EXPERIMENT-6,7

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EE22BTECH11025

Problem 1:

Aim:

To measure the impedance (and hence capacitance/inductance) of a R and C/L circuit using a digital oscilloscope (DSO), function generator, and reference resistor.

Material Required:

Breadboard, ref. Resistor(1kΩ,), Capacitor(10nF and 10μF) and Inductor(1mH and 100mH), DSO, Function generator .

Theory:

Impedance is the total opposition to current flow in an alternating current circuit. It is made up of resistance (real) and reactance (imaginary) and is usually represented in complex notation as $Z = R + jX$, where R is the resistance and X is the reactance.

For this experiment we need to calculate the impedance which is achieve by V-I method.
This method is nothing more than calculating the ratio of voltage drop across our DUT and current flowing through it.

$$Z = \frac{V_{A1}.R_{ref}}{V_{A1} - V_{A2}}$$

Note: as there will phase difference between $A_1$and A_2 , $V_{A1} - V_{A2}$ will be a vector sum.

Procedure:

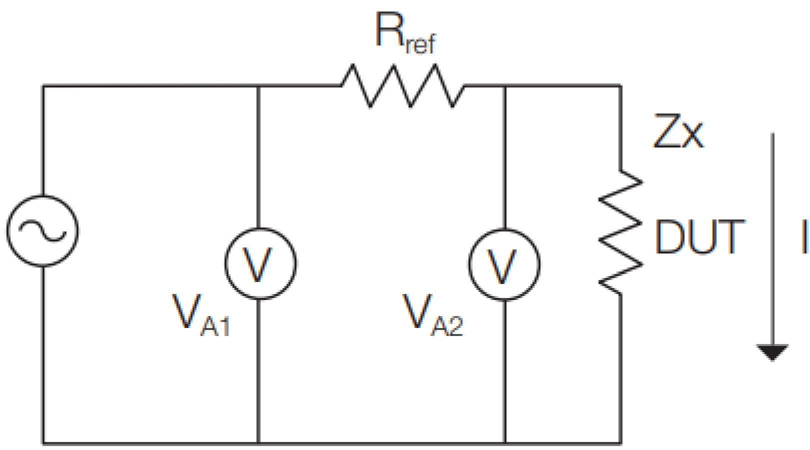


Figure 2. The I-V method test circuit.

We connect the RC/L same as above. We need to record the voltage at nodes A_1 and A_2 across precision resistor and the phase difference between nodes A_1 and A_2. The impedance and angle of impedance is calculated and tabulated.

$$Z = \frac{V_{A1}.R_{ref}}{\sqrt{V^2_{A1} - 2.V_{A1}.V_{A2}cos(\Theta) + V^2_{A2}}}$$

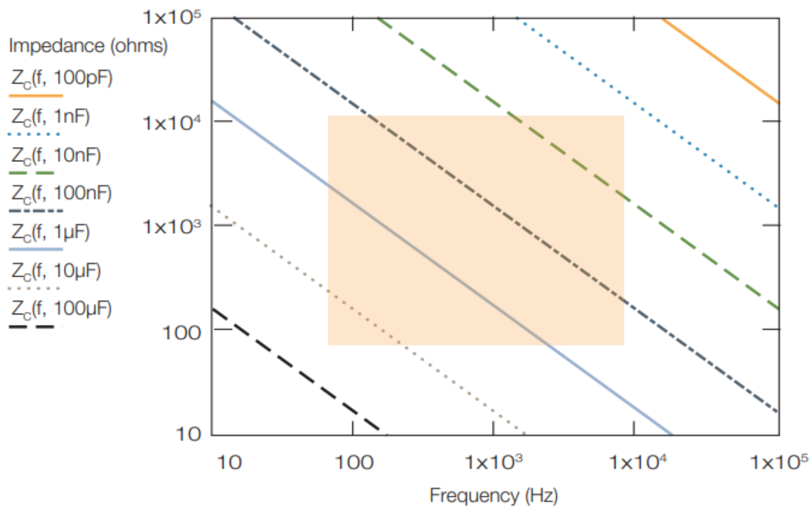
$$\alpha = \Theta - tan\left(\frac{-V_{A2}sin(\Theta)}{V_{A1} - V_{A2}cos(\Theta)}\right)$$

We also need to calculate the capacitance and inductance from Z and α given by,

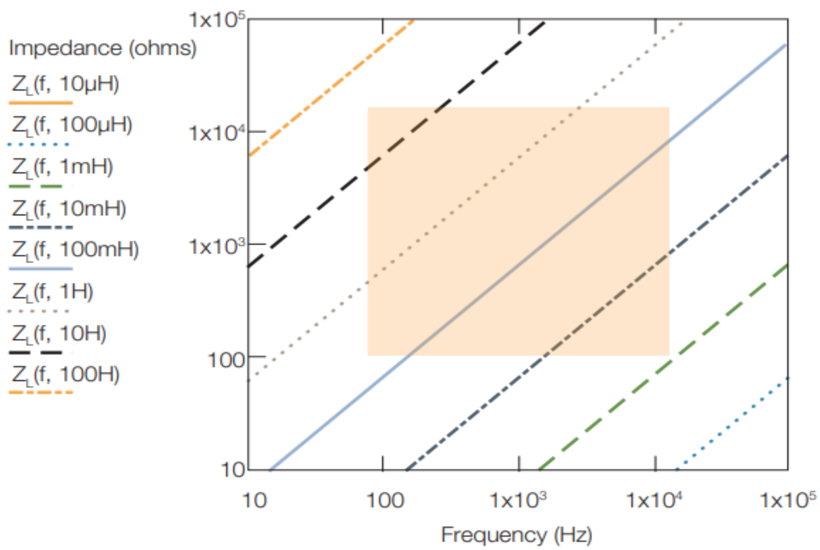
$$C = \frac{-1}{2\pi f Z sin(\alpha)}$$

$$L = \frac{Z sin(\alpha)}{2\pi f}$$

Calibration: The measurement frequency should be chosen such that the impedance of the capacitor or inductor is within the range of the reference resistor.



Impedance (ohms)
Z_C(f, 100pF)
Z_C(f, 1nF)
Z_C(f, 10nF)
Z_C(f, 100nF)
Z_C(f, 1μF)
Z_C(f, 10μF)
Z_C(f, 100μF)
$1x10^5$
$1x10^4$
$1x10^3$
100
10
10
100
$1x10^3$
$1x10^4$
$1x10^5$
Frequency (Hz)



Impedance (ohms)
Z_L(f, 10μH)
Z_L(f, 100μH)
Z_L(f, 1mH)
Z_L(f, 10mH)
Z_L(f, 100mH)
Z_L(f, 1H)
Z_L(f, 10H)
Z_L(f, 100H)
$1x10^5$
$1x10^4$
$1x10^3$
100
10
10
100
$1x10^3$
$1x10^4$
$1x10^5$
Frequency (Hz)

Observations:

- **Capacitance = 10nF measurement**

Frequency	V_{A1}	V_{A2}	Δt	Θ	Z	α	C
3.00E+04	1.92	1.261	-4.60E-06	-8.67E-01	475.047	-1.72E+00	1.13E-08
4.00E+04	1.92E+00	0.86	-2.10E-05	-3.02E+02	332.001	-3.03E+02	1.26E-08
2.50E+04	1.92	1.63	-3.50E-05	-3.15E+02	502.606	-3.16E+02	1.30E-08

Experimental Value of the capacitance from multimeter: 11.9 nF

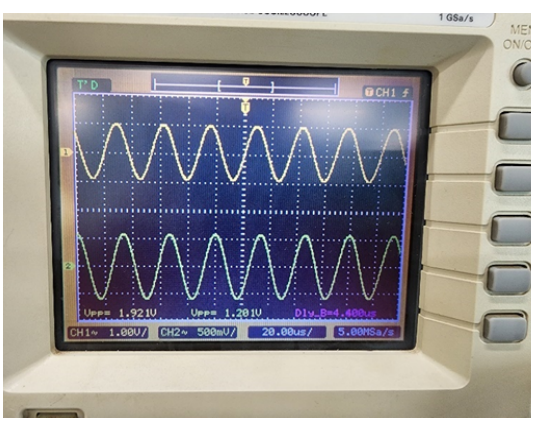
R(ref)=1000 ohms..

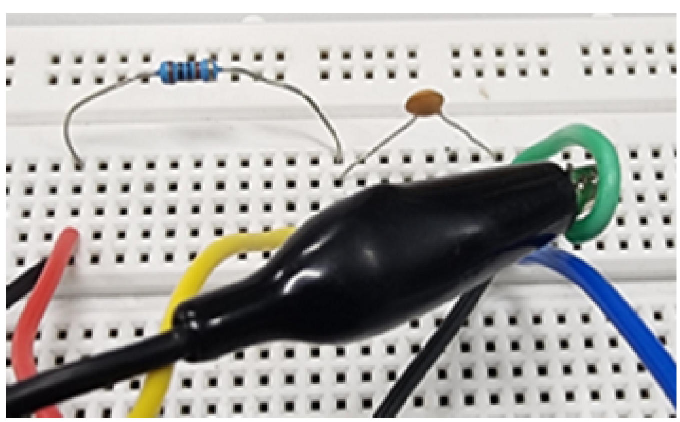
∴ The parameters are

1) $C_{avg} = 12.3nF$

2) Deviation = 0.4nF

3) %Error = 3.36%





f=30Khz

- **Capacitance = 1uF measurement**

Experimental readings:

The Readings are given below:

Frequency	V_{A1}	V_{A2}	**Δt**	**Θ**	**Z**	**α**	**C**
6.00E+02	**1.88**	**0.544**	**-3.40E-04**	**-1.28E+00**	**258.950**	-1.58E+00	**1.02E-06**
8.00E+02	**1.88E+00**	**0.424**	**-9.90E-04**	**-2.84E+02**	**196.441**	-2.84E+02	**1.11E-06**
9.00E+02	**1.84**	**0.372**	**2.45E-04**	**7.94E+01**	**230.243**	7.92E+01	**1.18E-06**

Experimental Value of the capacitance from multimeter: 1.07 uF

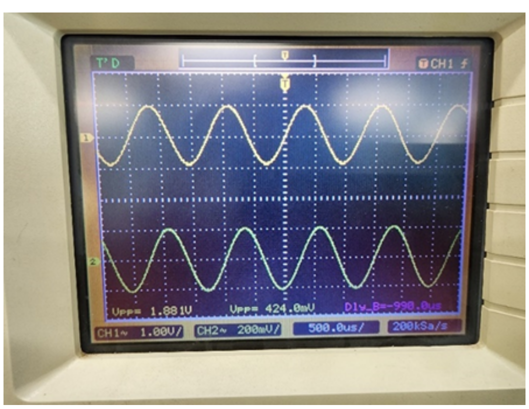
R(ref)=1000 ohms.

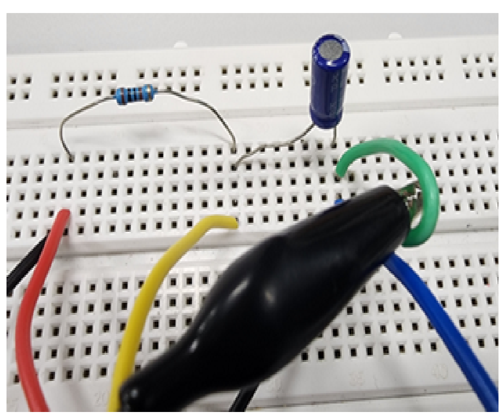
∴ The parameters are

1) $C_{avg} = 1.1nF$

2) Deviation = 0.03nF

3) %Error = 3.1%





f = 800Hz

- **Inductance = 1mH measurement**

<u>Experimental readings:</u>

The Readings are given below:

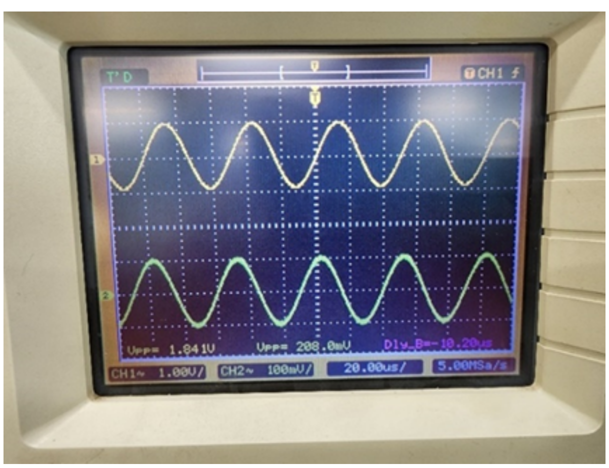
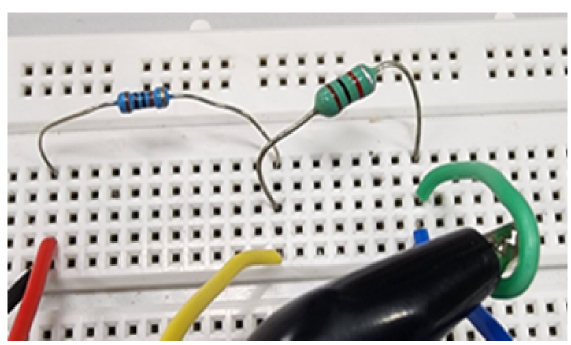
Frequency	V_{A1}	V_{A2}	**Δt**	**Θ**	**Z**	**α**	**L**
1.00E+04	**1.88**	**0.112**	**-2.05E-05**	**-1.29E+00**	**56.457**	**-1.34E+00**	**9.08E-04**
2.00E+04	**1.88E+00**	**0.208**	**-1.06E-05**	**-8.35E+01**	**157.803**	**-8.37E+01**	**1.15E-03**
3.00E+04	**1.92**	**0.388**	**-6.60E-06**	**-7.13E+01**	**223.905**	**-7.14E+01**	**8.74E-04**

Experimental Value of the capacitance from multimeter: 0.98 mH

R(ref)=1000 ohms.

∴ The parameters are

1) $L_{avg} = 0.9733\, mH$
2) Deviation = 0.13 mH
3) %Error = 0.68%

f = 20kHz

- **Inductance = 100mH measurement**

Experimental readings:

The Readings are given below:

Frequency	V_{A1}	V_{A2}	Δt	Θ	Z	α	L
2.00E+02	1.92	2.90E-01	-1.18E-03	-1.48E+00	1.47E+02	-1.63E+00	1.17E-01
3.00E+02	1.92E+00	9.60E-01	2.65E-03	2.86E+02	9.14E+02	2.86E+02	1.01E-01
4.00E+02	1.92	7.00E-01	-3.55E-03	-5.11E+02	4.46E+02	-5.11E+02	1.08E-01

Experimental Value of the capacitance from multimeter: 0.98 mH

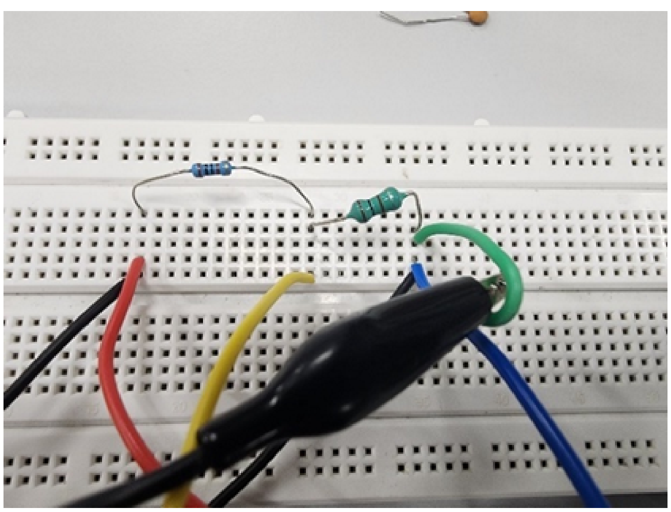
R(ref)=1000 ohms.

∴ The parameters are

1) $L_{avg} = 108\, mH$

2) Deviation = 0.04 mH

3) %Error = 3.57%



Problem 2:

Aim:

To calculate the capacitance and series resistance of a solar cell using small signal analysis

Material Required:

Breadboard, Resistor(1kΩ), solar cell, DSO and function generator.

Theory:

Capacitance of Solar Cells Capacitance of solar cells can be calculated in the same way as we found capacitance or inductance values in the previous step. In this step, the solar cell is the device being tested (DUT). The DUT is kept in a dark environment to ensure precise measurement.

A solar cell acts in a way similar to p-n junction diodes. In the fused region of a solar cell, charge carriers of the opposite charge are present on both sides of the junction. The result of this configuration is known as junction capacitance, also known as capacitance.ts. It is important to note that junction capacitance is very dependent on the applied DC voltage bias of the solar cell.

For this capacitance measurement, we change the bias voltage of the solar cell, and keep the amplitude of input waveform 5- to 10 fold smaller than in the previous experiments. It is also important that the magnitude of the AC voltage and current used in the measurement is much smaller than the DC bias voltage.

Capacitance of a reverse bias junction can be used to determine important parameters of a solar cell, including the doping level and the built in voltage. In the case of a single-sided (high-doped) reverse bias junction, the capacitance can be used to gain important insights into the characteristics and behavior of a solar cell.

$$Cj = \frac{A}{2}\sqrt{\frac{2q\varepsilon_{si}N}{V_{bi}-V}}$$

$$\frac{1}{C_j^2} = \frac{2(V_{bi} - V)}{q\varepsilon_{si} N A^2}$$

Where,

Junction Area (A): To estimate the junction area, you can use the physical area of the silicon (Si) wafer, as the junction usually covers a portion of it.

Permittivity of Silicon (ε): This parameter represents the ability of silicon to store electric charge and affects the capacitance behavior.

Carrier Concentration (N): N signifies the density of charge carriers within the silicon, measured in .

Built-In Potential (): This is the inherent voltage across the solar cell's junction when it's not under any external bias.

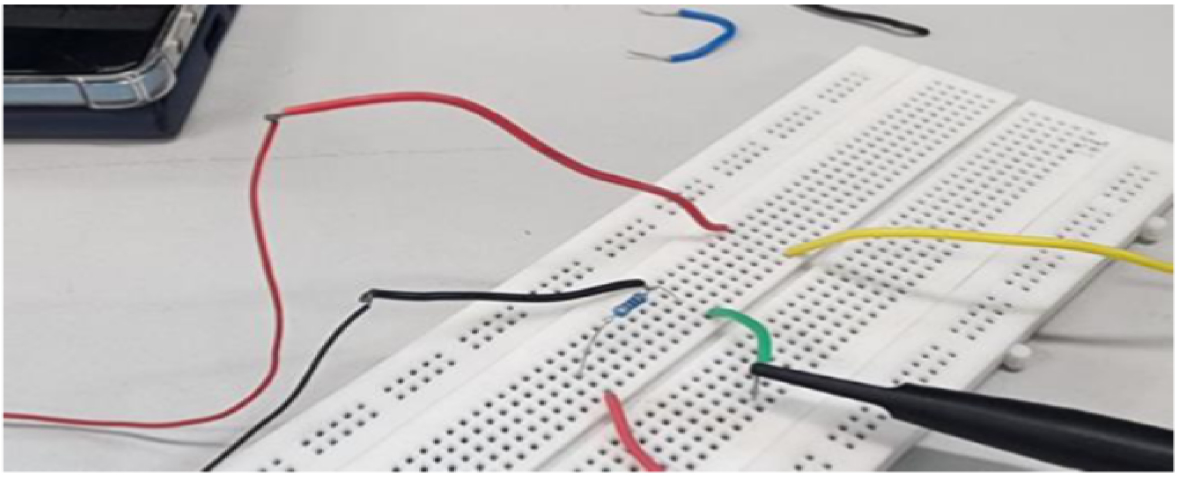
By plotting $\frac{1}{C_j^2}$ against rev. V, you can deduce two critical values:

- **Carrier Concentration (N):** It can be determined from the slope of the plot.
- **Built-In Potential ():** This can be derived from the intercept of the plot.

Note: solar cell must be placed in complete darkness and maintain a low input voltage amplitude of 0.2

Procedure:

1. Determine the capacitance, series resistance, and doping of solar cells.
2. Determine the built in voltage and capacitance of solar cells using reverse bias junction
3. Ploting $\frac{1}{C_j^2}$ vs rev. V , in order to determine N (slope) and V_{bi} (by the intercept)

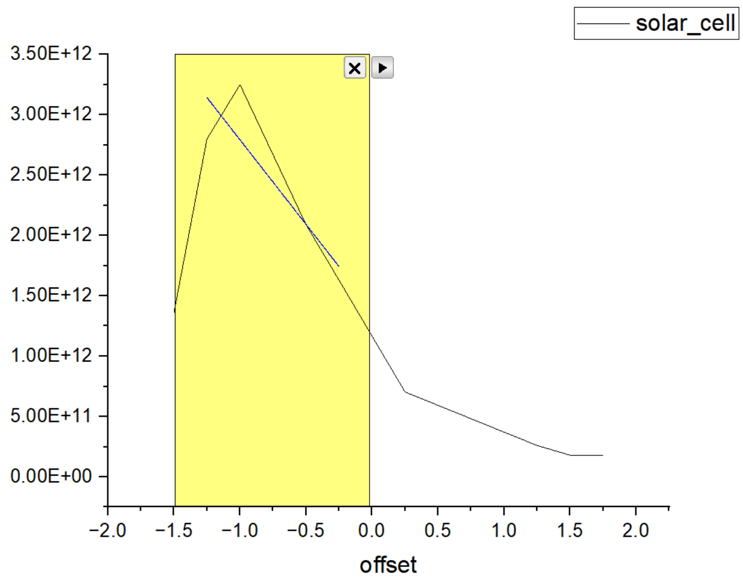


Observations:

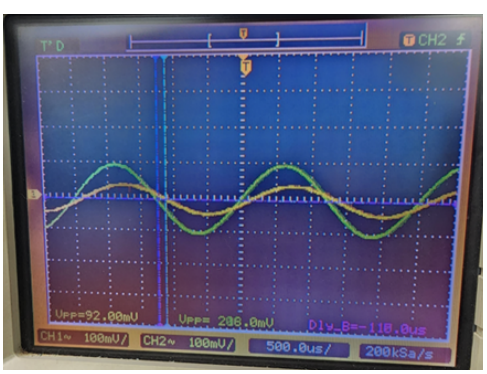
Experimental readings:

offset	1/C^2
-1.9	4.8E12
-1.2	4.78E12
-0.5	3.14E12
0.5	1.19E11
0.8	4.53E10
1.2	4.8E10
1.5	6.27E10
1.8	9.21E10

All readings are taken at 800Hz

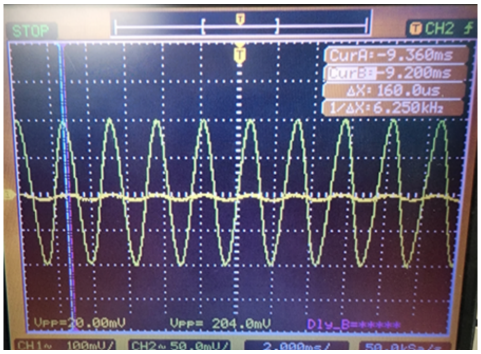


The 1/C2 vs DC bias graph obtained from the following readings is given below

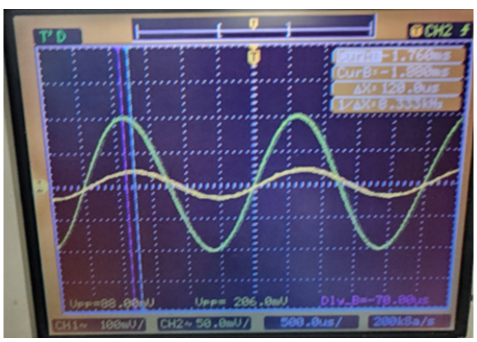


Reverse bias:

$V_{off} = 1.5V$



Forward bias:
$V_{off} = 1.5V$



Reverse bias:
$V_{off} = 1.25V$

- Capacitance of the diode can be found at V-offset voltage = 0, i.e., $C_{cell} \approx 1\ \mu F$

By the above graph we see that, the y-intercept of the slope (c) is 1×10^{12} and the slope of line (m) is -1.667×10^{12}

From the graph we also get the built-in potential, $V_{bi} \approx$ 0.6V

Aim:

$$N = \frac{2C_j^2}{A^2 q \varepsilon_{si}} (V_{bi} - V)$$

$A = 2.5 \times 5 = 12.5\, cm^2 = 12.5 \times 10^{-4}\, m^2$

$q = 1.6 \times 10^{-19} C$

$\varepsilon_{si} = 11.7 \times 8.85 \times 10^{-12}$

Upon further inputting the values of A, , V = 0, q and We will get the value approximately equal to the slope of the graph drawn at x=0

$$N \approx 4.635 \times 10^{22}/m^3$$

Problem 3:

Aim:

To Measure C-V and estimate doping in any other diode or pn junction available in the lab.

Material Required:

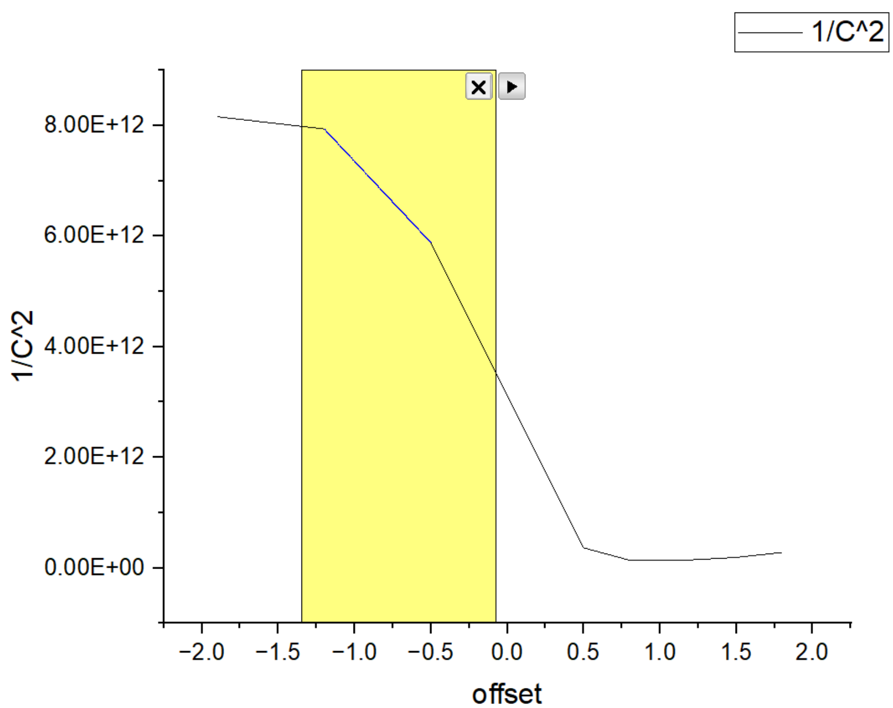
Breadboard, Resistor(1kΩ),diode(IN4007), Oscilloscope and function generator

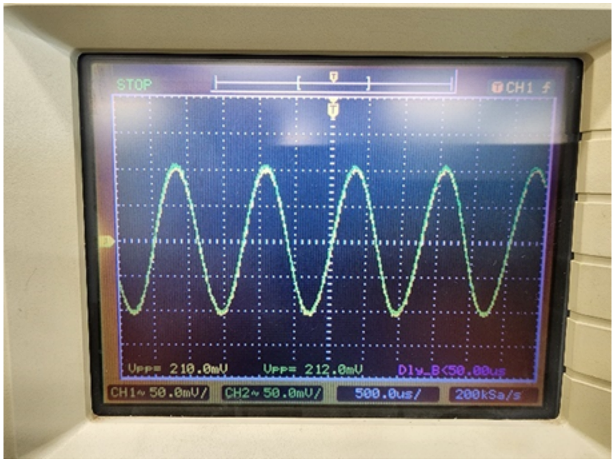
Procedure:

We do the procedure as in task-2 ,but with a diode (IN4007) instead of a solar cell.

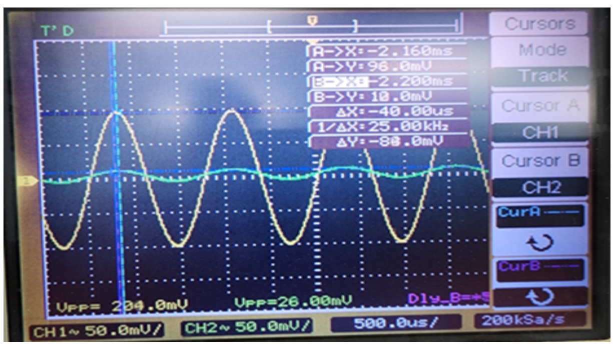
Observations:

offset	1/C^2	Resistance
		diode
-1.9	8.16E12	486.94592
-1.2	7.94E12	495.06658
-0.5	5.88E12	503.8244
0.5	3.66E11	333.36862
0.8	1.42E11	648.14387
1.2	1.5E11	577.95974
1.5	1.95E11	444.17382
1.8	2.85E11	471.09245





Reverse bias:
$V_{off} = 1.9V$



Forward bias:
$V_{off} = 1.2V$

Capacitance of the diode can be found at V-offset voltage = 0, i.e., $C_{cell} \approx 0.559\ \mu F$

By the above graph we see that, the y-intercept of slope (c) is 3.2×10^{13}

and the slope of line (m) is -5.33×10^{12}

From the graph we also get the built-in potential, $V_{bi} \approx$ 0.6V

$$N = \frac{2C_j^2}{A^2 q \varepsilon_{si}} (V_{bi} - V)$$

$A = 4.9 \times 10^{-10}\, m^2$

$q = 1.6 \times 10^{-19} C$

$\varepsilon_{si} = 11.7 \times 8.85 \times 10^{-12}$

Upon further inputting the values of A, , V = 0, q and We will get the value approximately equal to the slope of the graph drawn at x=0

$$N \approx 9.43 \times 10^{34} /m^{3}$$

Conclusion:

In tasks 2 & 3, we learned how to measure solar cell capacitance using small signals. The higher the impedance, the more accurate the capacitance values will be with less variability. It is important to be smart about the signal size / amplitude to get the desired results. Measurement markers should be placed correctly to minimize errors. For better results, keep the AC signal very small compared to the DC signal.