AV241 – Instrumentation and Control Lab

Instrumentation Lab-3

All-Pass Filters and Phase Detector Schemes

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SC22B146

Aim :

(a) Design and implement an all-pass filter and verify its response.

(b) Detect phase difference between two signals using a phase detector circuit.

Components and Equipments Required :

1. DC power supply.
2. Function generator.
3. Digital Storage Oscilloscope.
4. Opamp IC OP07
5. Comparator IC LM311
6. XOR IC 7486
7. Resistors
8. Capacitors

Theory :

An all-pass filter is that which passes all frequency components of the input signal without attenuation but provides predictable phase shifts for different frequencies of the input signals.

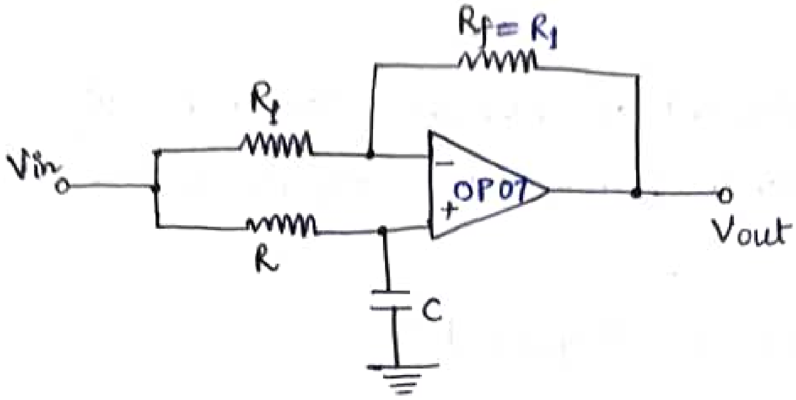
The phase angle ϕ is given by

$$\phi = 2\tan^{-1}(2\pi f CR)$$

Phase detector circuit is used to detect phase difference between two sinusoidal signals. It consists of two comparators followed by an XOR gate and a low pass filter.

The low-pass filter cut-off frequency should be less than 5 Hz.
The output voltage is given by

$$V_{avg} = \frac{V_1 \theta}{\pi}.$$



Procedure:

Part (a):

① Design the all-phase circuit such that it can offer a phase difference of 90° to a sine wave input of frequency 500 Hz.

② Implement the above circuit in a breadboard. Note the actual phase delay b/w the input and output waves.

③ Suitably change the design of the circuit (variable resistor) so that the phase delay can be changed to 30°, 60°, 120° and 150°. Plot the actual vs. calculated reading and find the error.

Part (b):

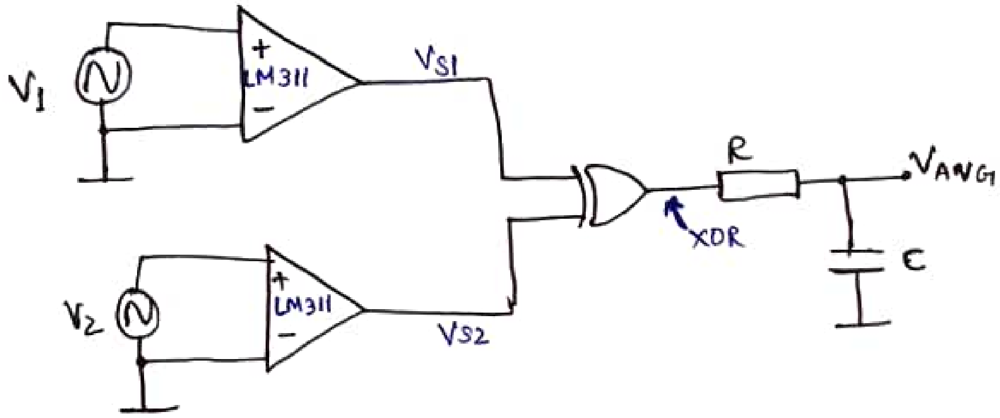
① Design the phase detector circuit for input sine waves of frequency 500 Hz.

② Implement the comparators (using LM311 IC) and ensure the compatibility of their output is compatible with TTL standard. Observe the plot of comparators outputs for typical inputs.

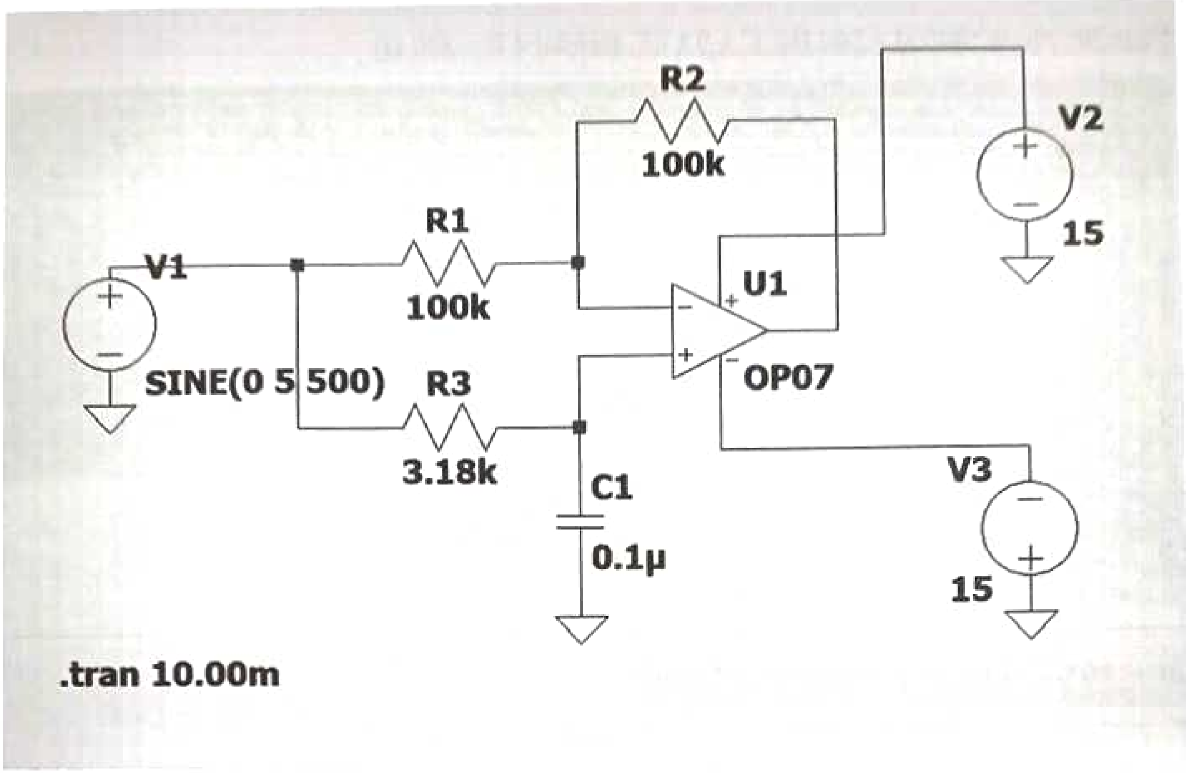
③ Include the XOR gate and filter circuit in the breadboard. Vary the phase delays (θ) between V_1 and V_2 in steps of 15° and measure the output signal of the filter (V_{avg}.) for each case using a digital multimeter.

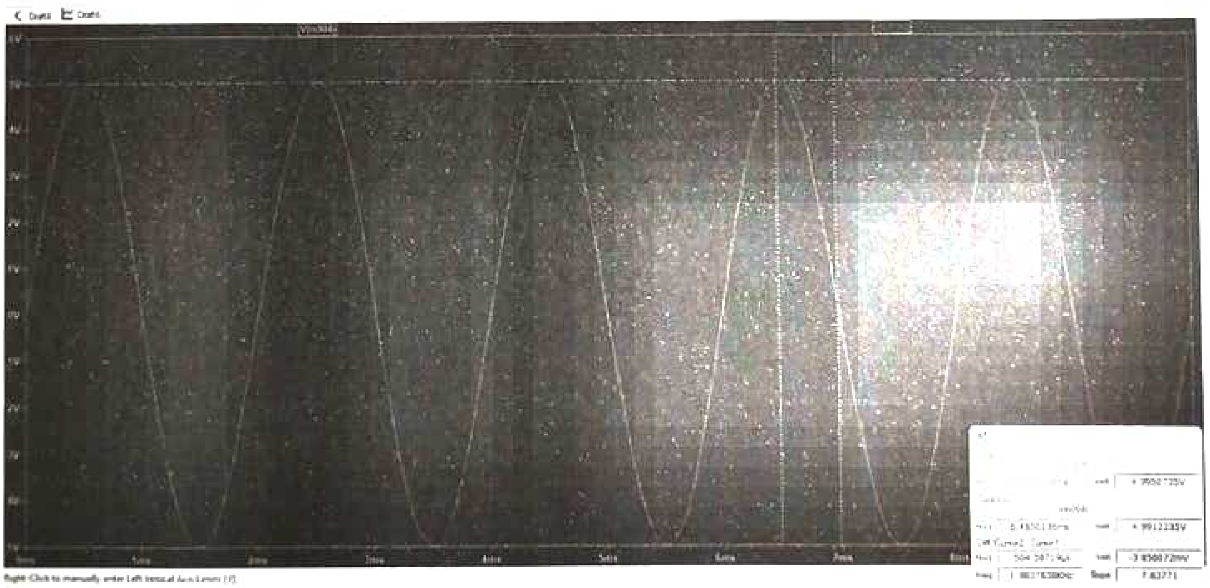
[Use that all-pass filter circuit implemented in part ① to obtain multiple phase delays.] ③

④ Plot the output signal, $V_{avg.}$, with θ and determine the error. Calculate the non-linearity of the phase detector with respect to the best-fit straight line.



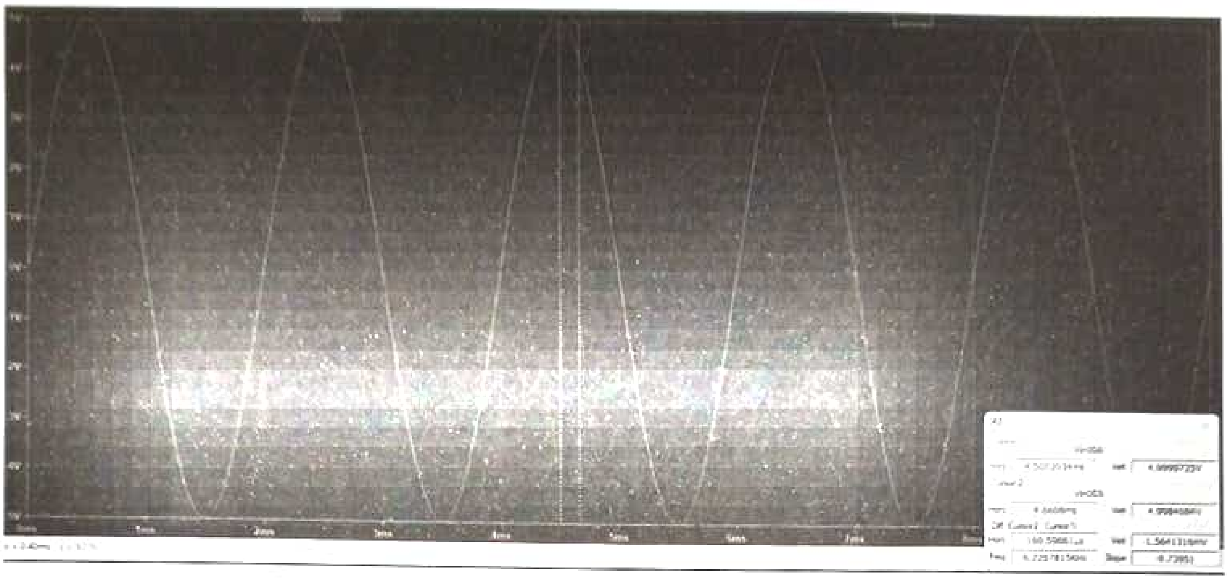
Experimental Simulations:





Change in time (Δt) = 504.08 $\mu s \Rightarrow \varphi = \omega \Delta t = 90.699^{\circ}$
Expected value = 90°; error = 0.0493%

Plot: 30° Phase Shift (f = 500 Hz, C = 0.1 μF, standard R = 820 Ω)

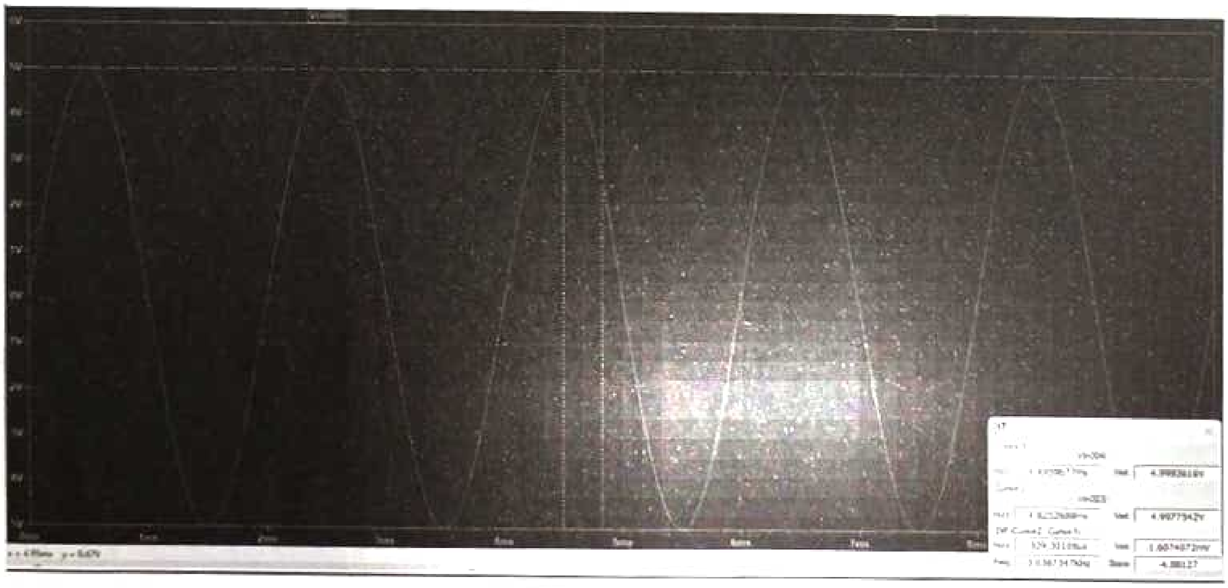


$\Delta t = 161.591\ \mu s \Rightarrow \varphi = \omega\Delta t = 29.1386^{\circ}$

Expected value @ 820 Ω = 28.892°; error (expected value) = 0.672%

Error (desired value) = -2.8713%

Plot: 60° Phase Shift (f = 500 Hz, C = 0.1 μF, standard R = 1.8 kΩ)

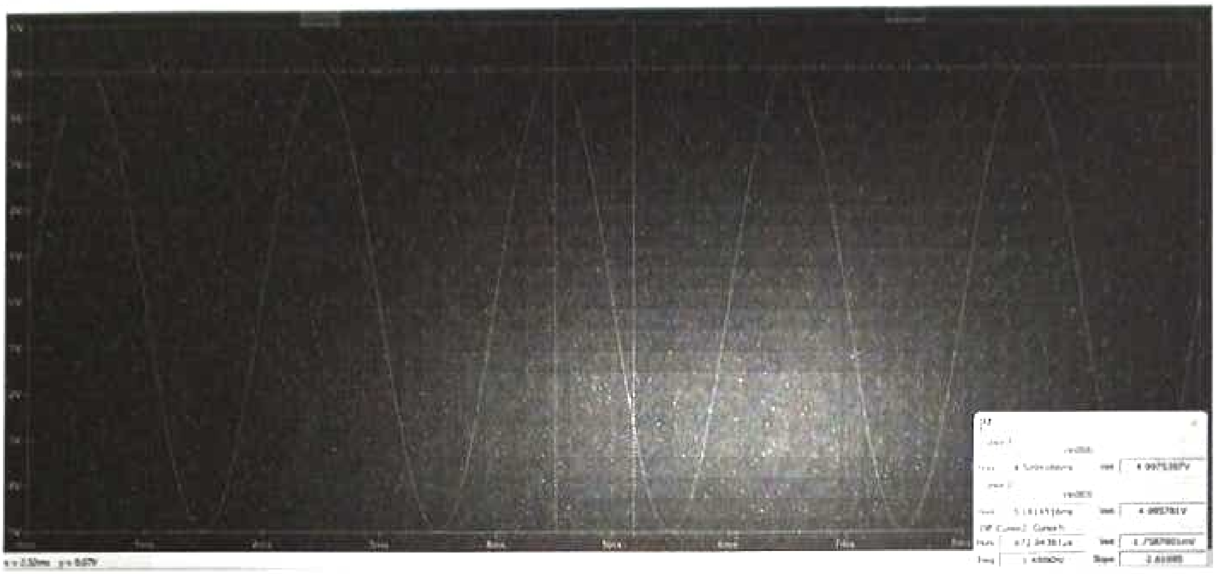


$\boldsymbol{\Delta t = 329.301\ \mu s \Rightarrow \varphi = \omega\Delta t = 59.2741^{\circ}}$

Expected value @ 1.8 kΩ = 58.975°; error (expected value) = 0.507%

Error (desired value) = -1.3913%

Plot: 120° Phase Shift (f = 500 Hz, C = 0.1 μF, standard R = 5.6 kΩ)



Plot: 120° Phase Shift (f = 500 Hz, C = 0.1 μF, standard R = 5.6 kΩ)

$\Delta t = 672.0430\,\mu s \Rightarrow \varphi = \omega\Delta t = 0.6709547\pi\, rad = 120.96^\circ$

Expected value @ 5.6 kΩ = 120.771289°; error (expected value) = 0.163%

Error (desired value) = 0.6432%

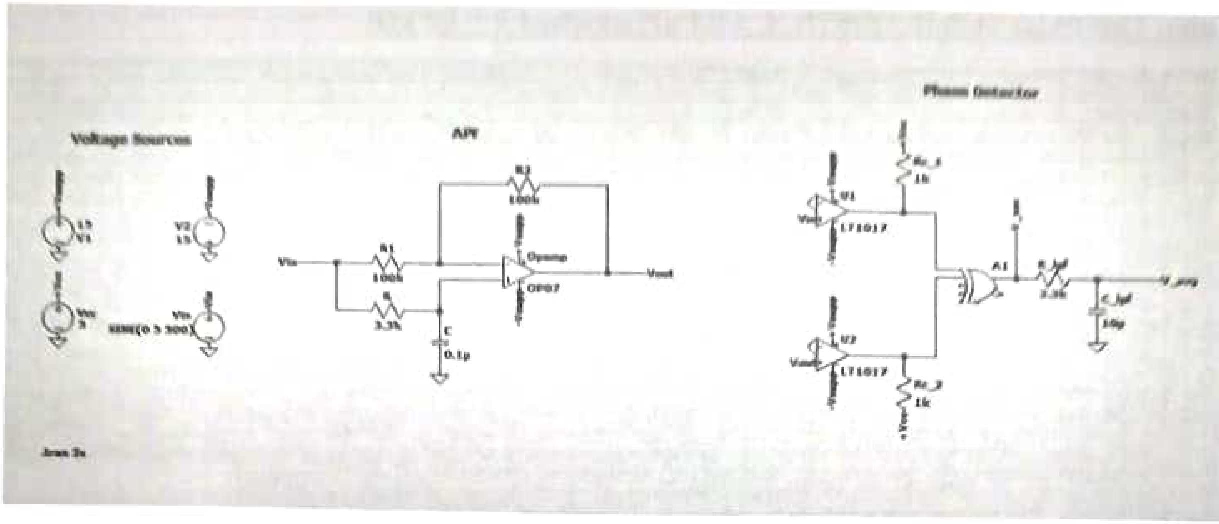
Plot: 150° Phase Shift (f = 500 Hz, C = 0.1 μF, standard R = 12 kΩ)

Plot: 150° Phase Shift (f = 500 Hz, C = 0.1 μF, R = 12 kΩ)

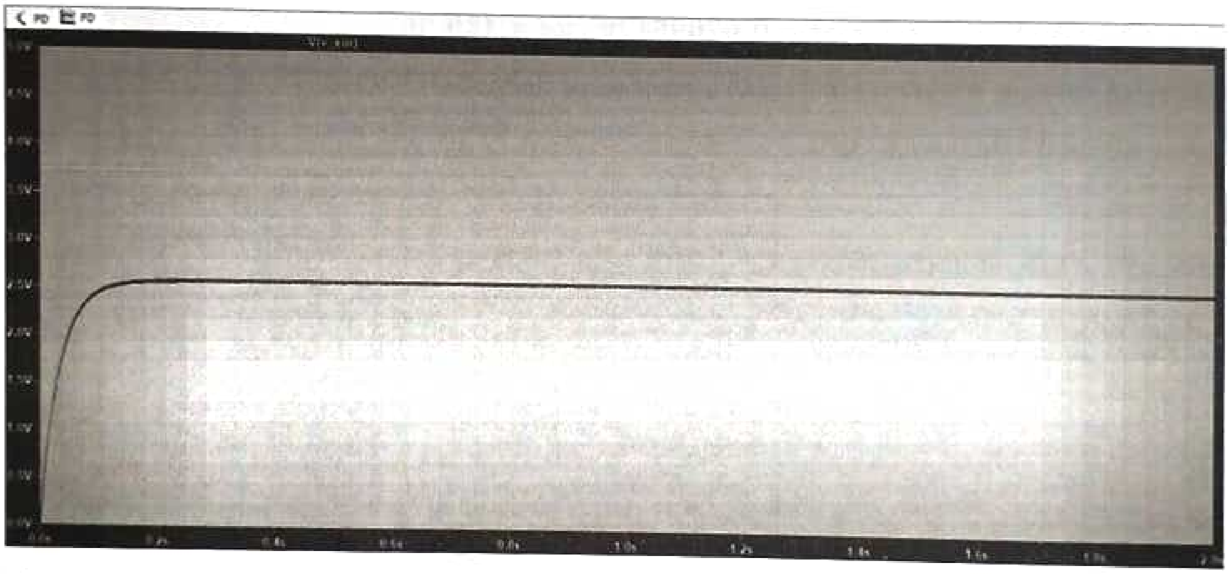
$\Delta t = 840.0536\,\mu s \Rightarrow \varphi = \omega\Delta t = 151.209^\circ$

Expected value @ 12 kΩ = 150.288°; error (expected value) = 0.6132%

Error (desired value) = 1.2897%



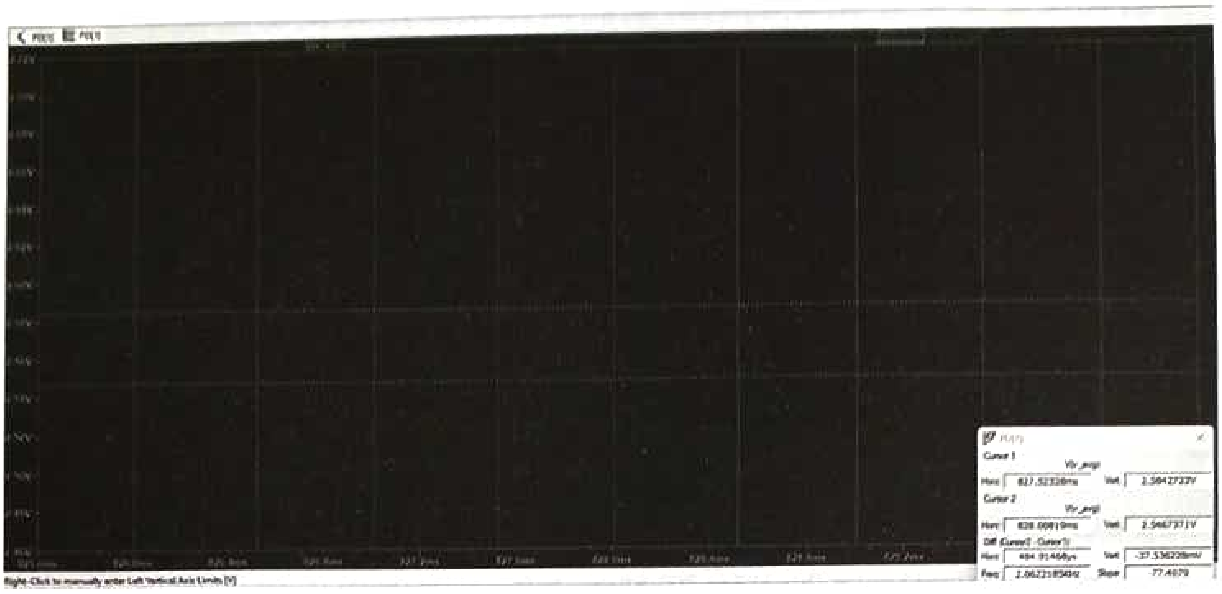
$\Phi = 90°$



Plot: v_xor (green) and v_avg (blue) for 90° phase shift

Plot: Close-up of XOR output (v_xor) for 90° phase shift

Logic HIGH of XOR, $V_H = 5$ V



Plot: Close-up of low-pass filter average output (v_avg) for 90° phase shift

$$V_{avg} = \frac{2.5842 + 2.546}{2} = 2.5655 \text{ V} \approx 2.5656 \text{ V}$$

Then,

$$V_{avg} = \frac{V_H \varphi}{\pi} \Rightarrow \varphi = \frac{V_{avg}\pi}{V_H} = 0.5131\pi\ rad = 92.36°$$

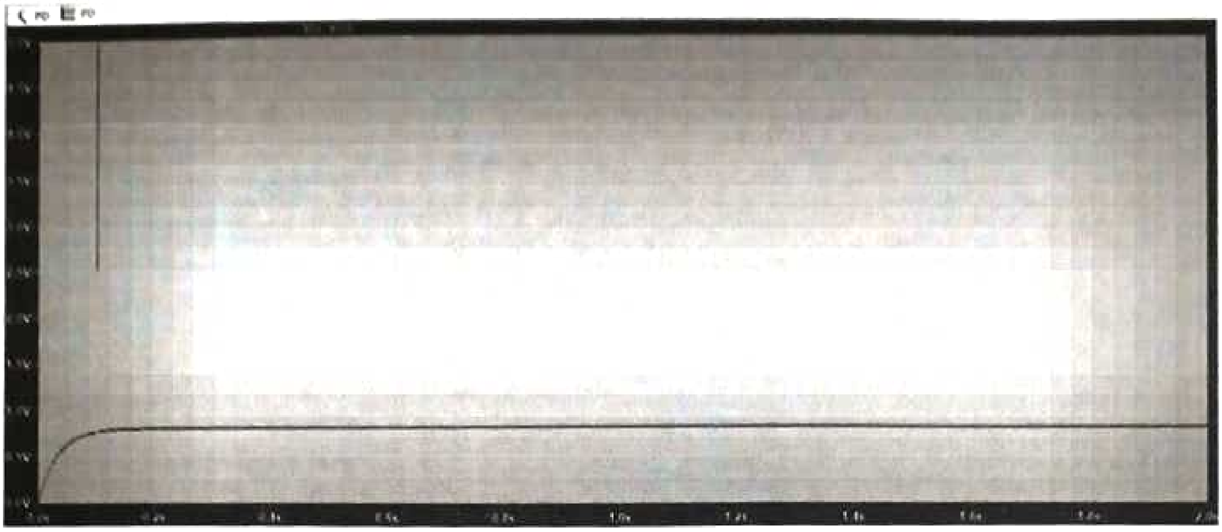
Expected value @ APF R = 3.3 kΩ = 92.066° (calculated) / 92.4137° (APF o/p)

So, error (calculated value) = 0.3194%;

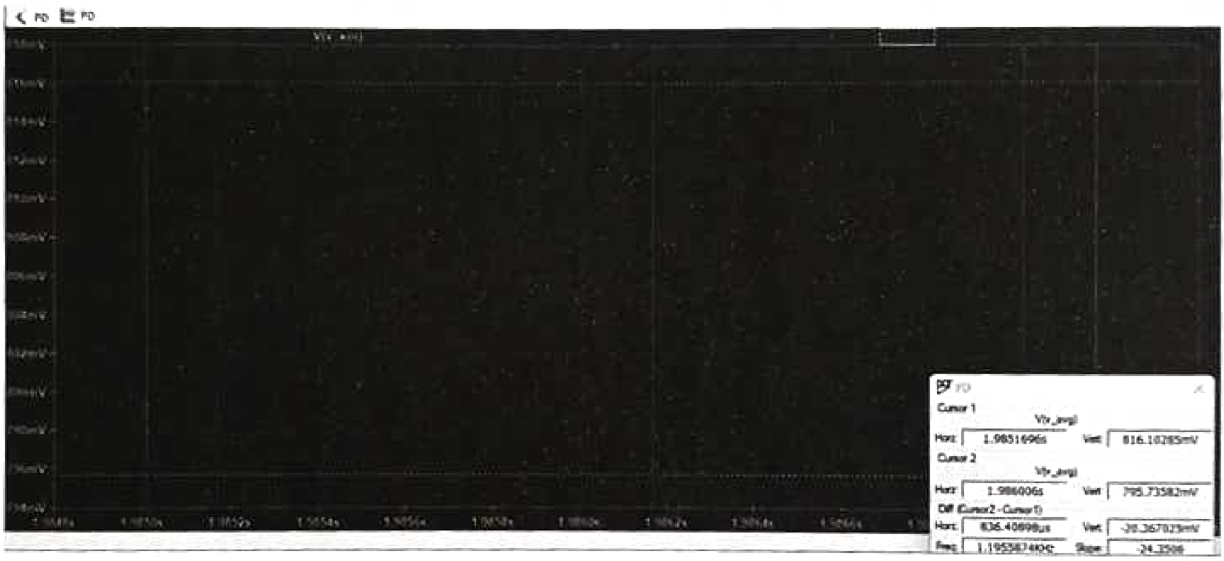
Error (APF o/p) = -0.0580%; and

Error (desired value) = 2.6223%

Φ = 30°



Plot: v_xor (green) and v_avg (blue) for 30° phase shift



Plot: Close-up of low-pass filter average output (v_avg) for 30° phase shift

$$V_{avg} = \frac{816.10285 + 795.7352}{2} = 805.919025 \text{ mV}$$

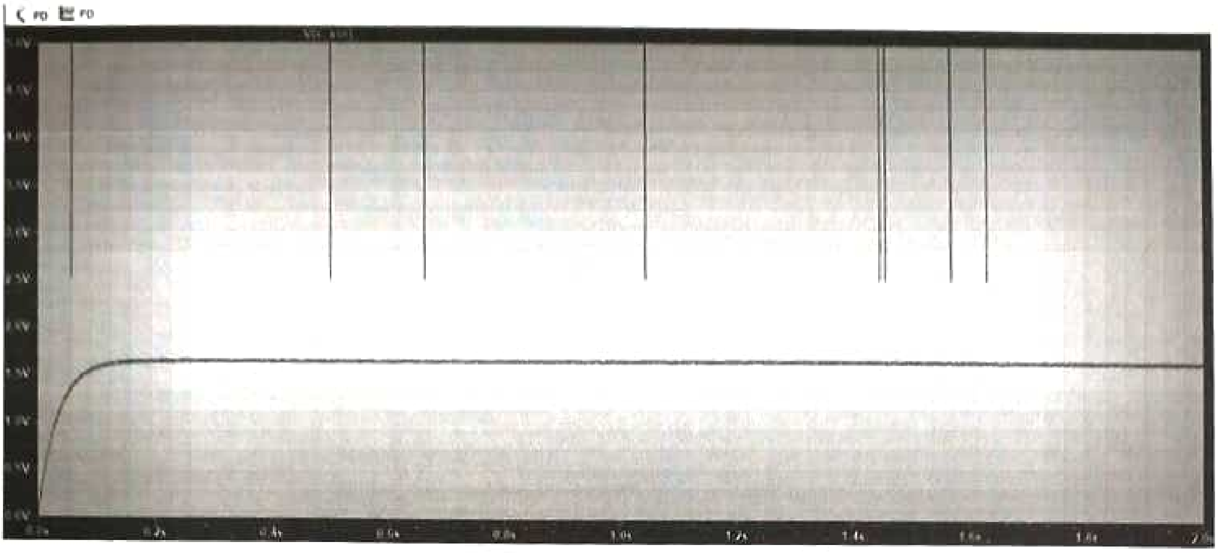
Then,

$$V_{avg} = \frac{V_H \varphi}{\pi} \Rightarrow \varphi = \frac{V_{avg}\pi}{V_H} = 0.1612\pi\, rad = 29.0131°$$

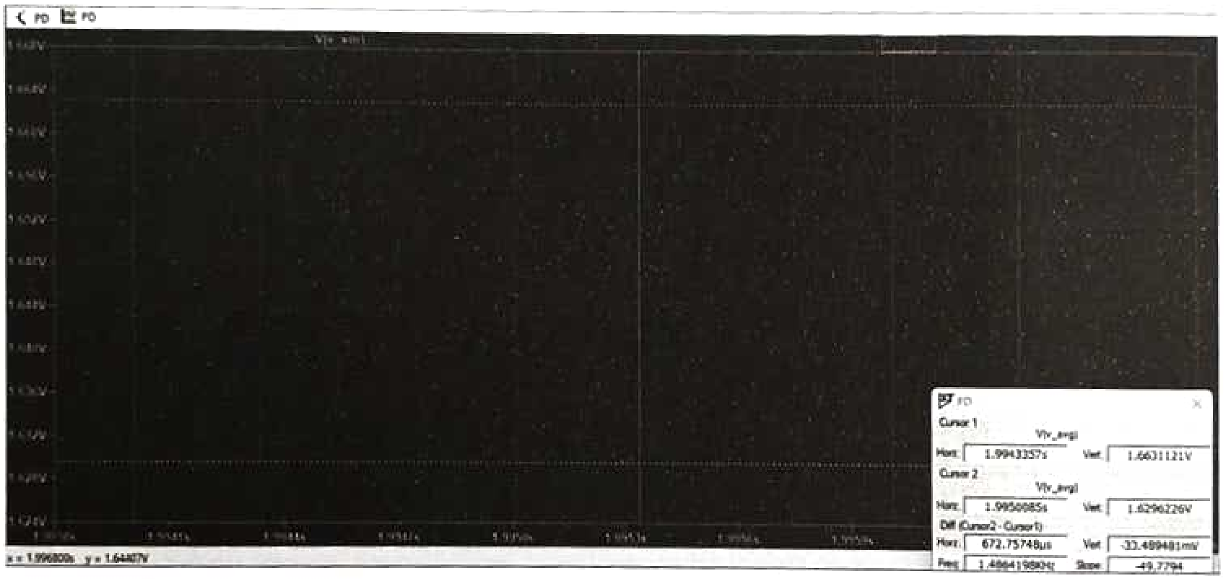
Expected value @ APF R = 820 Ω = 28.892° (calculated) / 29.1386° (APF o/p)

So, error (calculated value) = 0.4191%;

Φ = 60°



Plot: v_xor (green) and v_avg (blue) for 60° phase shift



Plot: Close-up of low-pass filter average output (v_avg) for 60° phase shift

$$V_{avg} = \frac{1.6631121 + 1.6296226}{2} = 1.64636735\text{ V}$$

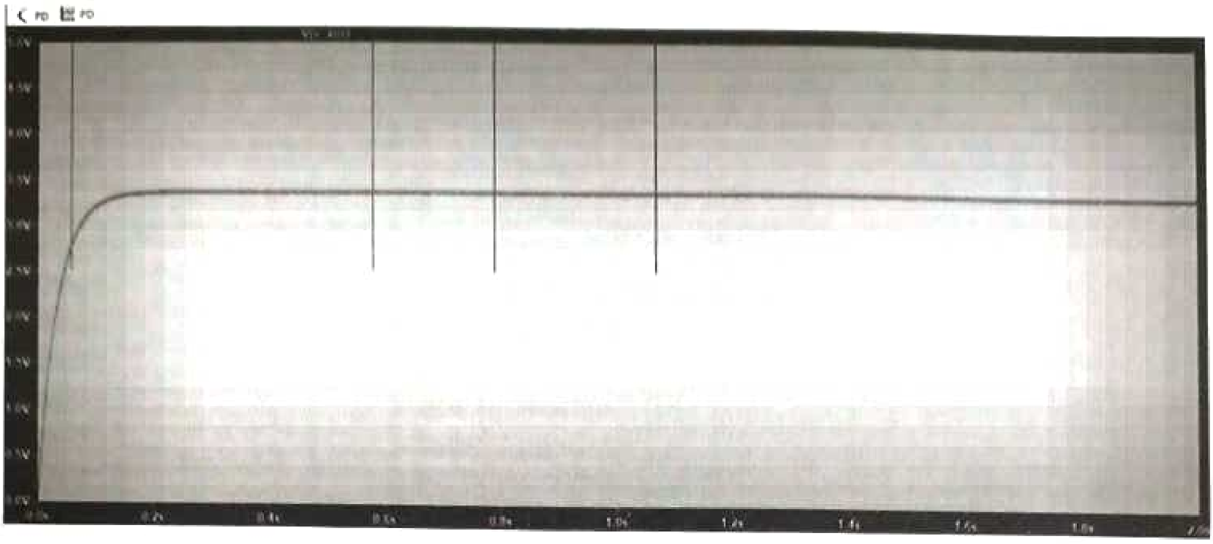
Then,

$$V_{avg} = \frac{V_H \varphi}{\pi} \Rightarrow \varphi = \frac{V_{avg}\pi}{V_H} = 0.3293\pi\ rad = 59.2692°$$

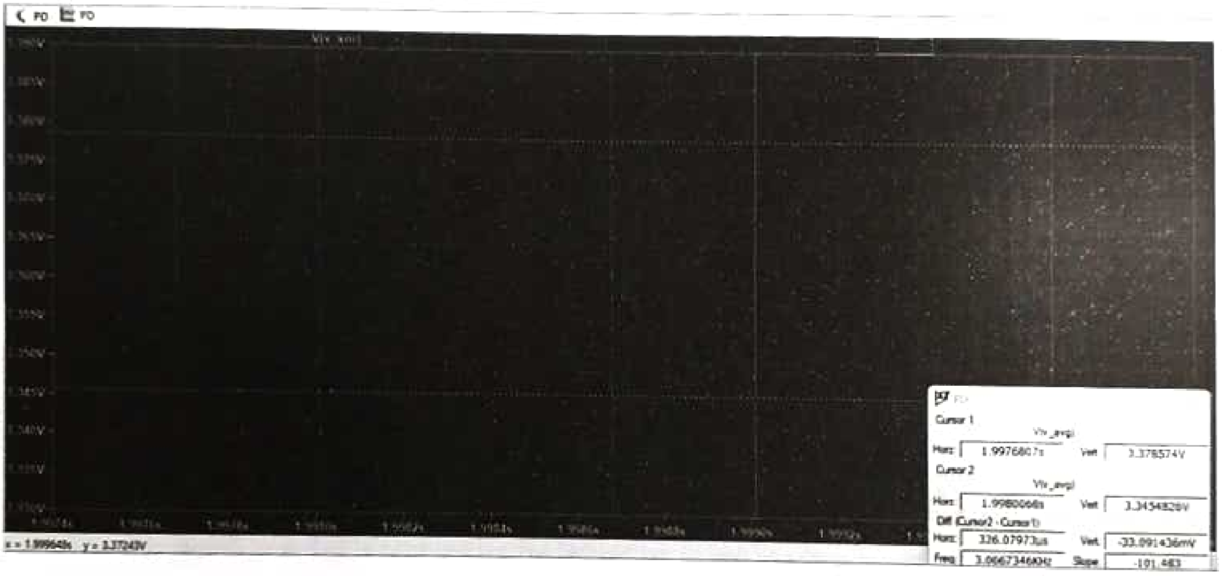
Expected value @ APF R = 1.8 kΩ = 58.975° (calculated) / 59.1652° (APF o/p)

So, error (calculated value) = 0.4989%;

Φ = 120°



Plot: v_xor (green) and v_avg (blue) for 120° phase shift



Plot: Close-up of low-pass filter average output (v_avg) for 120° phase shift

$$V_{avg} = \frac{3.378574 + 3.3454826}{2} = 3.3620283\ \text{V}$$

Then,

$$V_{avg} = \frac{V_H \varphi}{\pi} \Rightarrow \varphi = \frac{V_{avg}\pi}{V_H} = 0.67240566\pi\ rad = 121.0330°$$

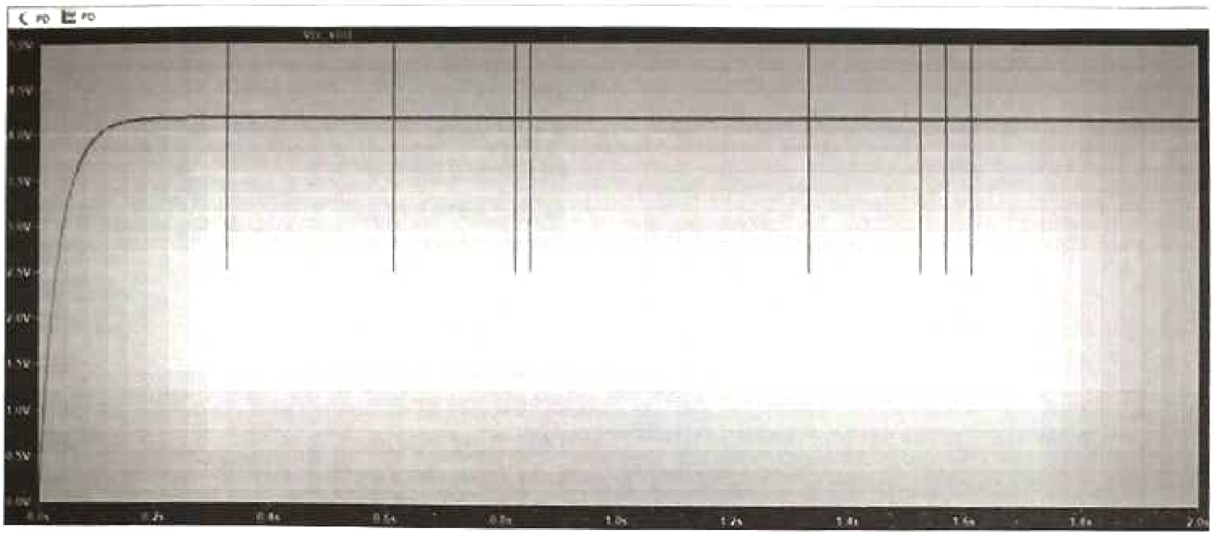
Expected value @ APF R = 5.6 kΩ = 120.771289° (calculated) / 120.771846° (APF o/p)

So, error (calculated value) = 0.2167%;

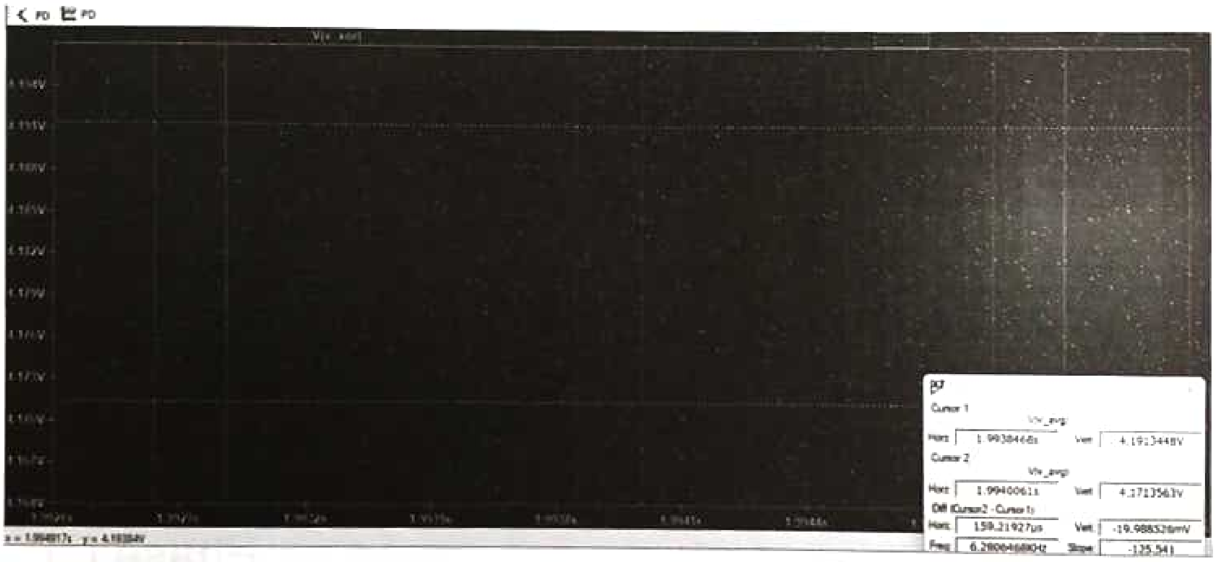
Error (APF o/p) = 0.2163%; and

Error (desired value) = 0.8808%

Φ = 150°



Plot: v_xor (green) and v_avg (blue) for 150° phase shift



Plot: Close-up of low-pass filter average output (v_avg) for 150° phase shift

$$V_{avg} = \frac{4.1913448 + 4.1713563}{2} = 4.18135055 \text{ V}$$

Then,

$$V_{avg} = \frac{V_H \varphi}{\pi} \Rightarrow \varphi = \frac{V_{avg}\pi}{V_H} = 0.8363\pi\, rad = 150.5286°$$

Expected value @ APF R = 3.3 kΩ = 150.288° (calculated) / 151.9481° (APF o/p)

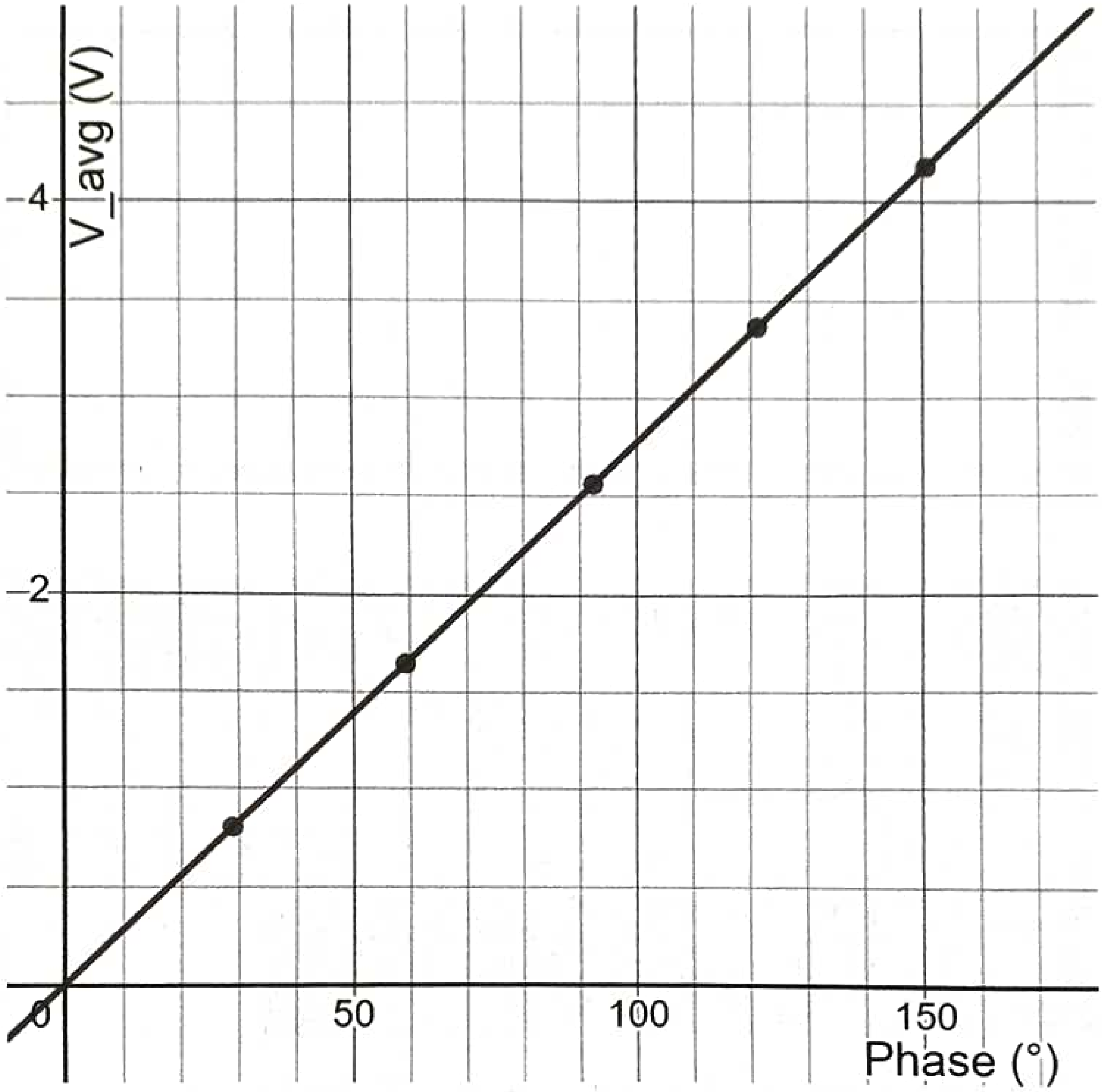
So, error (calculated value) = 0.1601%;

Error (APF o/p) = -0.9342%; and

Error (desired value) = 0.3524%

Non-linearity of Phase Detector:

Results : Phase detector



Plot: V_avg (V) vs Phase (°)

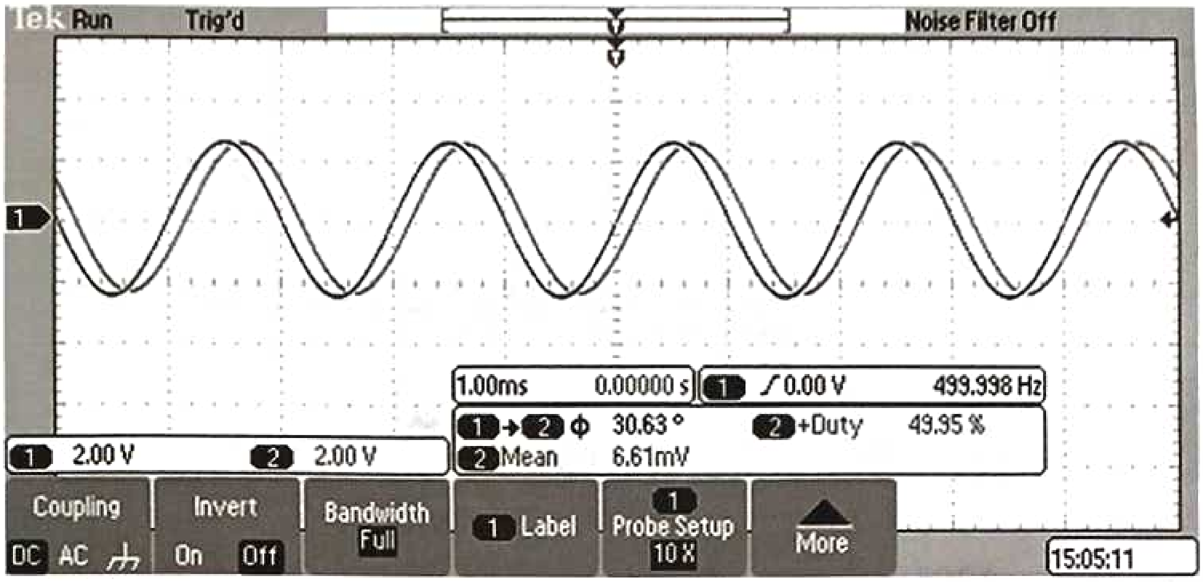
[Best-fit parameters: m = 0.027778, b = -0.00000719472; y = mx + b]

The simulated phase detector has negligible non-linearity.

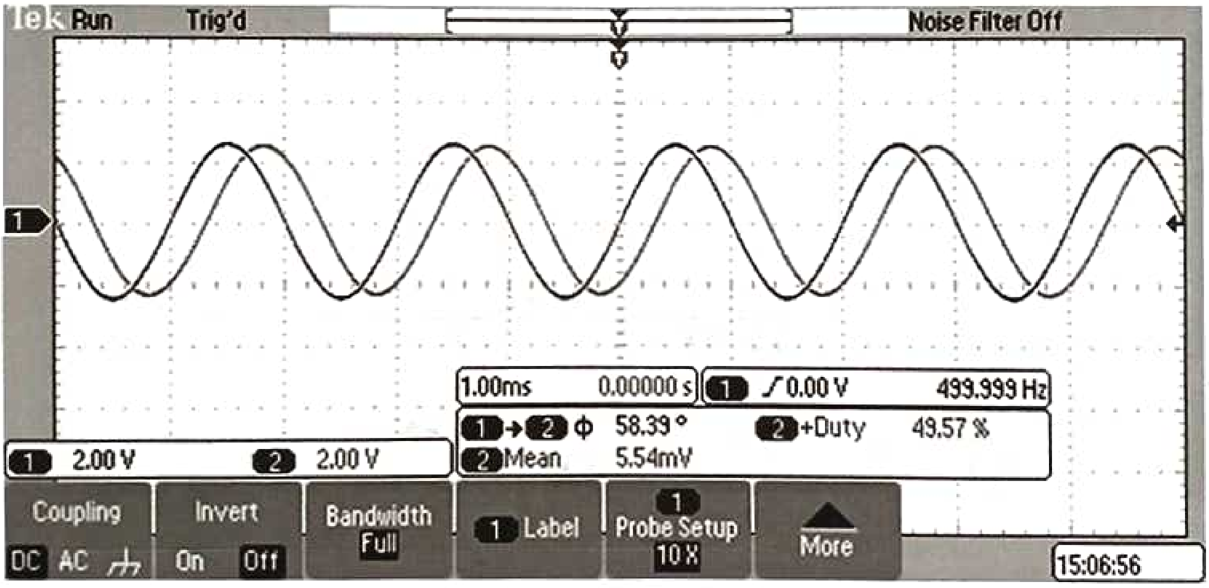
Results: All Pass Filter　　　　SC22B146　(15)

Phase Shift

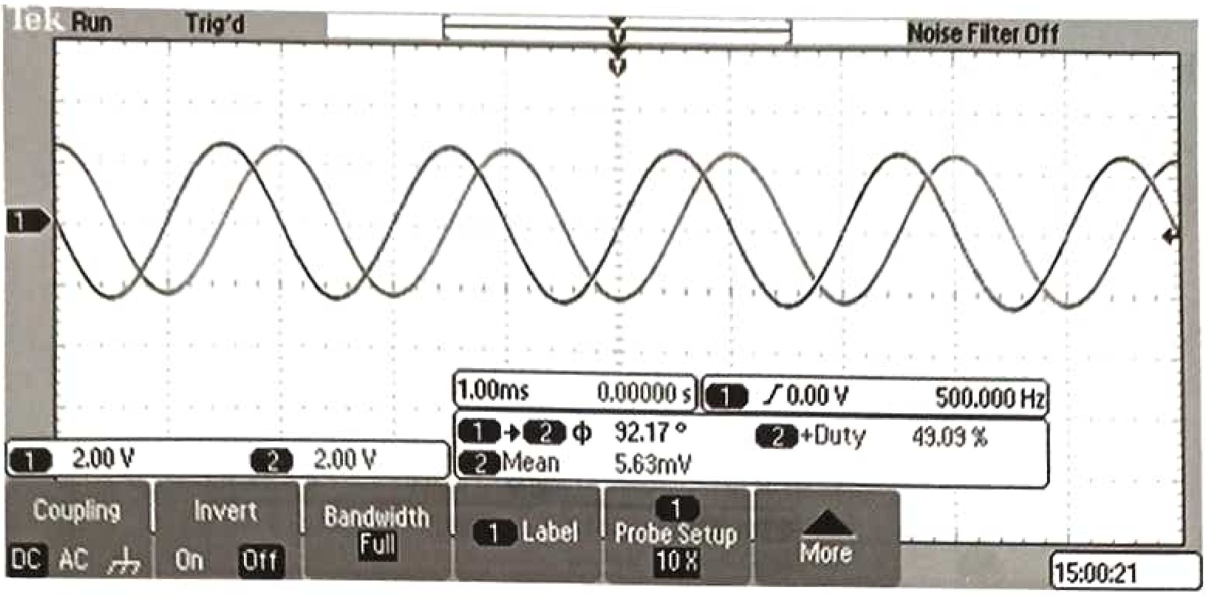
Phase shift = 30°



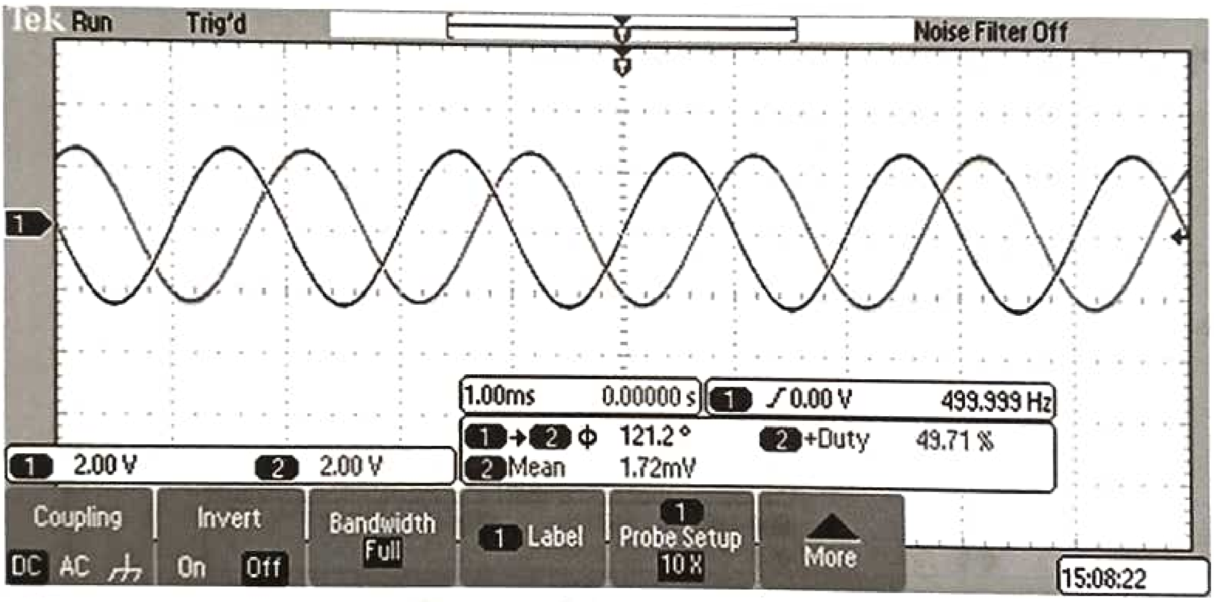
Phase shift = 60°



Phase shift = 90°



Phase shift = 120°



Phase shift = 150°