterpart, the rotary (or pulse) encoder.

SPECIFICATIONS OF PHASE ANGLE METER

Phase Angle Mode	
Item Displayed	Phase angle difference between two waves of same frequency
Display Units	1°, 0.1°
Frequency Range	20 Hz to 1 kHz
Reading rate time	2 to 3 readings per second
Display	
Readout	3½ LED Digits, 7-segment, 68mm x 44mm ,red
Range	180 lag or lead
Indicators	Four LED lamps
Inputs	
Type	AC
Signal ground	Common ground for channels A & B
Maximum Signal	5 V ac (rms),1 kHz ,

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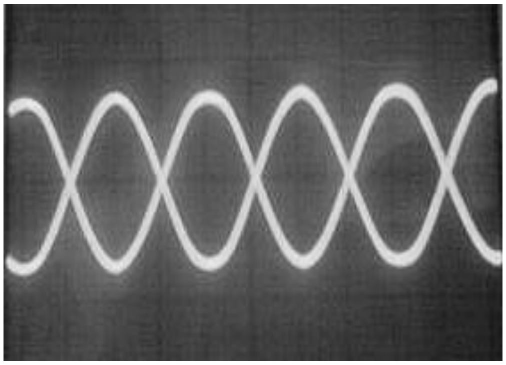
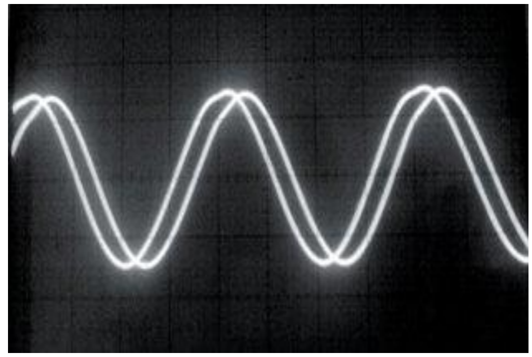
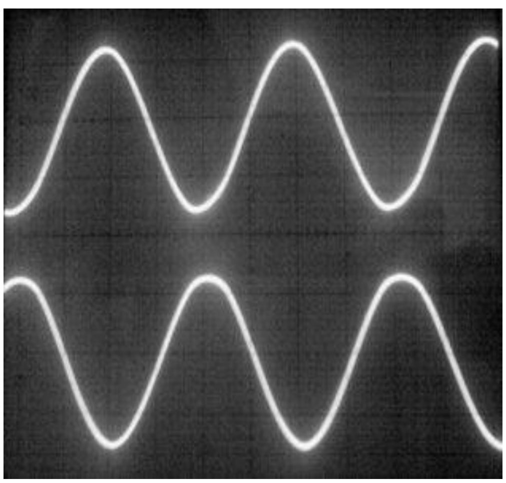
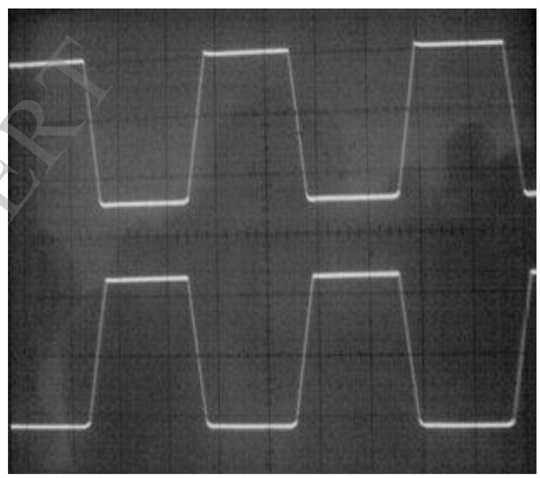
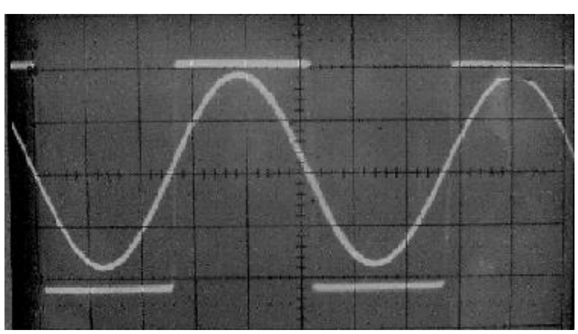
WAVEFORM PICTURES

Input waveforms

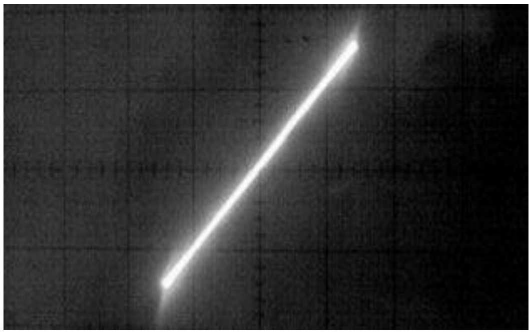


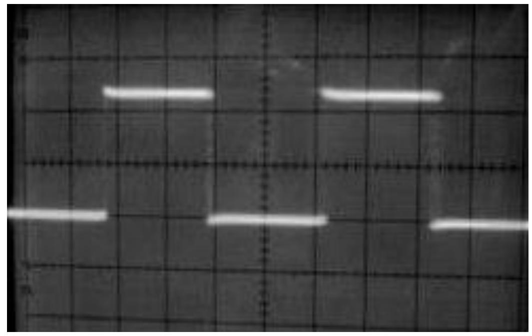
ZCD Input & Output

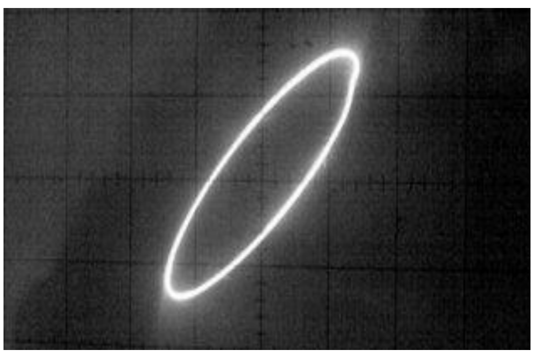
PHASE DIFFERENCE (0º TO 180º)

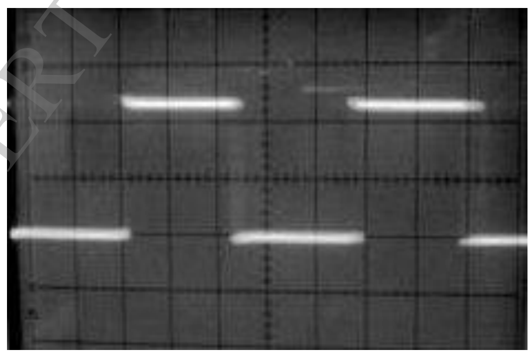
Lissajous Pattern

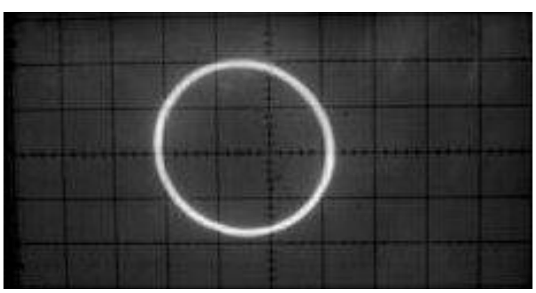
PLL Output

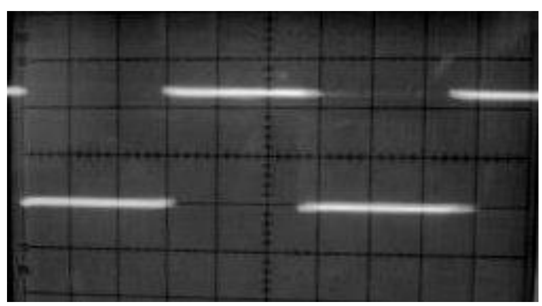












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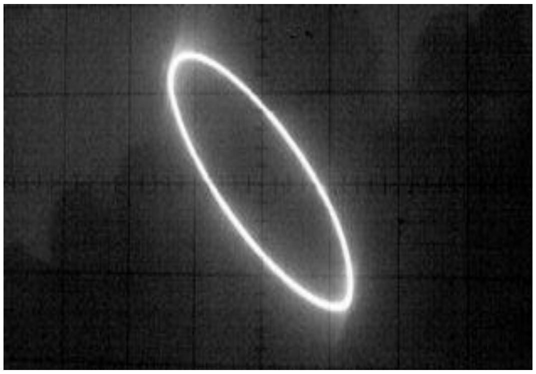
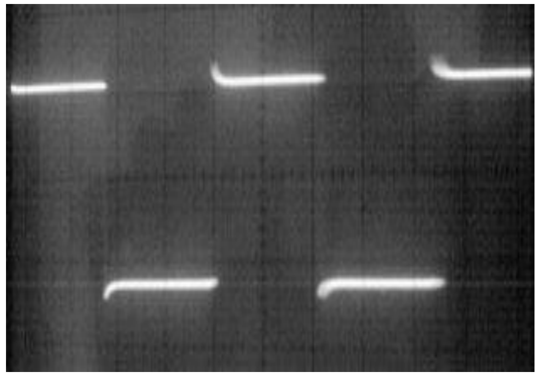
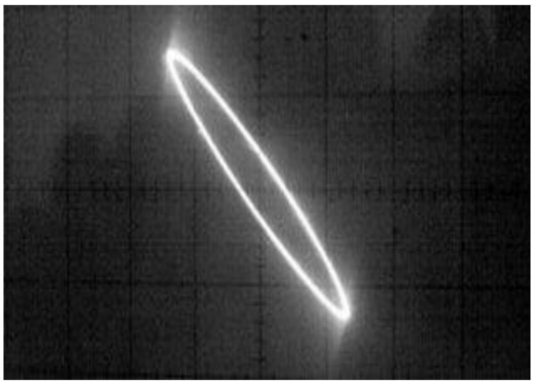
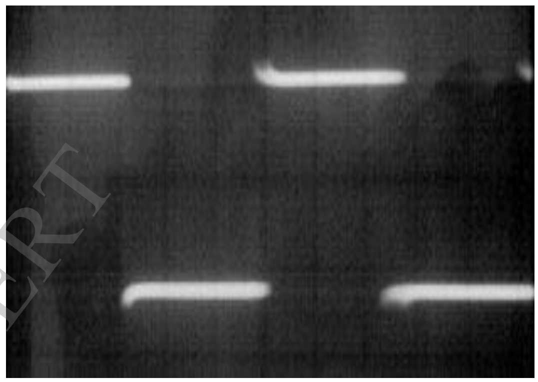
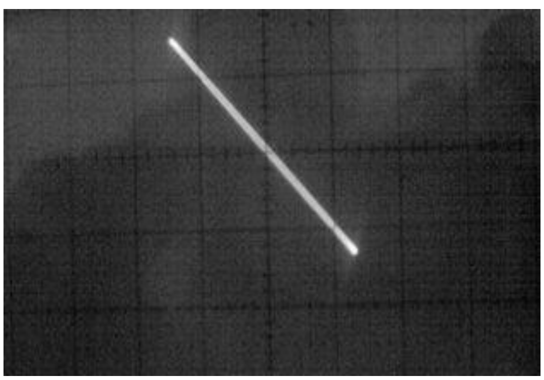
Lissajous Pattern **PLL Output**

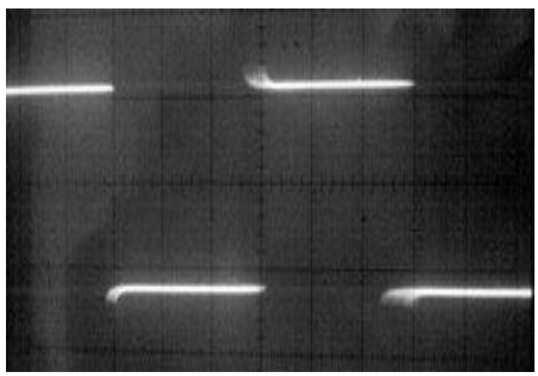












CONCLUSION

Measurement of phase angle is inevitable in the analysis of power system and in many electrical applications. The Phase Locked Loops thus provide a convenient method for measuring phase angle precisely. It is surely an economically viable method compared to the commercially available industrial phase angle meters like PAM360 which cost around £2000.00.

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GLOSSARY

Power factor of an AC electric power system is defined as the ratio of the real power to the apparent power, and is a number between 0 and 1 (frequently expressed as a percentage, e.g. 0.5 pf = 50% pf).
Apparent power is the product of the current and voltage of the circuit (in VA).

Real power is the capacity of the circuit for performing work in a particular time (in kW).

The **phase of an oscillation or wave** is the fraction of a complete cycle corresponding to an offset in the displacement from a specified reference point at time t = 0

The **phase angle** of a periodic wave is the number of suitable units of angular measure between a point on the wave and a reference point.

A **phase-locked loop** or **phase lock loop** (PLL) is a control system that generates a signal that has a fixed relation to the phase of a "reference" signal. A phase-locked loop circuit responds to both the frequency and the phase of the input signals, automatically raising or lowering the frequency of a controlled oscillator until it is matched to the reference in both frequency and phase. A phase-locked loop is an example of a control system using negative feedback.

Light emitting diode, usually called an **LED**, is a semiconductor diode that emits incoherent narrow-spectrum light when electrically biased in the forward direction of the p-n junction, as in the common LED circuit. This effect is a form of electroluminescence. LEDs are often used as small indicator lights on electronic devices.

A **liquid crystal display** (**LCD**) is a thin, flat display device made up of any number of color or monochrome pixels arrayed in front of a light source or reflector. It is often utilized in battery-powered electronic devices because it uses very small amounts of electric power.

The **phase shifter** produces an output voltage with the same magnitude as the input voltage, but with a phase angle that can be varied continuously between 0° and -180°.

A **test circuit** is the one which provides the necessary and suitable conditions for checking the proper functioning of any other circuit.

A **zero crossing threshold detector** is an electronic circuit that consists of an operational amplifier with an input voltage at its positive input .Often used in conjunction with other circuit elements; it usually functions as a simple voltage switch. When the input voltage is positive, the output voltage is a positive value, when the input voltage is negative; the output voltage is a negative value. It is generally used as a sine wave to square wave converter.

A **flip-flop** is a kind of **bistable multivibrator**, an electronic circuit which has two stable states and thereby is capable of serving as one bit of memory. A flip-flop is controlled by (usually) one or two control signals and/or a gate or clock signal. The output often includes the complement as well as the normal output. As flip-flops are implemented electronically, they require power and ground connections.

The **JK flip-flop** augments the behavior of the SR flip-flop by interpreting the S = R = 1 condition as a "flip" or toggle command.

J	K	Q_{next}	Comment
0	0	Q_{prev}	Hold state
0	1	0	Reset
1	0	1	Set
1	1	Q'_{prev}	Toggle

A circuit symbol for a JK flip-flop, where > is the clock input, J and K are data inputs, Q is the stored data output, and Q' is the inverse of Q. The characteristic equation of the JK flip-flop is:

$$Q_{next} = J\overline{Q} + \overline{K}Q$$

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