CSE-251 - Electronic Devices and Circuits Lab

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Group: 4

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Group No: 4

Experiment-02

Study of Op-Amp: Introduction to Op-Amp, Comparator Circuits, Non-Inverting Amplifier, Inverting Amplifier & Inverting Summing Amplifier

CSE251 - Electronic Devices and Circuits Lab

Objective

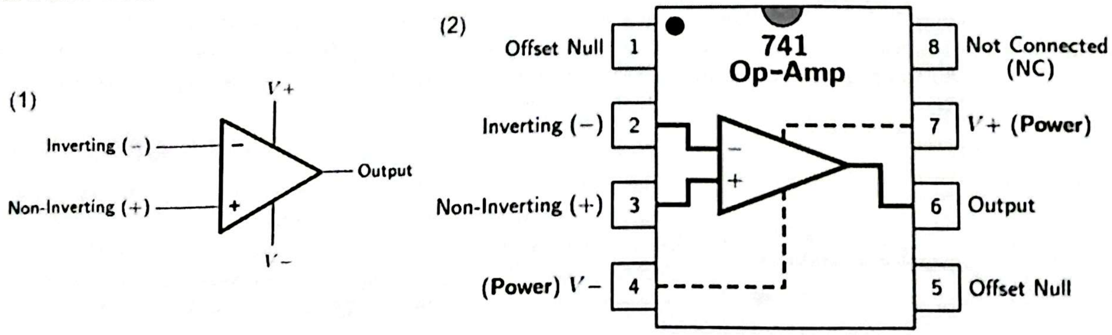
1. To understand the basic principles and characteristics of an Operational Amplifier (Op-Amp)
2. To understand Operational Amplifier (Op-Amp) as a Comparator and investigate its use
3. To investigate the use of Operational Amplifier (Op-Amp) as Non-Inverting Amplifier, Inverting Amplifier and Inverting Summing Amplifier

Equipment

1. Op-Amp (uA741)
2. Resistance ($1k\Omega$, $2.7k\Omega$, $10k\Omega$)
3. DC Power Supply
4. Function Generator
5. Digital Multimeter
6. Trainer Board, Breadboard, Chords and Wires

Background Theory

Introduction

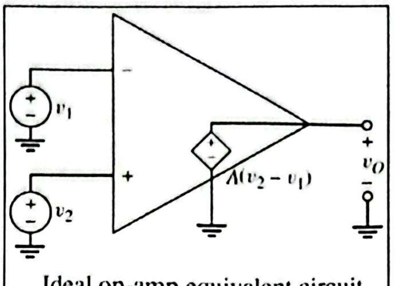


(1) Op-Amp Simplified Circuit Symbol (2) Op-Amp IC Pin Diagram

One of the most widely used electronic devices in linear applications is the Operational Amplifier, commonly known as the Op-Amp. An Op-Amp is an integrated circuit that amplifies the difference between two input voltages and produces a single output. We can also do various mathematical operations like addition, subtraction, multiplication, integration, differentiation etc. with the help of Op-Amp. With the addition of suitable external components, Op-Amp can be used for a variety of applications. The figure above shows the simplified circuit symbol of an Op-Amp. There are 2 terminals for input, 1 terminal for output and 2 terminals for powering up the Op-Amp. Inverting, Non-Inverting are the input terminals and V_S^+, V_S^- are the terminals used for powering up the Op-Amp. V_S^+ is referred to as 'Positive Supply Voltage' and V_S^- is referred to as 'Negative Supply Voltage'. The IC pin diagram of an Op-Amp is also shown where all of the terminals are labeled. Op-Amp is biased with dc supply voltages, although those connections are seldom explicitly shown.

Ideal Op-Amp

The ideal Op-Amp senses the difference between two input voltages and amplifies the difference to produce an output voltage. The figure shown on the right side represents the equivalent circuit of an ideal Op-Amp and the circuit configuration is known as the open-loop configuration of Op-Amp. The parameter 'A' shown in the equivalent circuit is the open-loop differential voltage gain of the Op-Amp. In an ideal Op-Amp, the open-loop gain 'A' is very large value approaching infinity and there is no current flowing into the the input terminals. But in a real Op-Amp, a small amount of current flows into the input terminals and the open-loop gain ranges from 10^4 to 10^5 or higher. We will analyze the circuits using the ideal Op-Amp throughout this experiment.



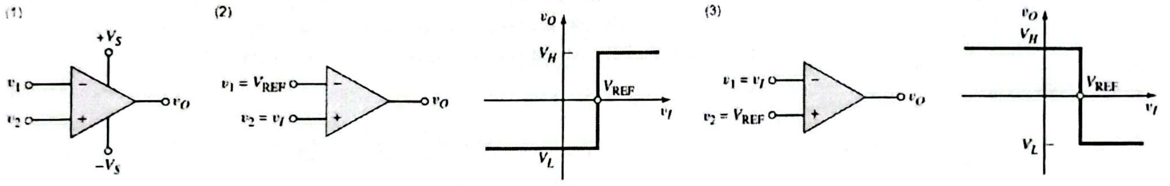
Ideal op-amp equivalent circuit

Practical Considerations

Looking into the equation of the output, $v_O = A(v_2 - v_1)$, one may think that, we can get any voltage at the output of the Op-Amp. But the output voltage is limited since the Op-Amp is composed of transistors biased in the active region by the dc supply voltages V_S^+ and V_S^-. When v_O approaches V_S^+, it will saturate, or be limited to a value almost equal to V_S^+, since it cannot go beyond the positive bias voltage. Similarly, when the output voltage approaches V_S^-, it will saturate at a value almost equal to V_S^-.

Op-Amp Comparator

The comparator is essentially an op-amp operated in an open-loop configuration, as shown below:



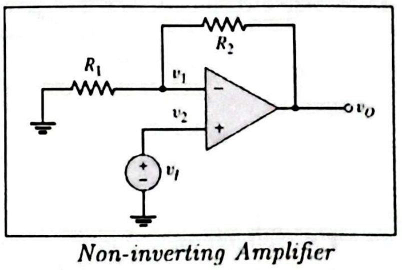
(1) Op-Amp Comparator (2) Non-inverting Circuit (3) Inverting Circuit

A comparator compares two voltages to determine which one is larger. Comparator is usually biased at voltages V_S^+ and V_S^- , although other biases are also possible. When, non-inverting input > inverting input then, $v_O = V_S^+$. When, inverting input > non-inverting input, i.e. $v_1 > v_2$ then, $v_O = V_S^-$. The figures above show two comparator configurations along with their voltage transfer characteristics to illustrate the behaviour of a comparator with V_{REF} as reference voltage which can be controlled to get the desired output.

Non-Inverting Amplifier

The amplifier circuit of an op-amp that does not invert the input voltage at the output is called the non-inverting amplifier. This circuit amplifies the input voltage, v_I according to the gain which can be controlled by the resistances R_1 and R_2. The following equation shows the relation between the input and output of a non-inverting amplifier:

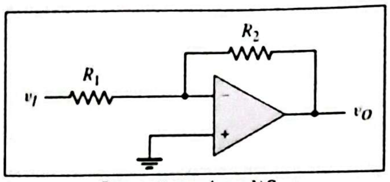
$$v_O = (1 + \frac{R_2}{R_1}) \times v_I; \texttt{ where, gain = } (1 + \frac{R_2}{R_1})$$



Non-inverting Amplifier

Inverting Amplifier

Inverting amplifier configuration of an op-amp is one of the most widely used op-amp circuits. It amplifies the input voltage, v_I according to the gain which can be controlled by the resistances R_1 and R_2. The input voltage gets inverted at the output, hence the name inverting amplifier. The following equation shows the relation between the input and output of an inverting amplifier:

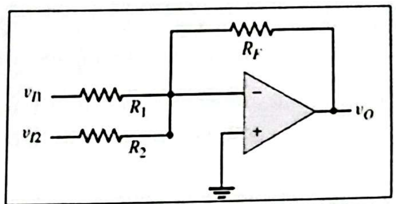


Inverting Amplifier

$$v_O = -(\frac{R_2}{R_1}) \times v_I; \texttt{ where, gain = } -\frac{R_2}{R_1}$$

Inverting Summing Amplifier

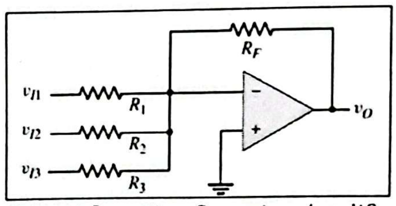
The figure shows the circuit configuration of an op-amp known as inverting summing amplifier that does the job of weighted summation. The input voltages are added according to their weight and gets inverted at the output. The weight of each input voltage during the summing operation can be controlled by the resistances R_1, R_2 and R_F. The following equation shows the relation between input and output of the circuit:



Inverting Summing Amplifier

$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2}); \quad \texttt{where, gain for } v_{I1} = -\frac{R_F}{R_1}\texttt{, gain for } v_{I2} = -\frac{R_F}{R_2}$$

The inverting summing amplifier circuit has 2 inputs which can be extended to as many inputs as we want and the equation will change accordingly. Let's say, we need to add another input, v_{I3}. The equation will become:

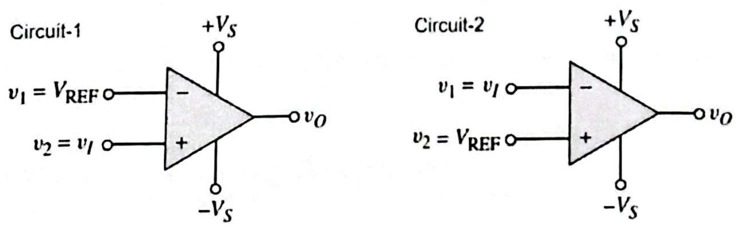


3-input Inverting Summing Amplifier

$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2} + \frac{R_F}{R_3} \times v_{I3})$$

$$\texttt{where, gain for } v_{I1} = -\frac{R_F}{R_1}\texttt{, gain for } v_{I2} = -\frac{R_F}{R_2}$$
$$\texttt{gain for } v_{I3} = -\frac{R_F}{R_3}$$

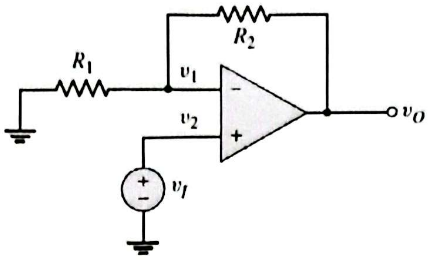
Task-01: Input, Output Waveform of Op-Amp Comparator



Procedure

1. Construct ***Circuit-1*** with $v_I = 2$ V (p-p), 1 kHz sine wave and $V_{REF} = 0.5$ V. Use the trainer board for the supply voltages, $V_S^+ = +8V$ and $V_S^- = -8V$ and **use these supply voltages for the next tasks**.
2. **The ground of the oscilloscope, trainer board and function generator should be connected.**
3. Connect CH1 and CH2 of the oscilloscope to v_I and v_O respectively. Observe the input and output waveform and capture them using a camera.
4. Now, construct ***Circuit-2*** and repeat the experiment with same values given above. Observe the input and output waveform and capture them using a camera.

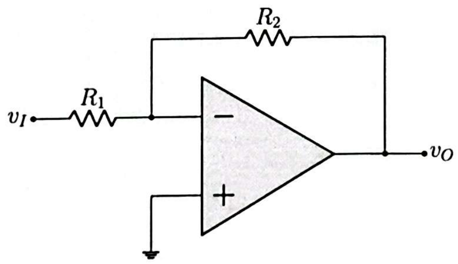
Task-02: Non-Inverting Amplifier



Procedure

1. Construct the circuit with v_I = 2 V (p-p), 1 kHz sine wave. Use $R_1 = 1$ kΩ, $R_2 = 2.7$ kΩ. Use the supply voltages, $V_S^+ = +8V$ and $V_S^- = -8V$ and **use these supply voltages for the next tasks**.
2. Connect the CH1 and CH2 of the Oscilloscope to v_I and v_O respectively. Use the ***Scale*** knob to make sure that the scales of CH1 and CH2 are the same. Observe the input and output waveform and capture them using a camera.
3. Use the ***Measure*** button to get necessary data for the 'Data Sheet' attached at the end of the lab sheet. Capture the measurements of CH1 and CH2 using a camera.

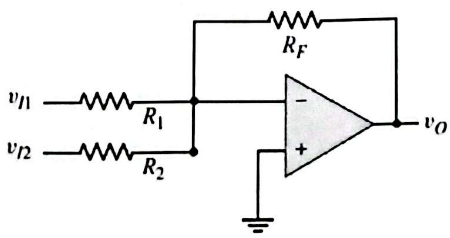
Task-03: Inverting Amplifier



Procedure

1. Construct the circuit with v_I = 2 V (p-p), 1 kHz sine wave. Use $R_1 = 1$ kΩ, $R_2 = 2.7$ kΩ.
2. Connect the CH1 and CH2 of the Oscilloscope to v_I and v_O respectively. Use the ***Scale*** knob to make sure that the scales of CH1 and CH2 are the same. Observe the input and output waveform and capture them using a camera.
3. Use the ***Measure*** button to get necessary data for the 'Data Sheet'. Capture the measurements of CH1 and CH2 using a camera.

Task-04: Inverting Summing Amplifier



Procedure

1. Construct the circuit using the CH1 and CH2 of the DC Power Supply for $v_{I1} = 1$ V and $v_{I2} = 2$ V respectively.
2. Use $R_1 = 10$ kΩ, $R_2 = 10$ kΩ and $R_F = 10$ kΩ.
3. Use the digital multimeter to measure the output voltage v_O to get necessary data for the 'Data Sheet'.

Task-05: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission] ✓
2. Attach the signed Data Sheet. ✓
3. Attach the captured photos of all the waveforms you have observed in the oscilloscope. ✓
4. Answer the questions of the Test Your Understanding section.
5. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
   - What did you learn from this experiment?
   - What challenges did you face and how did you overcome the challenges? (if any)
   - What mistakes did you make and how did you correct the mistakes? (if any)
   - How will this experiment help you in future experiments of this course?

Data Sheet

For Task-02:

Value of R_1 using multimeter = 0.997
Value of R_2 using multimeter = 2.641
Input Amplitude from Oscilloscope (use the **Measure** button), $v_I = \frac{Pk-Pk}{2} = \frac{2.20}{2} = 1.10$
Output Amplitude from Oscilloscope (use the **Measure** button), $v_O = \frac{Pk-Pk}{2} = \frac{7.92}{2} = 3.96$
Output Amplitude from equation, $v_O = (1 + \frac{R_2}{R_1}) \times v_I = \left(1 + \frac{2.641}{0.997}\right) = 3.648$

For Task-03:

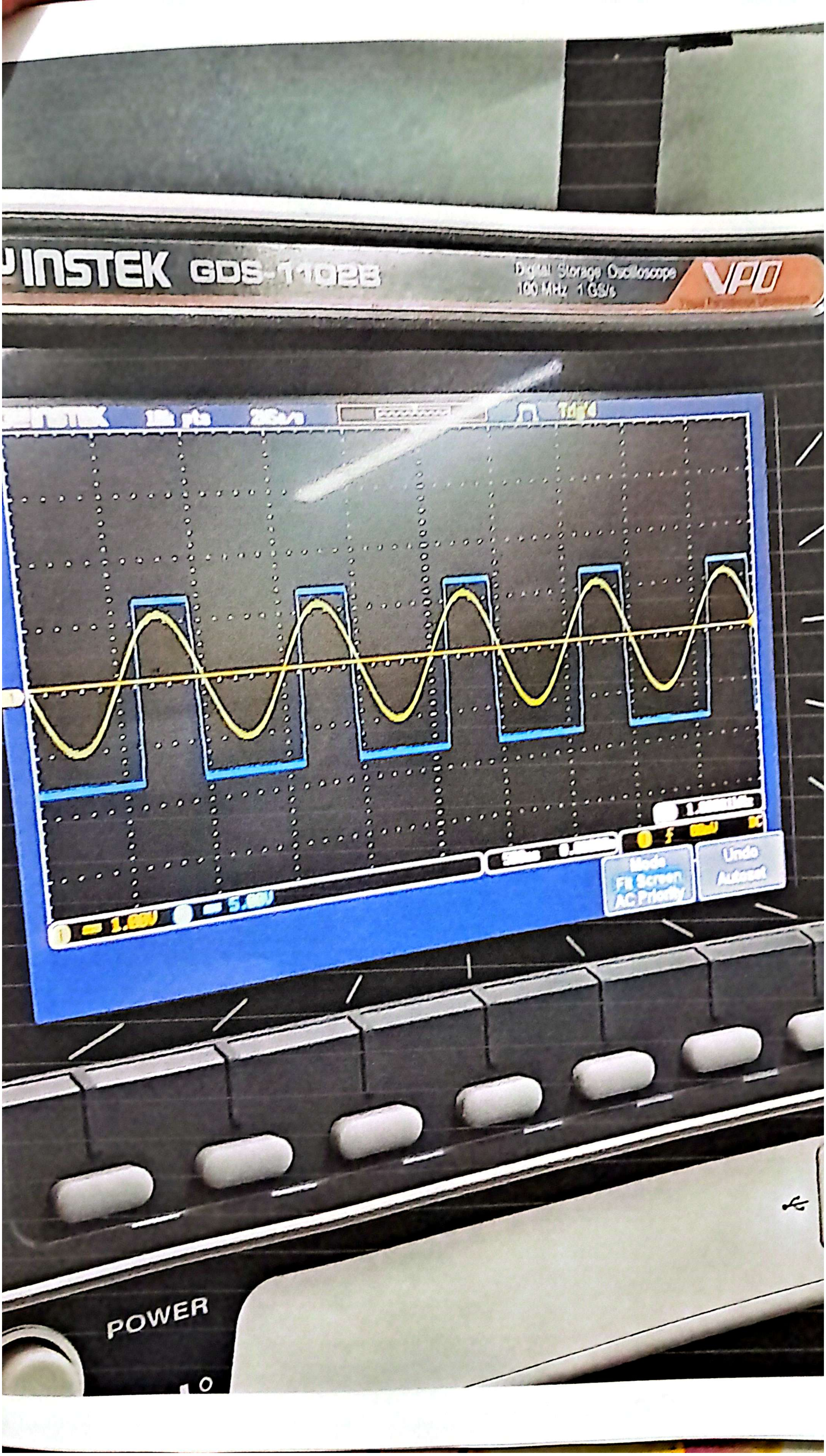
Value of R_1 using multimeter = 0.997
Value of R_2 using multimeter = 2.641
Input Amplitude from Oscilloscope (use the **Measure** button), $v_I = \frac{Pk-Pk}{2} = \frac{2.16}{2} = 1.08$
Output Amplitude from Oscilloscope (use the **Measure** button), $v_O = \frac{Pk-Pk}{2} = \frac{5.44}{2} = 2.72$
Output Amplitude from equation, $v_O = -(\frac{R_2}{R_1}) \times v_I = -2.648$

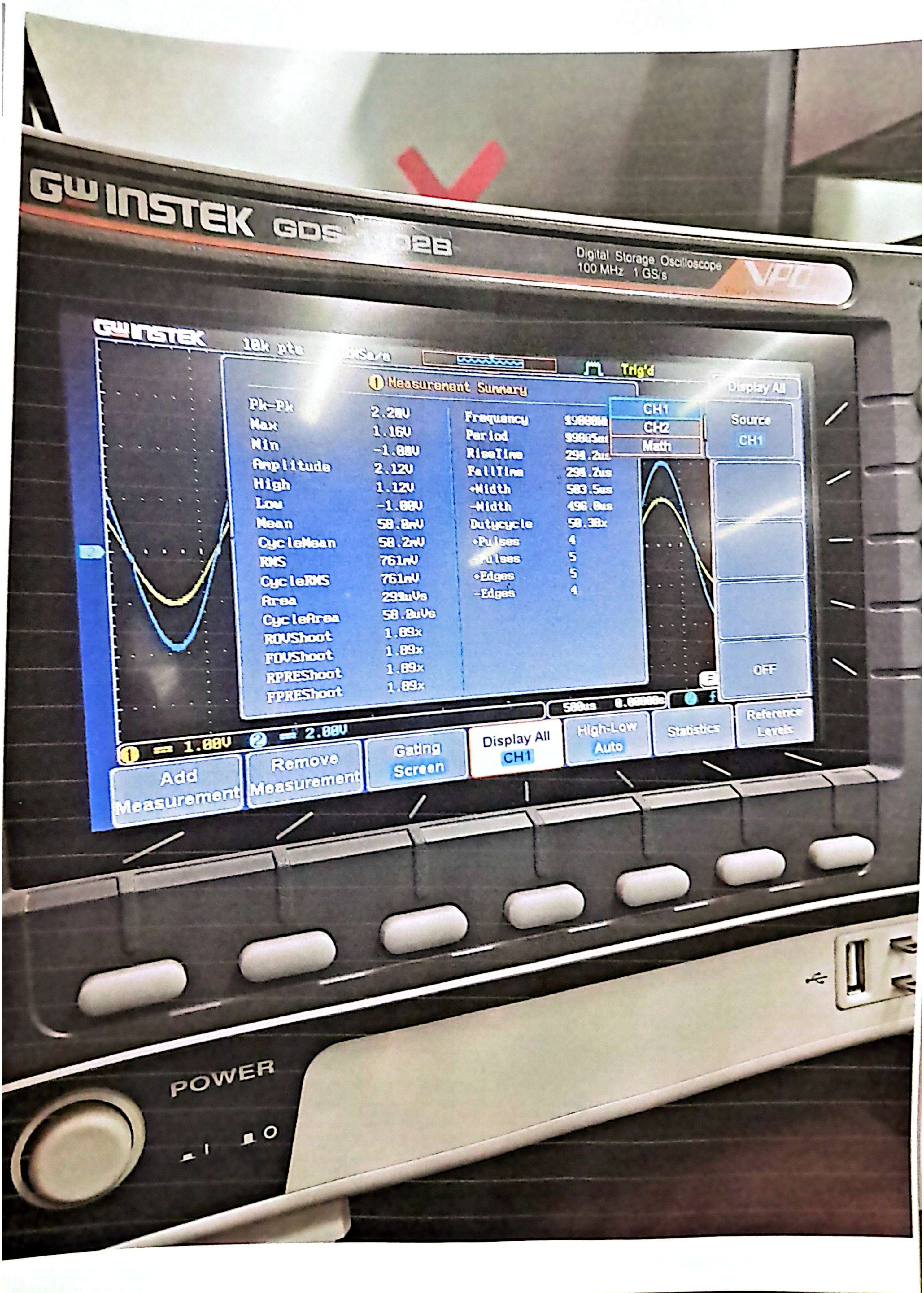
For Task-04:

Value of R_1 using multimeter = 9.93
Value of R_2 using multimeter = 9.95
Value of R_F using multimeter = 9.90
from multimeter, v_{I1} = 0.997
from multimeter, v_{I2} = 2.02
Output Amplitude from multimeter, v_O = −3.1
Output Amplitude from equation, $v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2}) = -\left\{\frac{9.90}{9.93} \times 0.997 + \frac{9.90}{9.95} \times 2.022\right.$

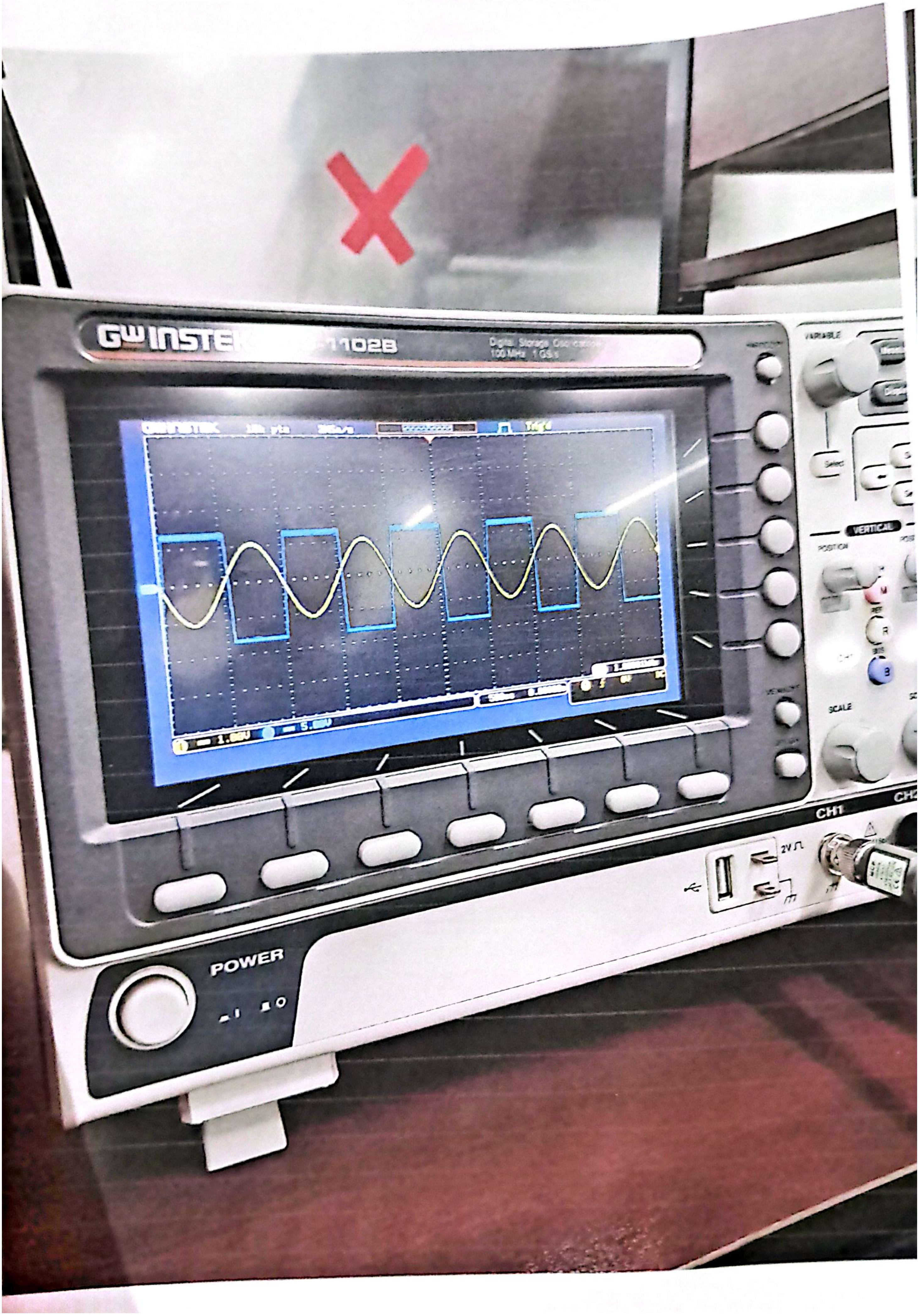
$= -3.00$

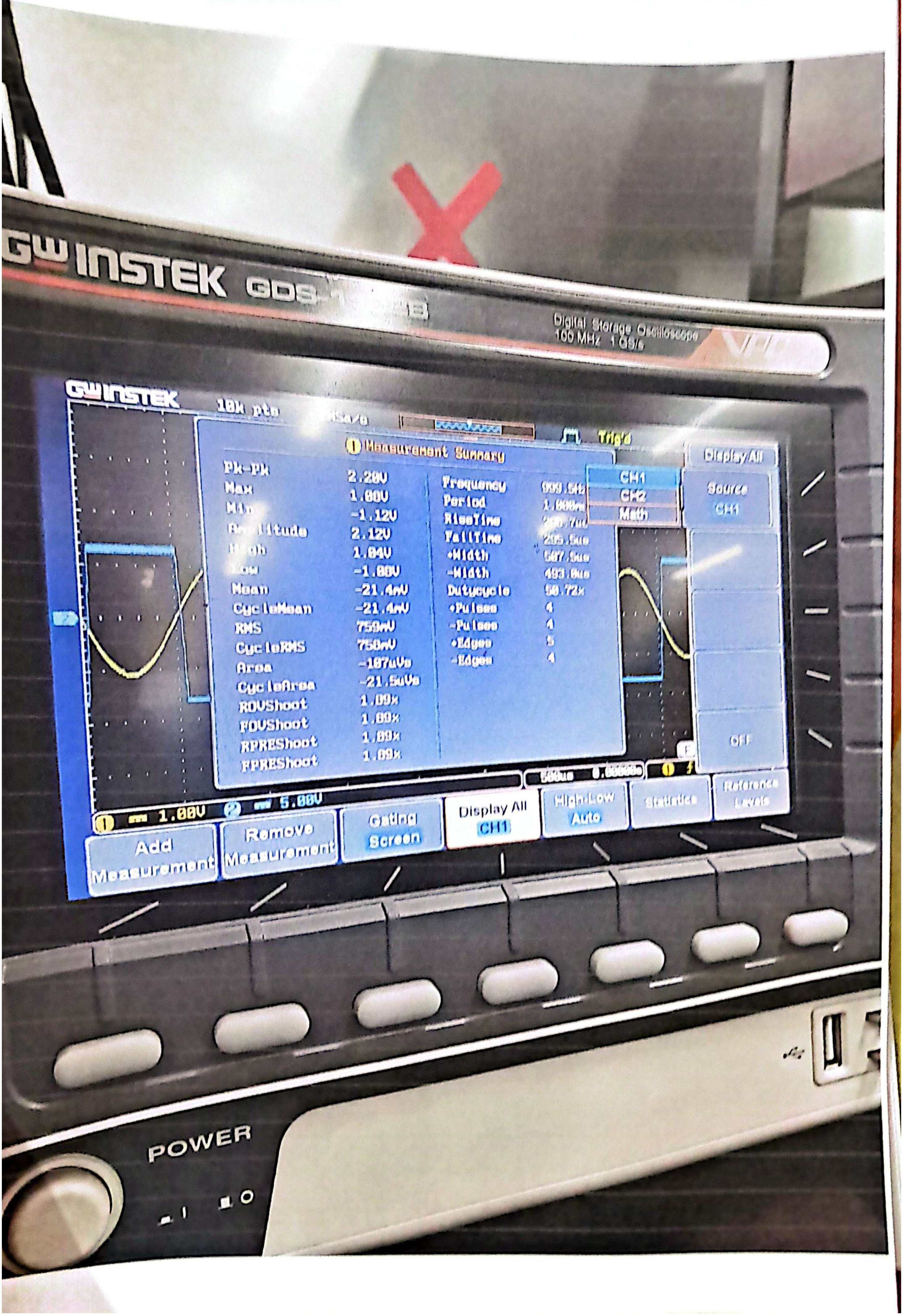
Signature of the lab faculty


INSTEK
GDS-1102B
Digital Storage Oscilloscope
100 MHz 1 GS/s
1.00V
5.00V
Mode
Fit Screen
AC Priority
Undo
Autoset
POWER


GW INSTEK
Digital Storage Oscilloscope
100 MHz 1 GS/s
10k pts
Trig'd
Measurement Summary
Pk-Pk 2.20V
Max 1.16V
Min -1.08V
Amplitude 2.12V
High 1.12V
Low -1.00V
Mean 58.8mV
CycleMean 58.2mV
RMS 761mV
CycleRMS 761mV
Area 293uVs
CycleArea 58.8uVs
ROVShoot 1.89%
FOVShoot 1.89%
RPREShoot 1.89%
FPREShoot 1.89%
Frequency
Period
RiseTime 298.2us
FallTime 298.7us
+Width 503.5us
-Width 496.0us
Dutycycle 50.38%
+Pulses 4
-Pulses 5
+Edges 5
-Edges 4
CH1
CH2
Math
Display All
Source
CH1
OFF
500us
1.00V
2.00V
Add Measurement
Remove Measurement
Gating Screen
Display All CH1
High-Low Auto
Statistics
Reference Levels
POWER

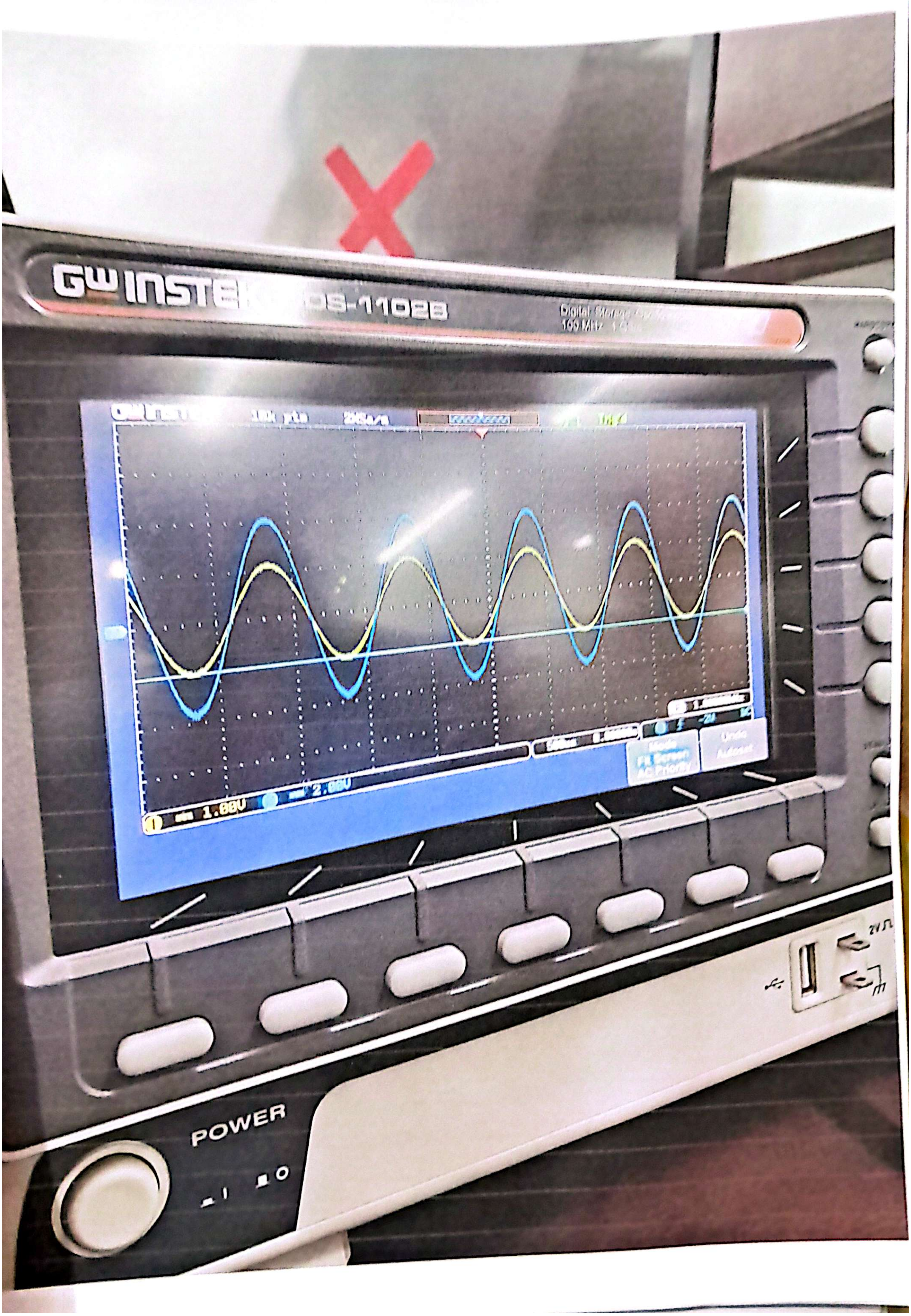

EK GDS-1102B
Digital Storage Oscilloscope
100 MHz 1 GSa/s
10k pts
2MSa/s
Trig'd
Measurement Summary
Pk-Pk 15.6V
Max 7.80V
Min -8.80V
Amplitude 14.6V
High 6.60V
Low -8.00V
Mean -2.91V
CycleMean -2.91V
RMS 7.36V
CycleRMS 7.36V
Area -14.5mVs
CycleArea -2.91mVs
ROVShoot 0.00%
FOVShoot 0.00%
RPREShoot 0.00%
FPREShoot 2.74%
Frequency 1.000k
Period 999.5us
RiseTime 23.27us
FallTime 25.35us
+Width 347.0us
-Width 652.5us
Dutycycle 34.72%
+Pulses 5
-Pulses 4
+Edges 5
-Edges 5
CH1
CH2
Math
Display All
Source
CH2
OFF
500us 0.00000s
5.00V
Remove Measurement
Gating Screen
Display All CH2
High-Low Auto
Statistics
Reference Levels

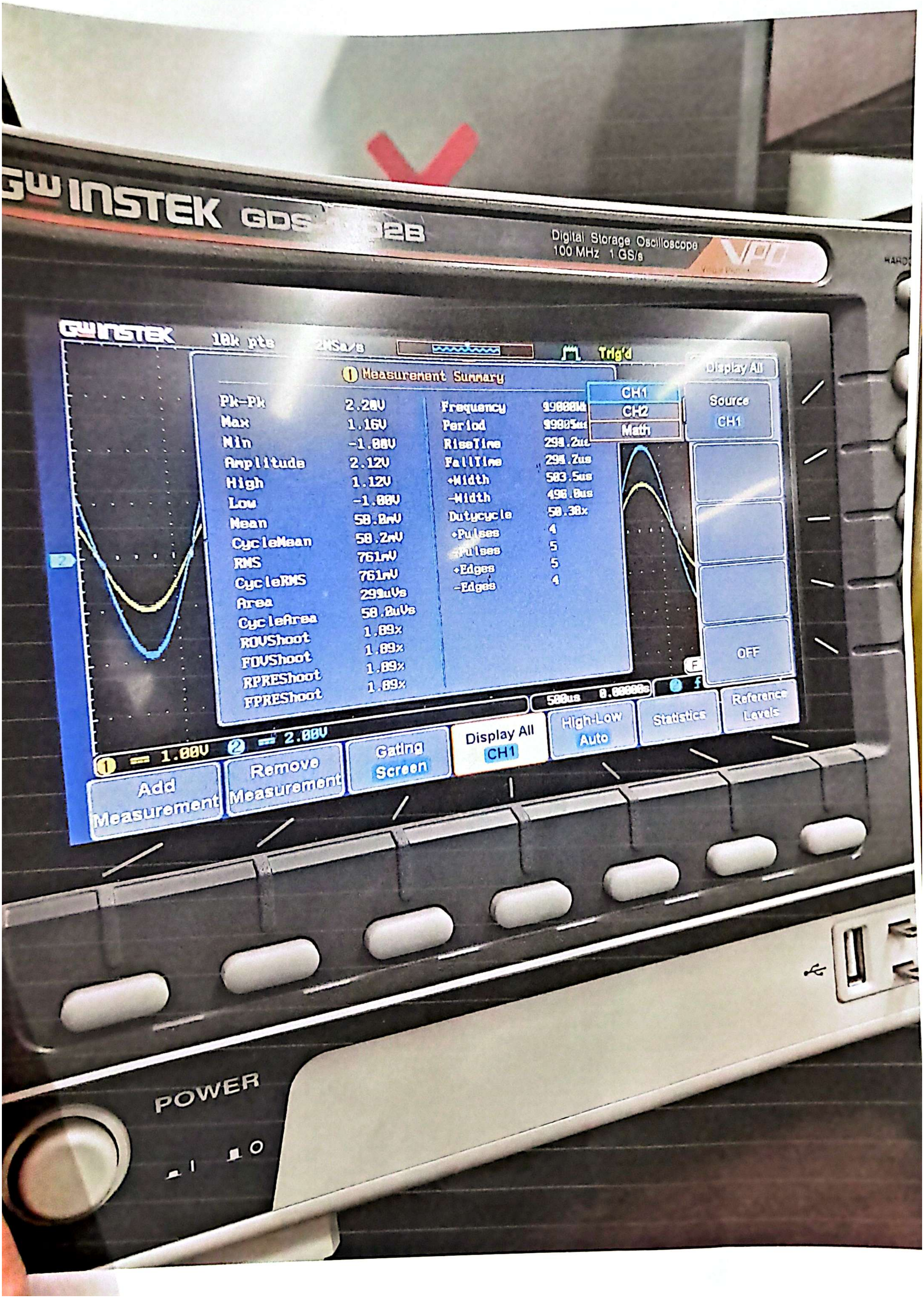

GW INSTEK
POWER
CH1
CH2
VERTICAL
SCALE
VARIABLE

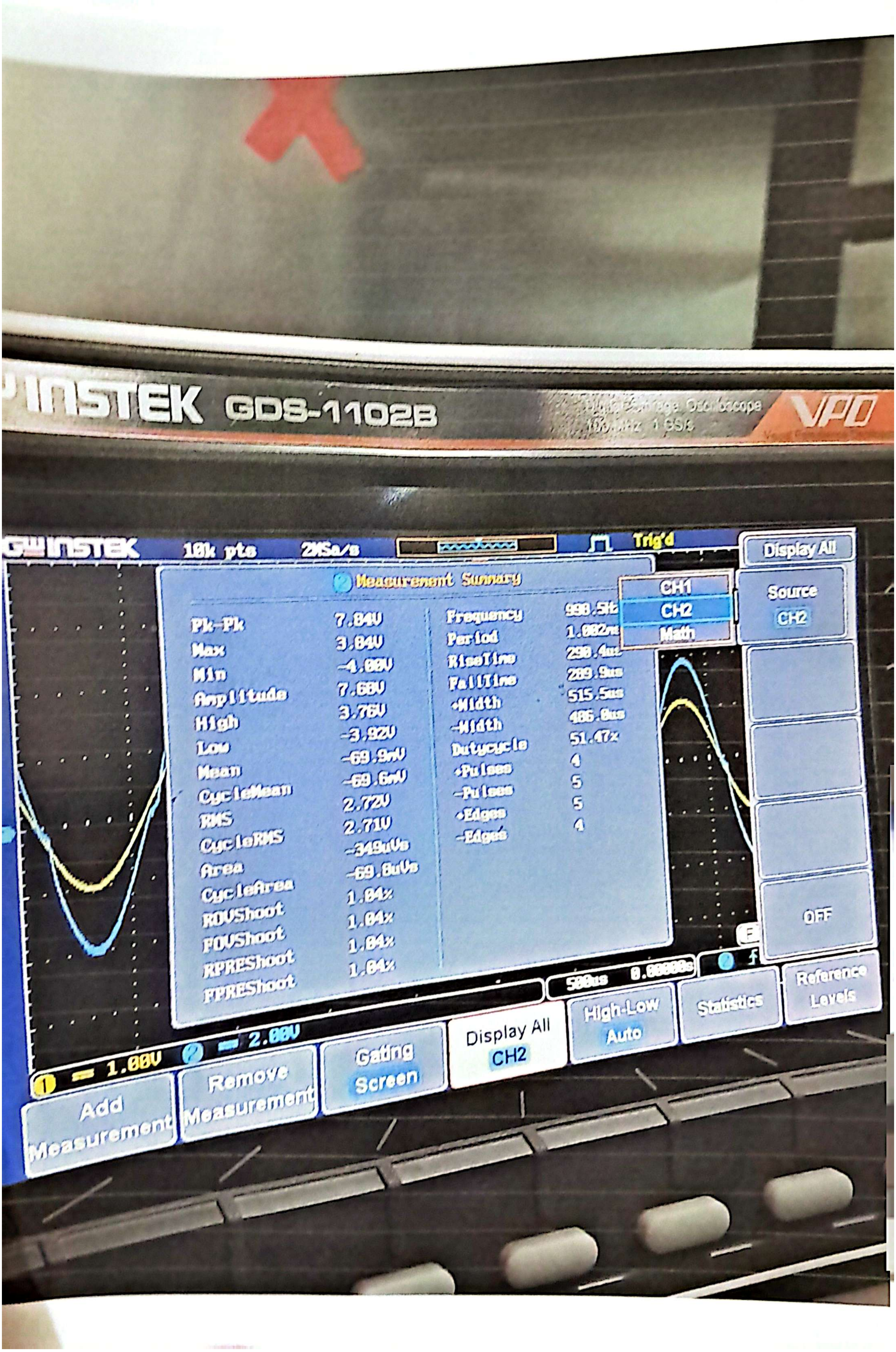


GW INSTEK
Digital Storage Oscilloscope
100 MHz 1 GS/s
10k pts
Trig'd
Measurement Summary
Pk-Pk 2.20V
Max 1.08V
Min -1.12V
High 1.04V
Low -1.08V
Mean -21.4mV
CycleMean -21.4mV
RMS 750mV
CycleRMS 750mV
Area -107uVs
CycleArea -21.5uVs
ROVShoot 1.09%
FOVShoot 1.09%
RPREShoot 1.09%
FPREShoot 1.09%
Frequency
Period
RiseTime
FallTime
+Width
-Width
Dutycycle 50.72%
+Pulses 4
-Pulses 4
+Edges 5
-Edges 4
CH1
CH2
Math
Display All
Source CH1
OFF
1.00V
5.00V
Add Measurement
Remove Measurement
Gating Screen
Display All CH1
High-Low Auto
Statistics
Reference Levels
POWER

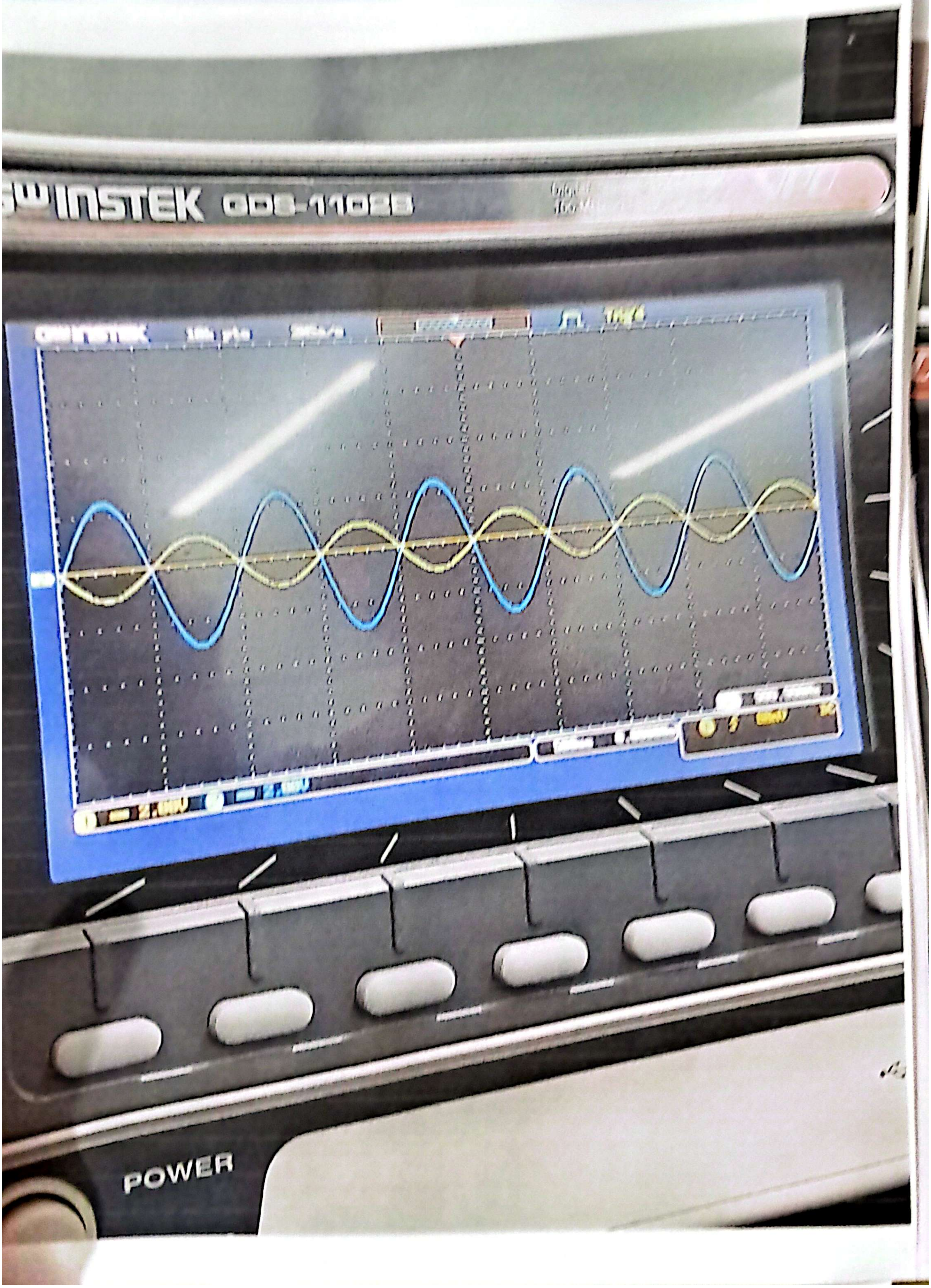
GW INSTEK
Digital Storage Oscilloscope
100 MHz 1 GS/s
Trig'd
Measurement Summary
Max 6.68V
Amplitude 14.6V
High 6.68V
RMS 7.13V
Frequency
Period
RiseTime 22.85us
FallTime 25.35us
+Width 509.5us
-Width 490.5us
Dutycycle 50.95%
+Pulses 5
-Pulses 4
+Edges 5
-Edges 5
CH1
CH2
Math
Display All
Source
CH2
OFF
Add Measurement
Remove Measurement
Gating Screen
Display All
CH2
High-Low Auto
Statistics
Reference Levels
500us
POWER


GW INSTEK
DS-1102B
Digital Storage Oscilloscope
100 MHz
1.00V
2.00V
POWER


GW INSTEK
Digital Storage Oscilloscope
100 MHz 1 GS/s
10k pts
Trig'd
Measurement Summary
Pk-Pk 2.20V
Max 1.16V
Min -1.08V
Amplitude 2.12V
High 1.12V
Low -1.00V
Mean 58.8mV
CycleMean 58.2mV
RMS 761mV
CycleRMS 761mV
Area
CycleArea 58.2uVs
ROVShoot 1.89%
FOVShoot 1.89%
RPREShoot 1.89%
FPREShoot 1.89%
Frequency
Period
RiseTime
FallTime
+Width 503.5us
-Width 496.8us
Dutycycle 50.38%
+Pulses 4
-Pulses 5
+Edges 5
-Edges 4
CH1
CH2
Math
Display All
Source CH1
OFF
Reference Levels
Statistics
High-Low Auto
Display All CH1
Gating Screen
Remove Measurement
Add Measurement
1.00V
2.00V
500us
POWER



INSTEK GDS-1102B
GW INSTEK
10k pts
2MSa/s
Trig'd
Measurement Summary
Pk-Pk 7.84V
Max 3.84V
Min -4.00V
Amplitude 7.68V
High 3.76V
Low -3.92V
Mean -69.9mV
CycleMean -69.6mV
RMS 2.72V
CycleRMS 2.71V
Area -349uVs
CycleArea -69.8uVs
ROVShoot 1.04%
FOVShoot 1.04%
RPREShoot 1.04%
FPREShoot 1.04%
Frequency 998.5Hz
Period 1.002ms
RiseTime 290.4us
FallTime 289.9us
+Width 515.5us
-Width 486.8us
Dutycycle 51.47%
+Pulses 4
-Pulses 5
+Edges 5
-Edges 4
CH1
CH2
Math
Display All
Source
CH2
OFF
500us 0.0000s
1.00V
2.00V
Add Measurement
Remove Measurement
Gating Screen
Display All CH2
High-Low Auto
Statistics
Reference Levels

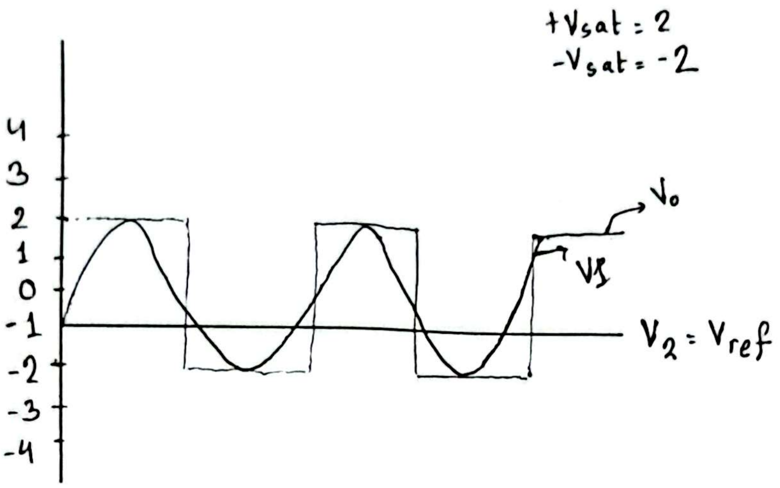

INSTEK GDS-1102B
POWER

Test Your Understanding

Answer the following questions:

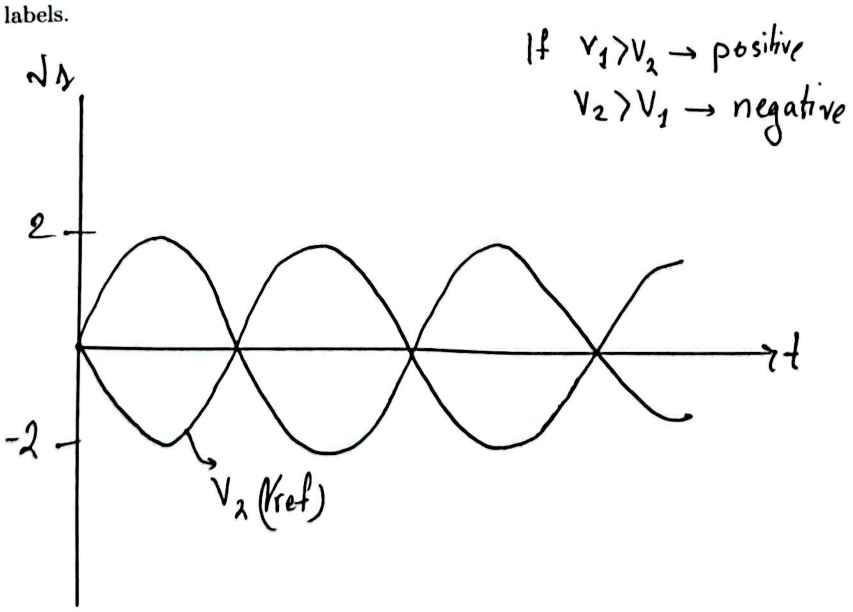
1. You are given an Op-Amp comparator with v_1 = 4 V (p-p) sine wave and $v_2 = V_{REF}$ = -1 V. Draw the waveform of v_1, v_2 and v_O in the same graph with proper labels.

   Answer:



2. You are given an Op-Amp comparator with v_i = 2 sin(t), where the two ends of the input voltage, v_i (sinusoidal source) is connected to v_1 and v_2 of Op-Amp. Draw the waveform of v_{AC} and v_O in the same graph with proper labels.

   Answer:

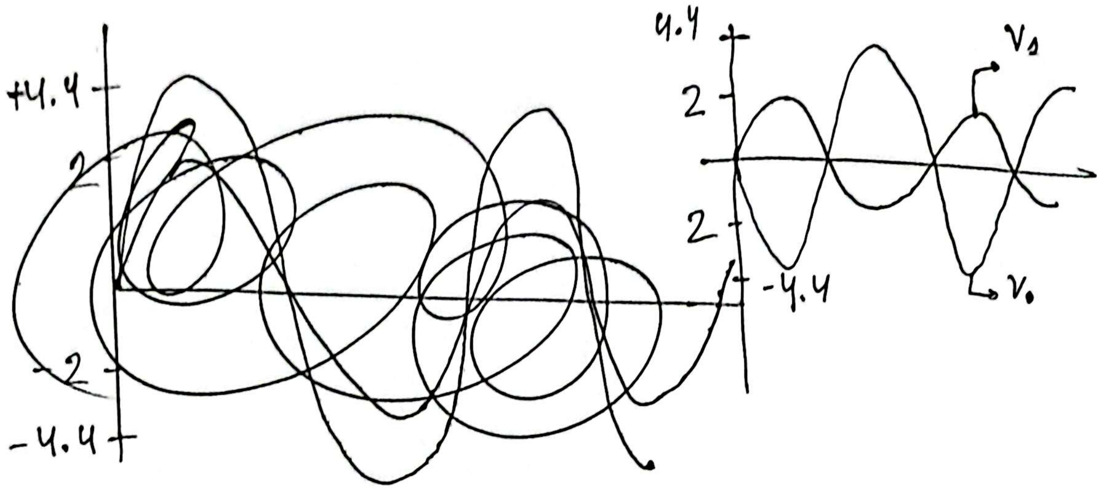


3. You are given an inverting amplifier with $v_I = 4$ V (p-p) sine wave, $R_1 = 1\ k\Omega$, $R_2 = 2.2\ k\Omega$. Draw the waveform of v_I and v_O in the same graph with proper labels.

Answer:

$V_o = \frac{-Rf}{Rf} V_1 = -2.2V_1$ $\quad V_1 = 4V(p-p)$ So, $+V_{sat} = 4.4$

$-V_{sat} = -4.4$

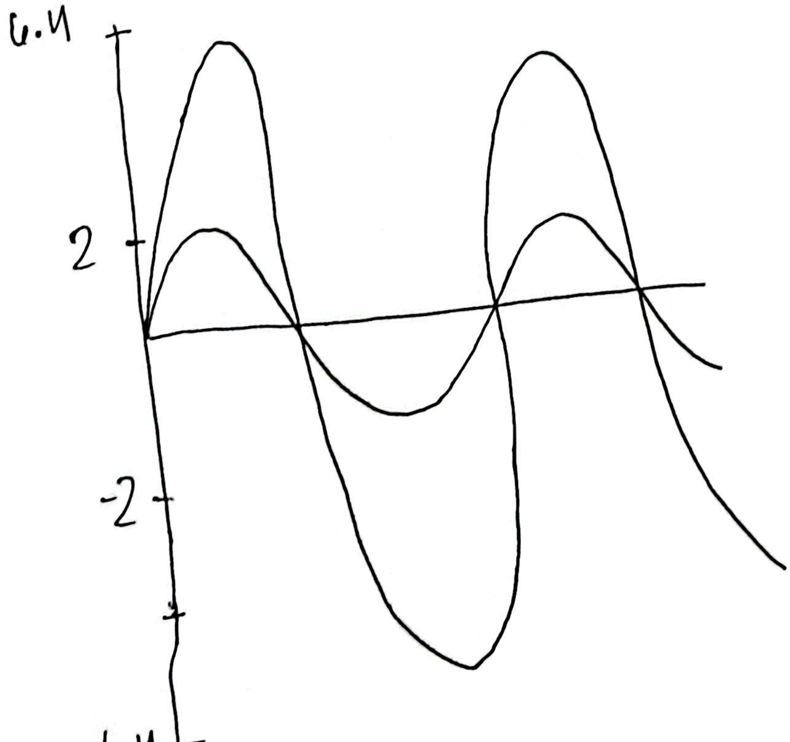


4. You are given a non-inverting amplifier with $v_I = 4$ V (p-p) sine wave, $R_1 = 1\ k\Omega$, $R_2 = 2.2\ k\Omega$. Draw the waveform of v_I and v_O in the same graph with proper labels.

Answer:

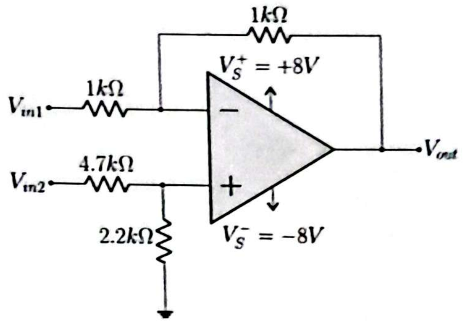
$V_o = \left(1 + \frac{R_2}{R_1}\right)V_1 = 3.2V_1$ $\quad$ So, $+V_{sat} = 6.4$

$-V_{sat} = -6.4$



5. Deduce the value of V_{out} from the circuit below.

[Hints: Consider the current towards the inverting and non-inverting terminals of Op-Amp is zero, and the voltage of the inverting terminal equals the voltage of the non-inverting terminal]



Answer:

Nodal analysis

$$V_{in_1}(1) - V + V_{out}(1) - V = 0$$

$$\Rightarrow \frac{V_{in} + V_{out}}{2} = V \quad \text{———} (i)$$

$$V\left(\frac{1}{4.7} + \frac{1}{2.2}\right) - \frac{V_{in_2}}{4.7} = 0$$

$$\Rightarrow V = \frac{2.2 V_{in2}}{6.9} \quad \text{———} (ii)$$

Since,

$$\frac{V_{in} + V_{out}}{2} = \frac{2.2 V_{in_2}}{6.9}$$

$$\Rightarrow V_{out} = \frac{4.4 V_{in_2} - 6.9 V_{in_1}}{6.9}$$

Discussion:

I learnt how an operational amplifliers (op-amp) works. And ~~[illegible]~~ how it amplifies the difference between two input voltage and produce a ~~sign~~ single output.

We faced some problems with the connections. We had to recheck the connections multiple times because of loose connections.