Radiation Effects on Solar Cell

BTP Project 2025

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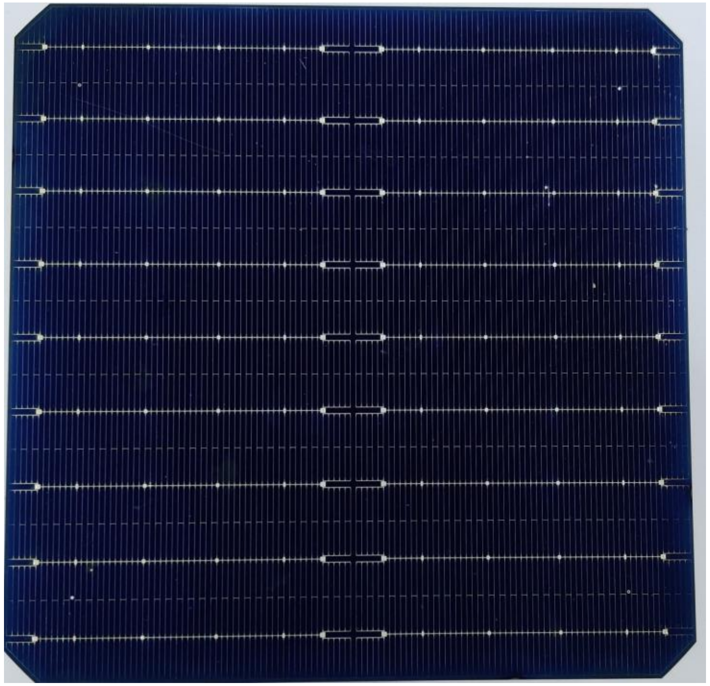
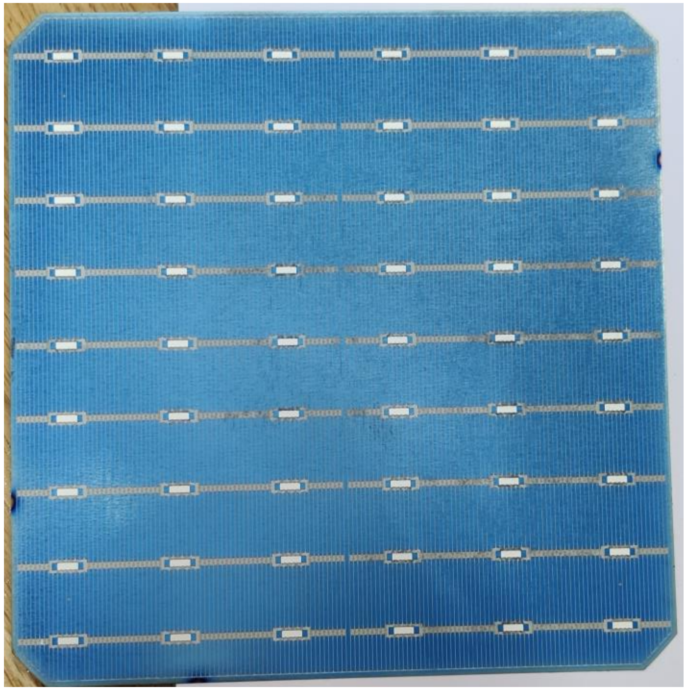
Introduction

Given a PV solar array:

The task is to accurately measure I-V characteristics of the solar array.



Top plate

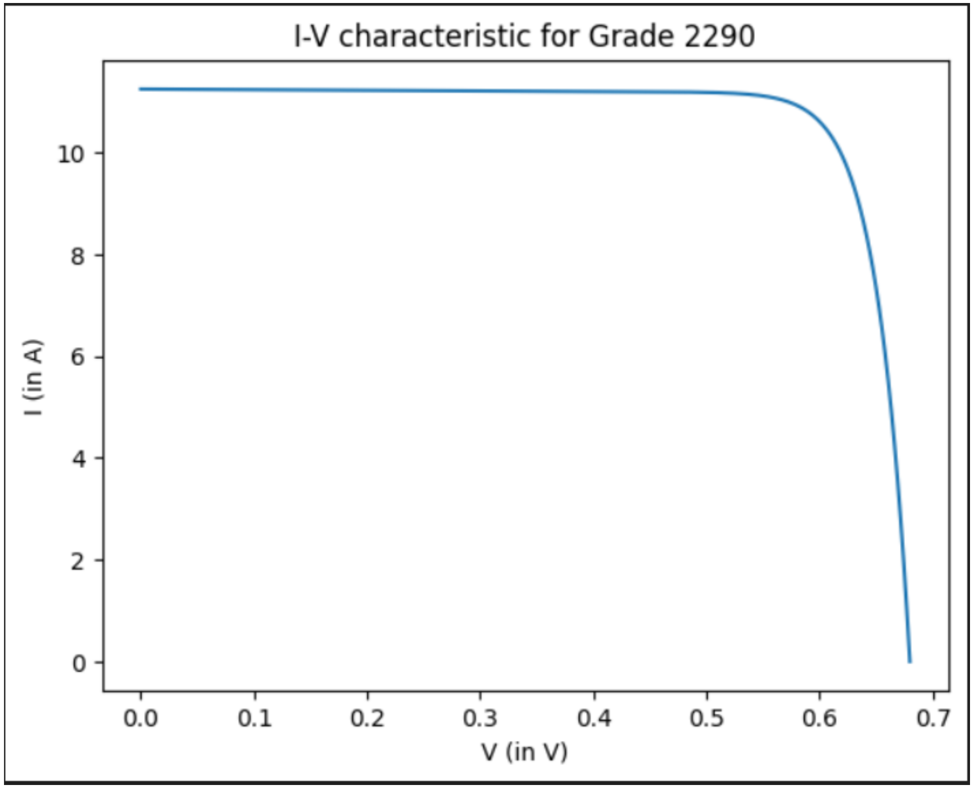


Bottom plate

What problem are we trying to solve?

Given a PV solar array:

The problem is to accurately measure I-V characteristics of the solar array.

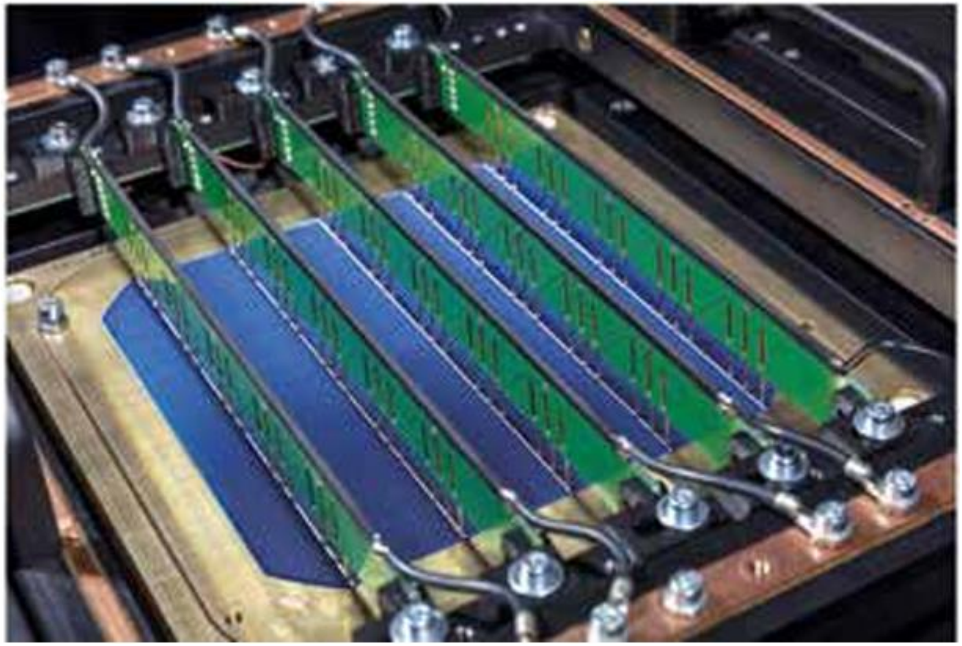


The given plot is the ideal IV characteristics that is required to be captured through the hardware

Hardware Setup

The probing method used at present:

- Top plate has 9 bus bars from which voltage and current probes (pogo pins) are taken.
- The configuration of one bus bar PCB is: 6 Current tabs and 1 Voltage tab.

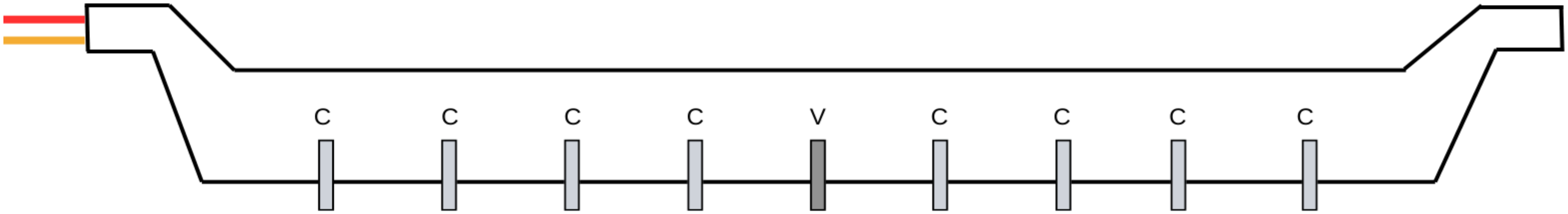


PV solar array with bus bars PCBs [1]

[1] - Bothe, K., & Hinken, D. (2019). Precise and accurate solar cell measurements at ISFH CalTeC. *Photovoltaics International*, 43, 74-81

Probing Setup - Top

The probing method used at present:

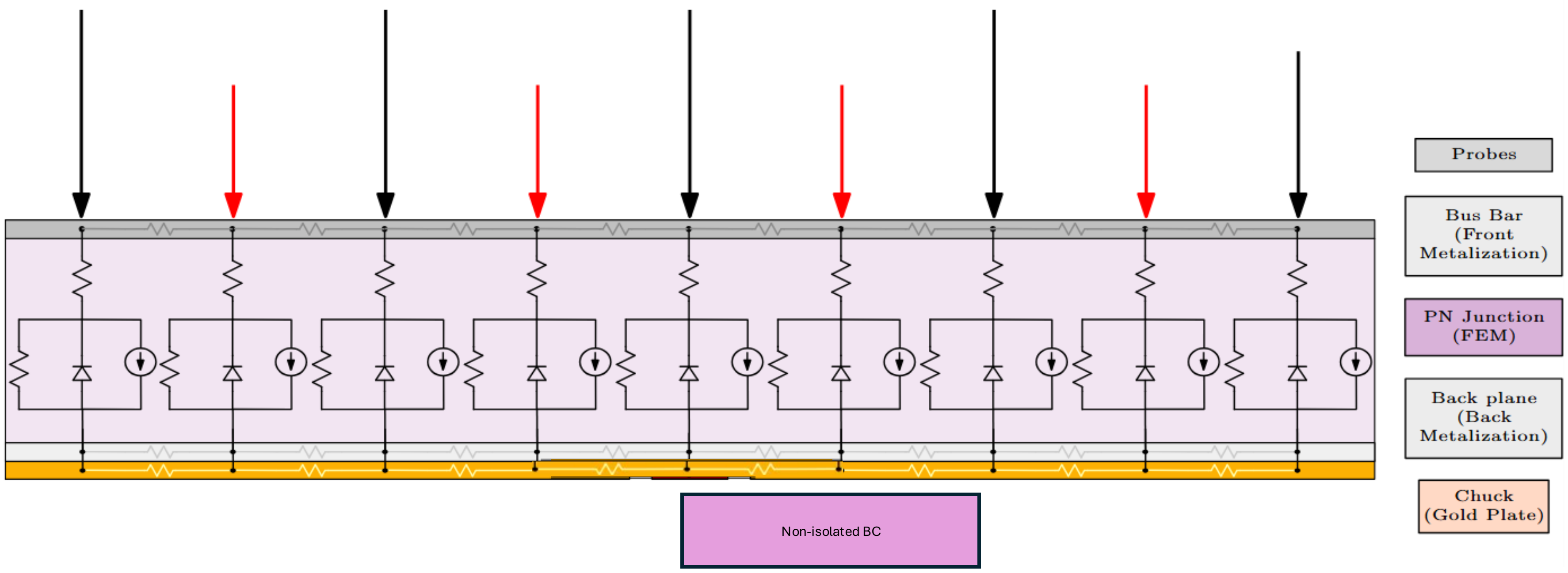


- The probe bar shown above is placed on all bus bars on top plate.
- All the current tabs are shorted and taken out from Yellow wire across all probe bars.
- Voltage tab is taken out from using Red wire and shorted across all probe bars.

Probing Setup - Bottom

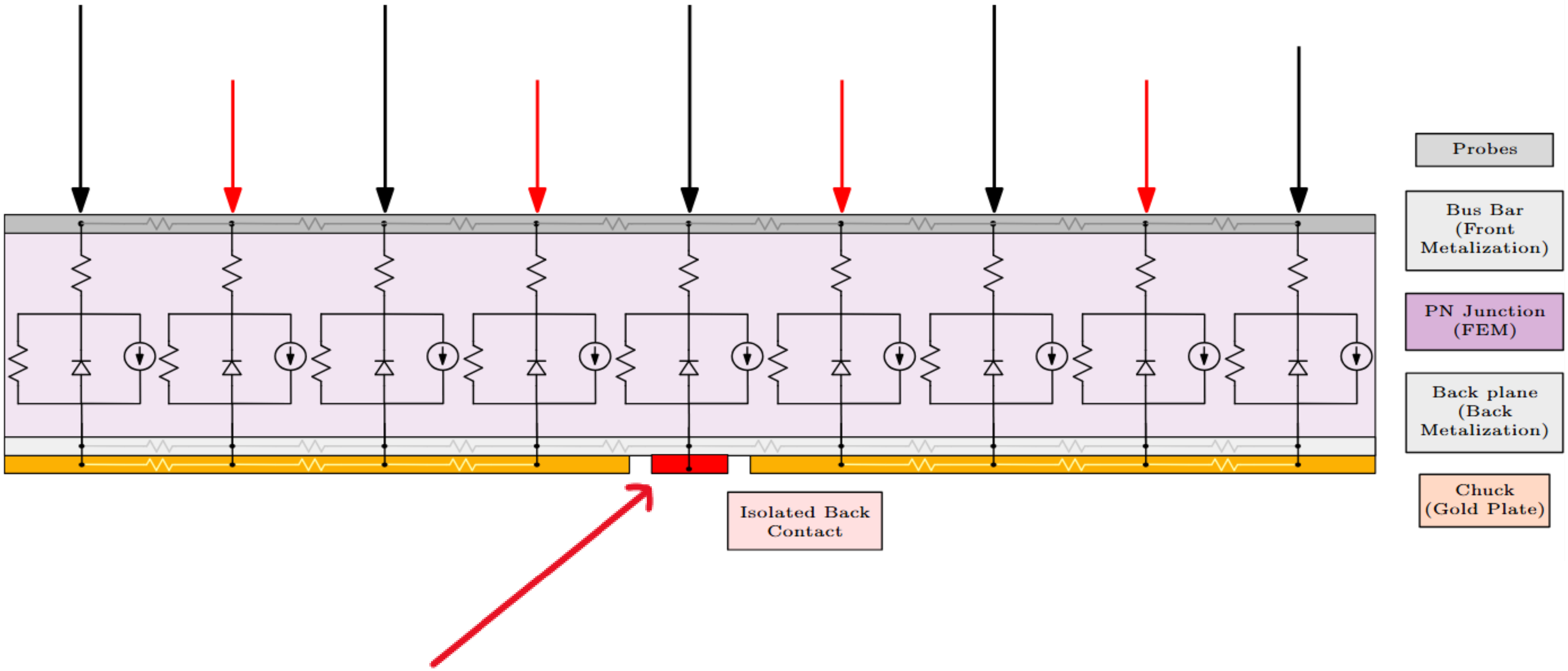
Back Contact configurations:

The comparison has to be made: **With isolated VS Without isolated back contact** to check if the isolated back contact is yielding a better result.



Probing Setup - Bottom

Back Contact configurations:



For isolated back contact the bottom probed directly touches the bottom of solar cell

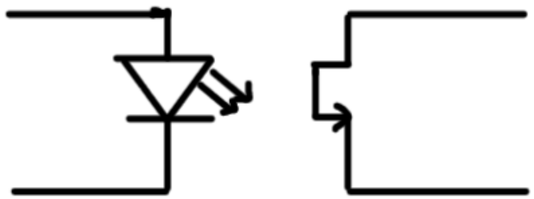
Problem Statement and Approach

The options available are:

1. Make **hardware changes** to yield better IV characteristics
2. Modify **Measurement circuitry**
3. Compare **Isolated and Non-isolated Back contact**

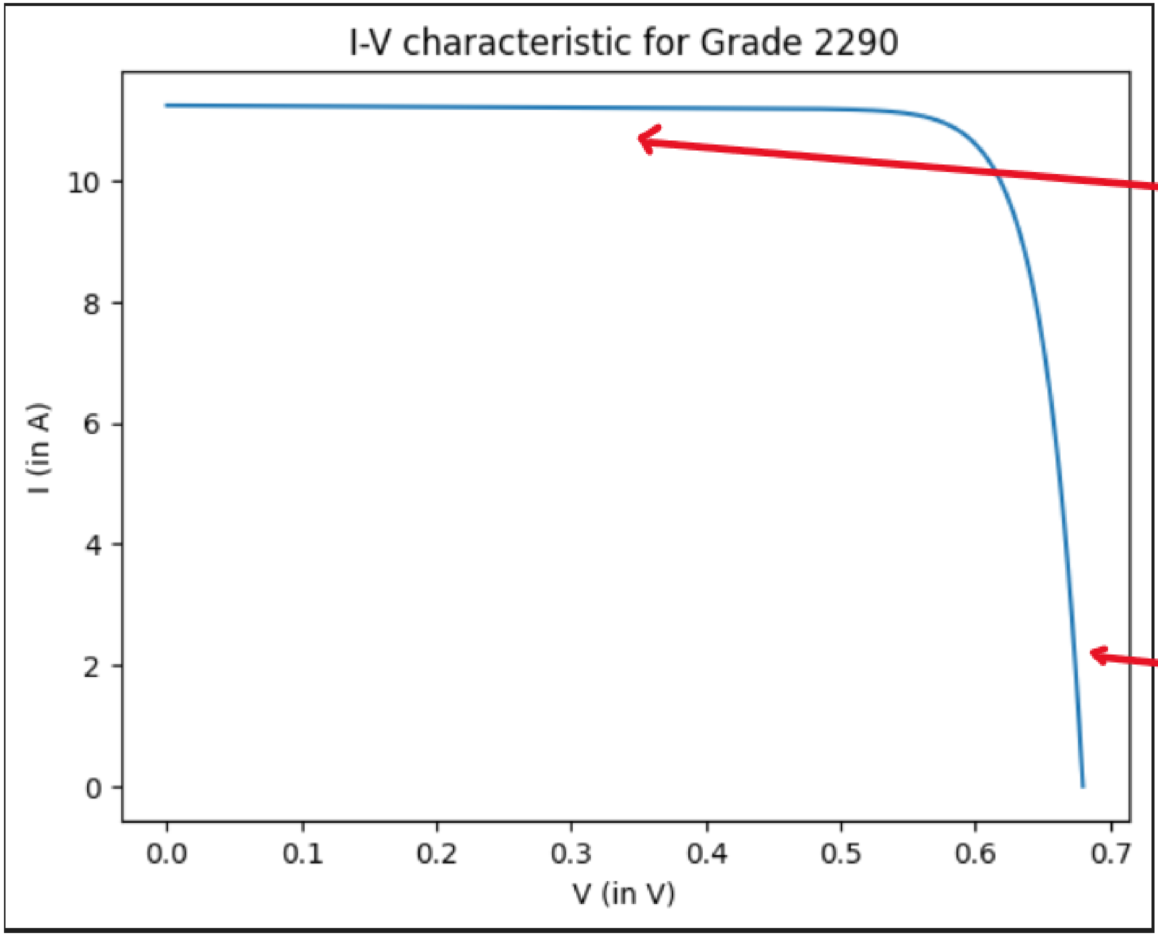
Approaches:

1. The probing contacts can be **galvanically isolated** in order to avoid ground looping
2. Electrically **isolating Power & Measurement circuit** to avoid ground looping
    - Opto-coupled OPAMPS are used to achieve isolation



    - There are Opto-coupled OPAMP ICs available like AMC1200, AMC1211,etc...
3. Simulate the complete setup with **different back contact configuration**

Isolation is critical when measuring low resistances as claimed by Megger in 'A guide to low resistance testing'



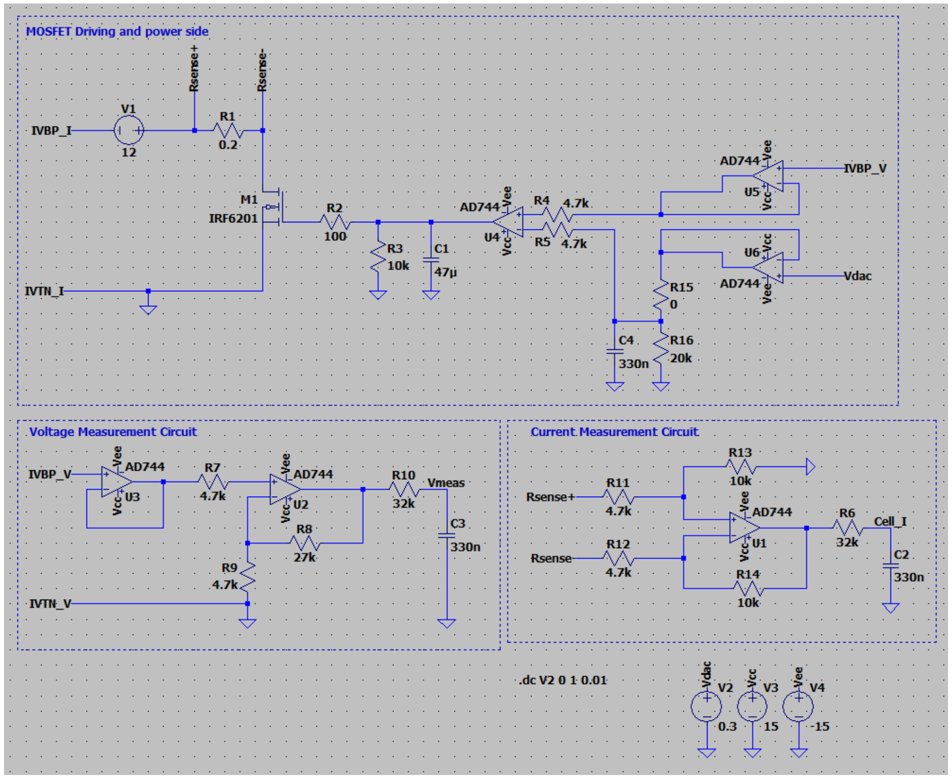
$$\frac{\delta I}{\delta V} \to 0$$

$$\implies R \to \infty$$

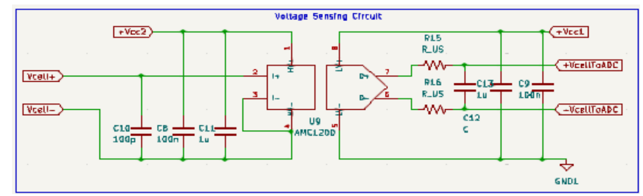
$$\frac{\delta I}{\delta V} \to \infty$$

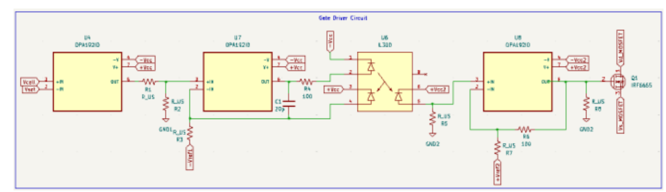
$$\implies R \to 0$$

Measurement circuitry to ensure electrical isolation:

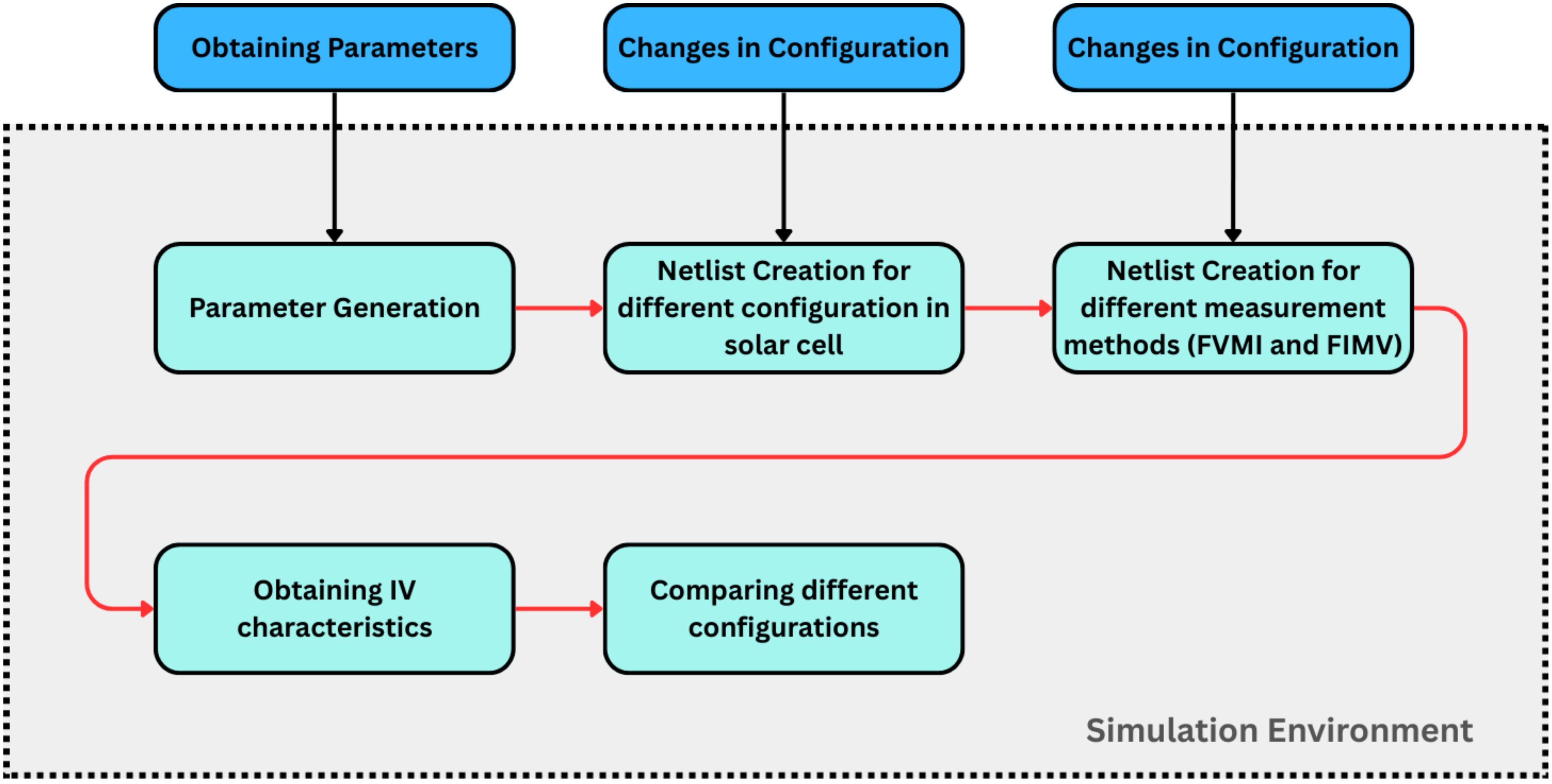


Modification in OPAMPs





METHODOLOGY – II (SIMULATION CHECK)

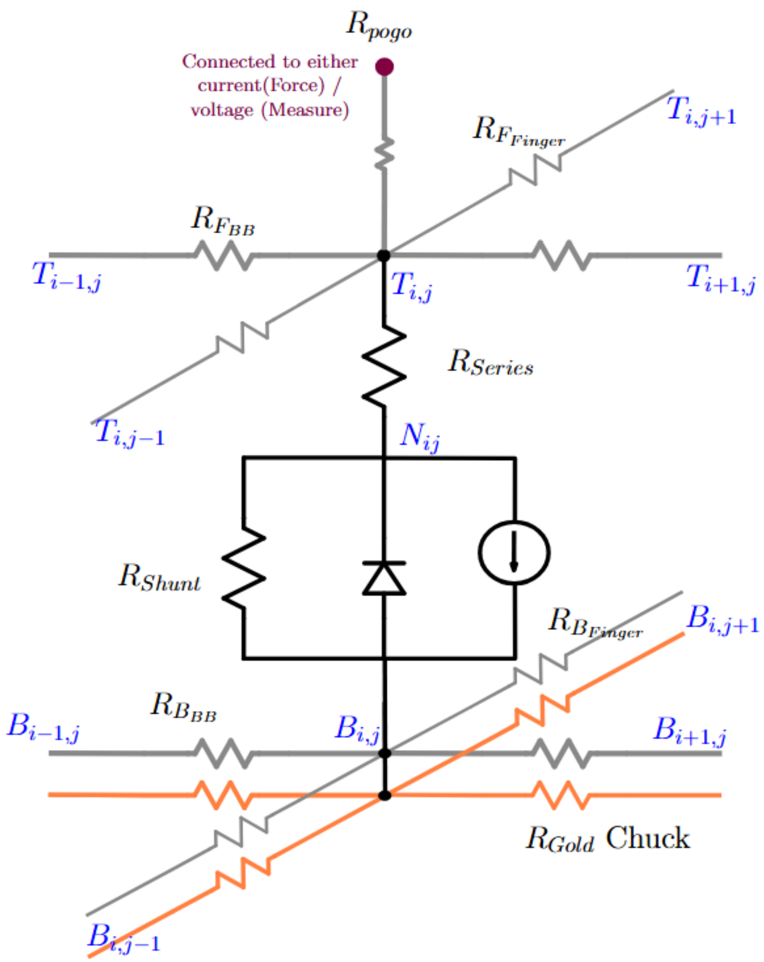


METHODOLOGY – II (SIMULATION CHECK)

Finite Element Model of Simulation:

A (m × n) resistance mesh grid is constructed, where m represents the number of bus bars and n denotes the number of fingers.

The finite element model incorporates a PN junction, represented by its equivalent circuit, which is connected to the grid nodes. Specific points are probed at the top nodes and designated as either force points or measurement points.



METHODOLOGY – II (SIMULATION CHECK)

Obtaining Parameters:

Busbars and fingers in 9BB solar cell

The provided 9BB solar cell has **9 busbars** and **120 fingers** with an overall dimension of 162mm $\times$ 162mm.

- Length of finger enclosed by adjacent busbars is 16.2mm
- Length of busbar enclosed by adjacent fingers is 1.34mm

The parameter that are required to be used in the LTSpice modelling are to be measured and estimated are shown below:

1. R_{busbar} measurement for metallization
2. R_{finger} measurement for metallization
3. R_{series} of solar cell
4. R_{shunt} of solar cell
5. Chuck resistance estimation
6. $R_{pogopin}$ measurement

METHODOLOGY – II (SIMULATION CHECK)

Obtaining Parameters: R_busbar metallization

Measurement method

Resistance per unit length ($m\Omega/mm$) is found using Multimeter

- For a length of 1.35mm on **front plate**, resistance per unit length varies between (40-60)mΩ/mm with a mean value of occurrence as 41.2mΩ/mm.
- For a length of 1.1mm on **bottom plate**, resistance per unit length varies between (5-7)mΩ/mm with a mean value of occurrence as 6mΩ/mm.

- Resistance of **busbar on front plate** enclosed by adjacent fingers is 1.34mm $\times$ 41.2mΩ/mm $= 55.208 m\Omega$.
- Resistance of **busbar on bottom plate** enclosed by adjacent fingers is 1.34mm $\times$ 6mΩ/mm $= 8.04 m\Omega$.

METHODOLOGY – II (SIMULATION CHECK)

Obtaining Parameters: R_finger metallization

Measurement method

Resistance per unit length ($m\Omega/mm$) is found using Multimeter

- For a length of 17.2mm on **front plate**, resistance per unit length varies between (80-120)mΩ/mm with a mean value of occurrence as 89mΩ/mm.
- For a length of 17.5mm on **bottom plate**, resistance per unit length varies between (40-60)mΩ/mm with a mean value of occurrence as 51.11 mΩ/mm.

- Resistance of **finger on front plate** enclosed by adjacent busbar is 16.2mm $\times$ 89mΩ/mm $=$ 1.4418Ω.
- Resistance of **finger on bottom plate** enclosed by adjacent busbar is 16.2mm $\times$ 51.11mΩ/mm $=$ 0.8279Ω.

METHODOLOGY – II (SIMULATION CHECK)

Obtaining Parameters: R_series and R_shunt with infinitesimal I

The parameters such as IFEM, Rshunt and Rseries for the infinitesimal model are deduced from the parameter extraction method used from the **shape parameters (m and γ parameters)** of the solar panel datasheet and current extraction approach from given parameters in datasheet.

- V_{OC} : Open circuit voltage (in V)
- I_{SC} : Short circuit current (in A)
- V_{mp} : Voltage at maximum power point (in V)
- I_{mp} : Current at maximum power point (in A)
- P_{mp} : Power at maximum power point (in W)
- $Efficiency$: Efficiency of solar to electrical energy conversion
- T : Temperature of PV solar array (in ^0C)
- $Area$: Area of PV solar array (in cm^2)

$$FF = v_p j_p$$

$$m\, log(v_p) + log(m+1) = 0$$

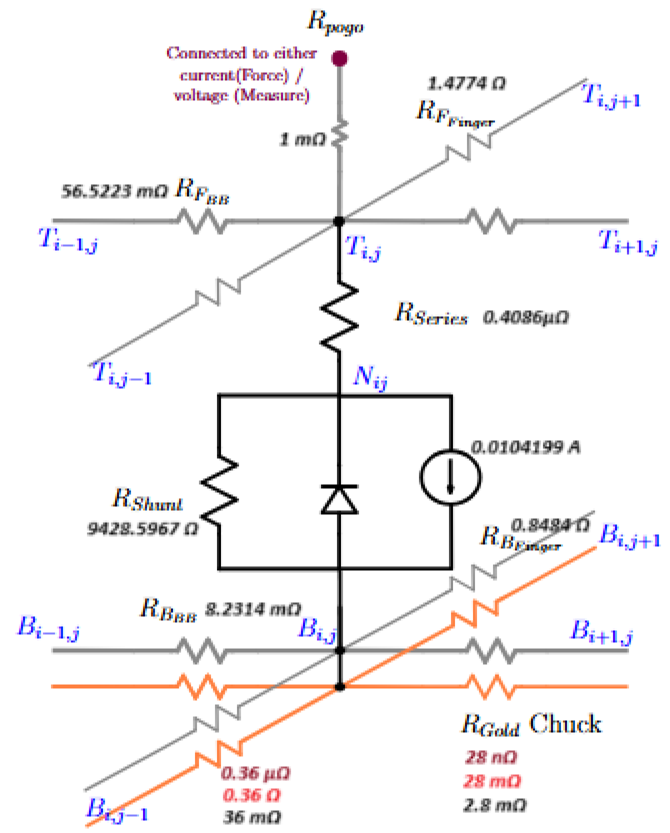
$$v_p[1 - (1-\gamma)v_p - \gamma v_p^m] - FF = 0$$

METHODOLOGY – II (SIMULATION CHECK)

Obtaining Parameters:

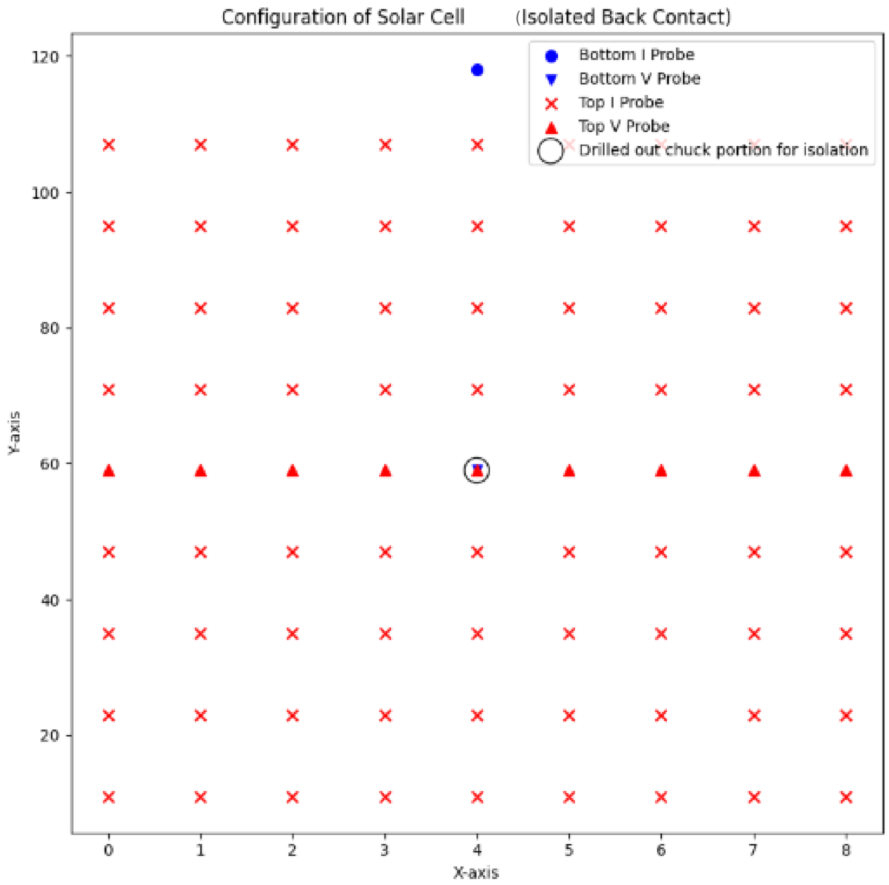
The parameter obtained or estimated are mentioned in the Finite Element Model of the solar cell as shown.

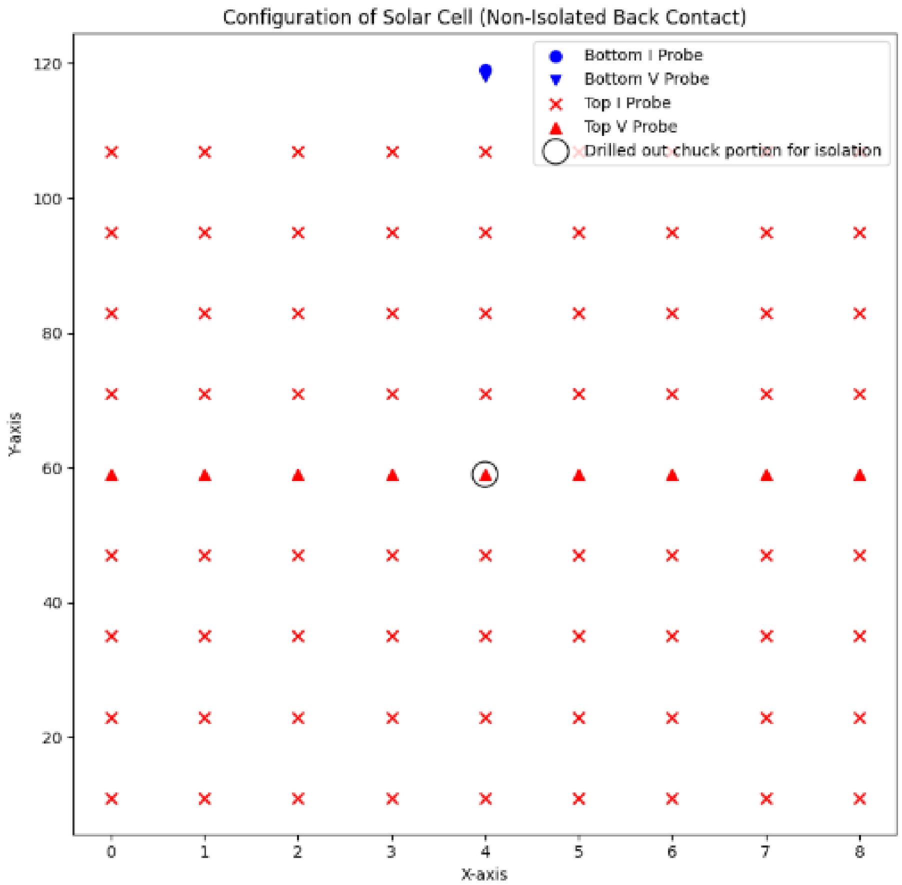
The values of Gold chuck resistance is **not known,** so different values are used to obtain the **best fit.**



METHODOLOGY – II (SIMULATION CHECK)

Configurations: *With isolated and without isolated back contact*





METHODOLOGY – II (SIMULATION CHECK)

Simulation circuit netlist:

Measurement methods of ***Force Current Measure Voltage (FIMV) and Force Voltage Measure Current (FVMI)*** are used for each configuration setup in simulation.

(I) Force Current Measure Voltage (FIMV):

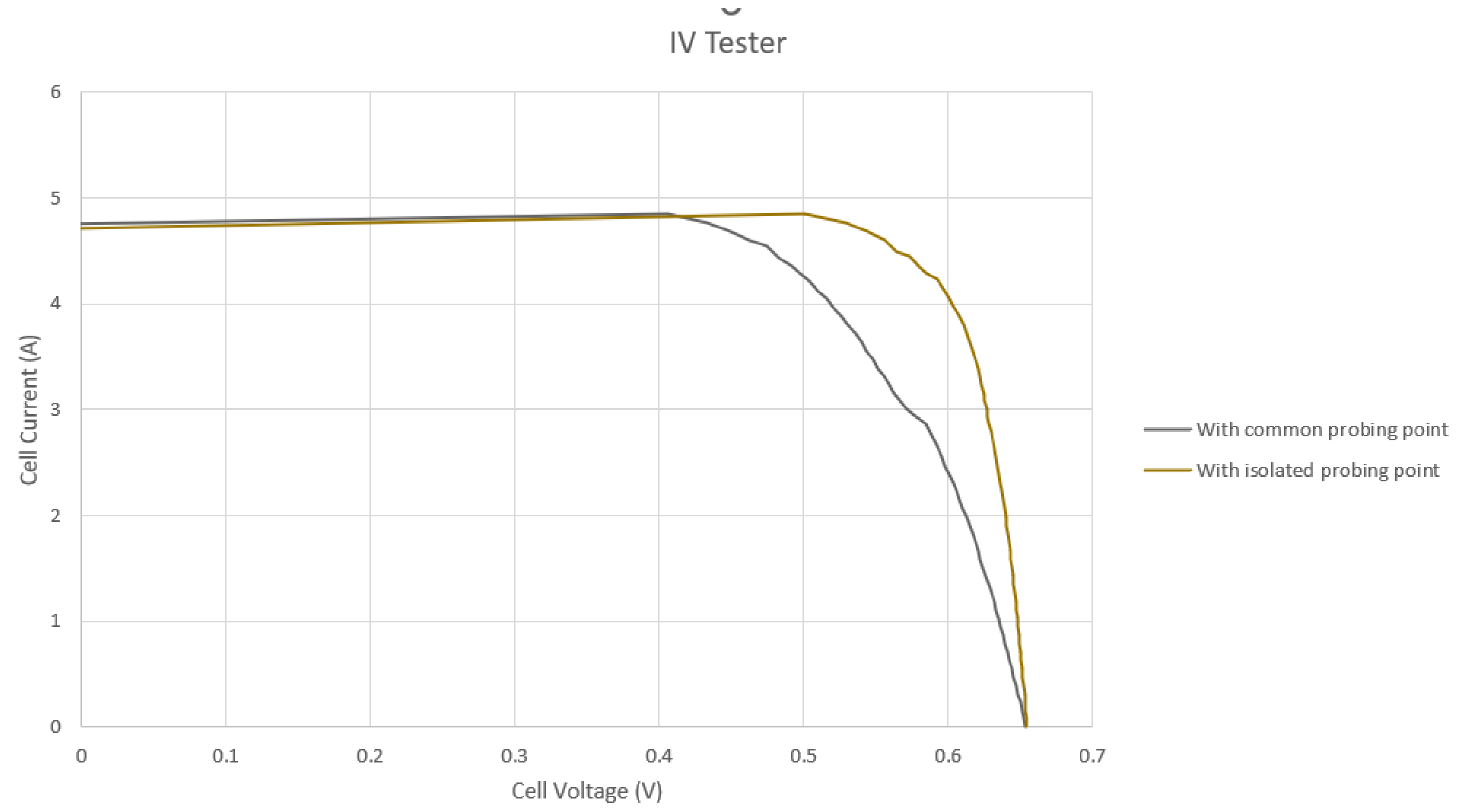
Voltage controlled current source is established with negative feedbacked loop to maintain desired voltage in the power circuit

(II) Force Voltage Measure Current (FVMI):

Current controlled current source is established with negative feedbacked loop to maintain desired current in the power circuit

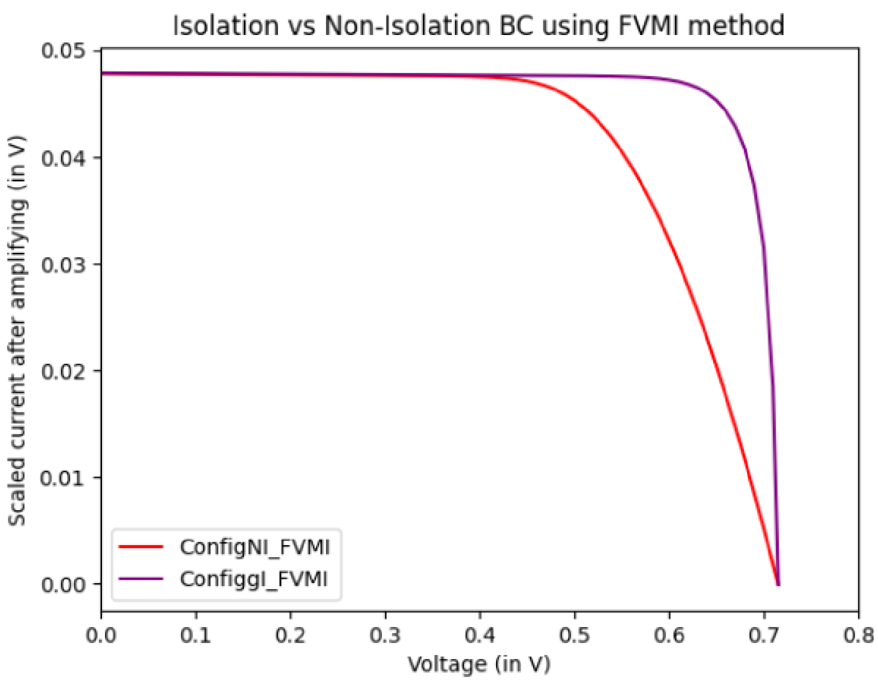
METHODOLOGY – II (SIMULATION CHECK)

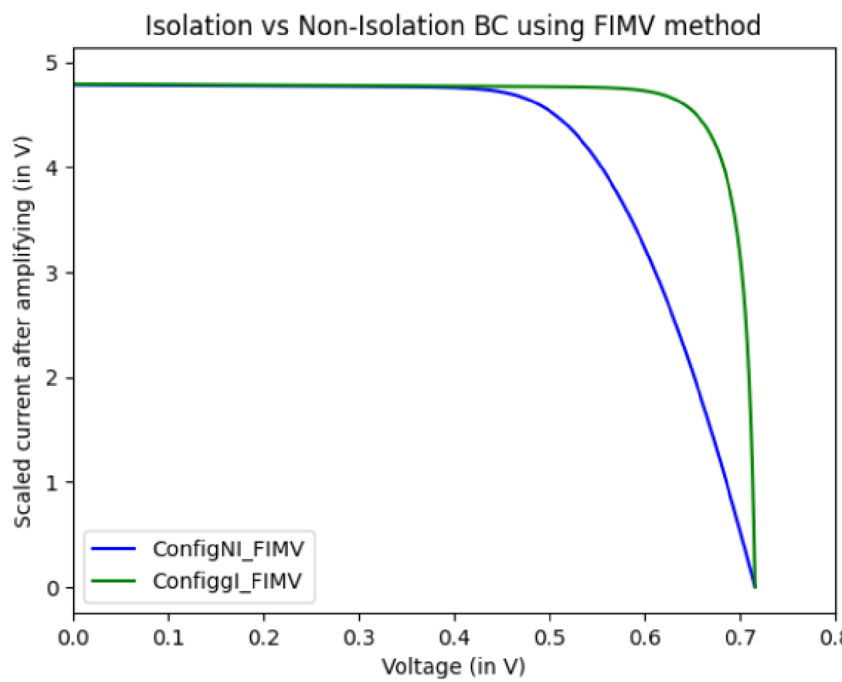
With isolated and without isolated back contact configurations are made in hardware and the IV characteristics are captured to be:



METHODOLOGY – II (SIMULATION CHECK)

Comparison of Isolated and Non-isolated Back contact:





METHODOLOGY – III (Gold Resistance Fit)

Iterative Approach to Estimate Gold Chuck Resistance:

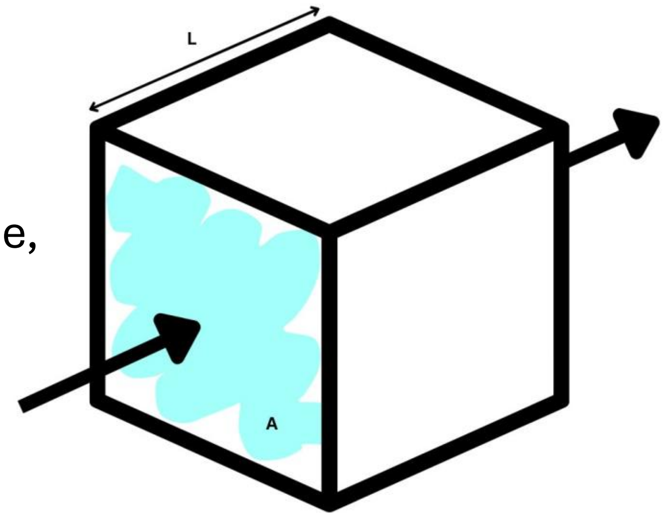
Why Estimate Gold Chuck Resistance?

- Accurate resistance modeling is essential for realistic IV curve simulation.
- Direct calculation of mesh resistance from sheet resistance is challenging due to:
    - Fine grid structure
    - Non-uniform contact areas
    - Complex current paths

What to consider as a reference?

By finding the equivalent Resistance from side-to-side, and having it as the reference

$$R_{side-to-side} = \frac{\rho L}{A}$$



METHODOLOGY – III (Gold Resistance Fit)

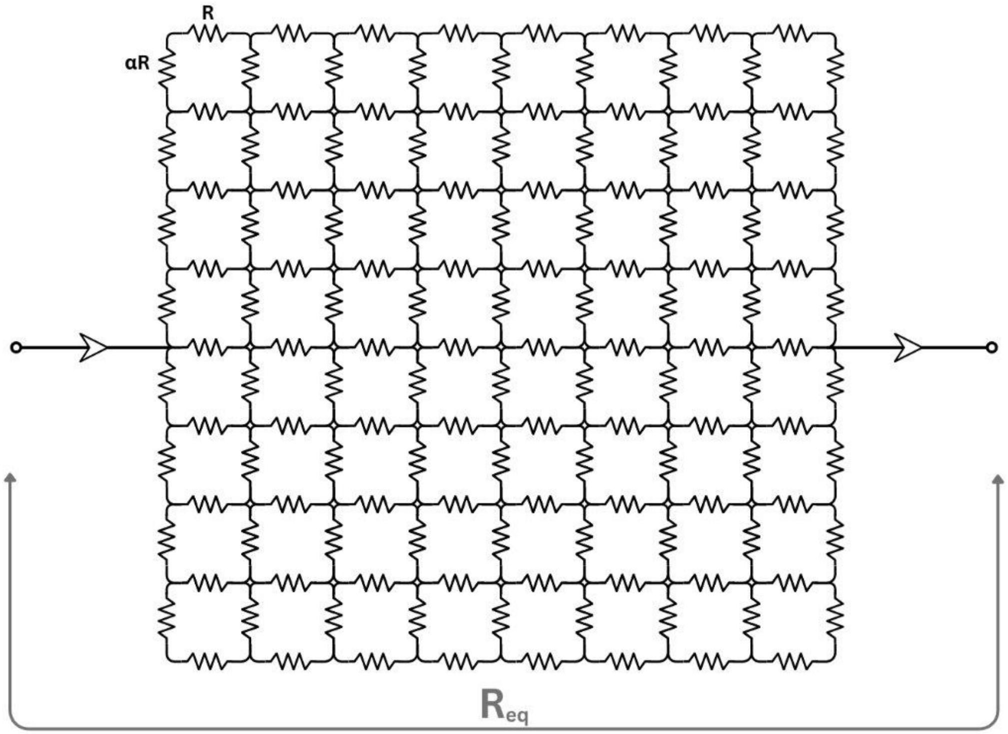
Iterative Approach to Estimate Gold Chuck Resistance:

How to find infinitesimal resistance?

- Create a mesh network in LTspice and apply a unit current to measure voltage.
- Adjust resistance per unit length iteratively until the simulated side-to-side resistance matches the analytical value.

Python-LTspice Integration:

- Automates netlist generation, simulation, and result comparison.
- Updates resistance values efficiently to ensure accurate modeling of the gold chuck.



Conclusion

Results:

1. The parameters found or estimated are provided below:

Parameter Name	Symbol	Value / Random Interval
Top Finger Resistance	$R_{\text{top-finger}}$	$1.376\ \Omega$ to $2.064\ \Omega$
Top Busbar Resistance	$R_{\text{top-busbar}}$	$0.06075\ \Omega$ to $0.108\ \Omega$
Bottom Finger Resistance	$R_{\text{bottom-finger}}$	$0.7\ \Omega$ to $1.05\ \Omega$
Bottom Busbar Resistance	$R_{\text{bottom-busbar}}$	$0.0055\ \Omega$ to $0.0077\ \Omega$
Chuck Finger Resistance	$R_{\text{chuck-finger}}$	$0.35\ \Omega$ to $0.37\ \Omega$
Chuck Busbar Resistance	$R_{\text{chuck-busbar}}$	$0.027\ \Omega$ to $0.029\ \Omega$
Shunt Resistance	R_{shunt}	$9800\ \Omega$ to $10000\ \Omega$
Series Resistance	R_{series}	$4.25 \times 10^{-7}\ \Omega$ to $4.3 \times 10^{-7}\ \Omega$
Pogo Pin Resistance	R_{pogo}	$1\ \text{m}\Omega$ (fixed)
Illumination Current	I_{FEM}	0.01047087 A (fixed)

2. The estimated order of gold chuck resistances are 28mΩ for busbar and 0.36Ω for finger.

Conclusion:

1. Accurate IV measurement in solar cells requires proper contact isolation, especially at low resistance regions.
2. Isolated back contact significantly improves measurement accuracy compared to non-isolated setups.
3. For gold chuck, resistance estimate close to the resistance of bottom plate yields an accurate depiction of experimental observation.

Acknowledgment

I would like to express my sincere gratitude to **Dr. Arvind Ajoy**, under whose guidance I completed this project.

I am also grateful to **Mr. Navaneeth** for his invaluable support throughout the work.

Additionally, I would like to thank **Manikantan R S** for his valuable ideas and insights that helped me move forward with this project.

Thank You