

## Table of Contents

1	Introduction	3
2.1	Installation	4
2.2	Module Quick Guide	6
2.3	Update Notifications	13
3	Detailed Operations on the Main Screen	14
3.1	Introduction	14
3.2	Module Layout Options	14
3.3	Shingled Cells Module	17
3.4	Ribbons and Cable Connectors	18
3.5	Temperature	20
3.6	Illumination and cell diode properties	21
3.7	Non-uniform Cell Parameters	22
3.8	Extra Ribbon Solder Point Contact Resistance	29
4	Cell Library	33
4.1	Introduction	33
4.2	Adding Cells from Zip File	34
4.3	Adding Cells from Griddler Files (For users with bundled software license)	34
4.4	Analyzing Griddler Cells Files (For users with bundled software license)	35
4.5	Editing Griddler Cell Files in Detail (For users with bundled software license)	36
4.6	Reverse Breakdown Voltage	39
4.7	Detailed Reverse Breakdown Simulations	40
5	Diode Library	46
6	Subcircuits Library	47
6.1	Introduction	47
6.2	Save Current Module Circuit As Subcircuit	47
6.3	Removing nodes and deactivating terminals	49
6.4	Place Subcircuits into Module	52
6.5	Making Connections	54
6.6	Creating New Nodes	60
6.7	Setting Module Terminals	62
6.8	Setting bypass diodes	63
7	Conductive Backsheet	65
7.1	Introduction	65
7.2	Conductive Backsheet Window	65
7.3	Conductive Backsheet Interconnection	68
7.4	Conductive Backsheet Connection Point Contact Resistance	73

#### **1** introduction

Welcome! Module is an easy to use finite-element simulation program for solar panels. Module session files are ZIP files, which packages the module layout and reduced cell models. It may also package the original Griddler cell models. To start, you can download models for a wide variety of common solar cell types, for different wafer sizes and cuts, at

Wafer Size	Cut	Multicrystalline PERC	Mono SE PERC	n-type TOPCON	multiwire HJT	n-type IBC
125 mm	Full					Griddler IBC model
125 mm	Full					Module cell model
125 mm	Half Cut					Griddler IBC model
125 mm	Half Cut					Module cell model
M1 (156 mm)	Full	Griddler model	Griddler model	Griddler model	Griddler model	Griddler IBC model
M1 (156 mm)	Full	Module cell model	Module cell model	Module cell model	Module cell model	Module cell model
M1 (156 mm)	Half Cut	Griddler model	Griddler model	Griddler model	Griddler model	Griddler IBC model
M1 (156 mm)	Half Cut	Module cell model	Module cell model	Module cell model	Module cell model	Module cell model
M1 (156 mm)	6th cut top	Griddler model	Griddler model	Griddler model		
M1 (156 mm)	6th cut top	Module cell model	Module cell model	Module cell model		
M1 (156 mm)	6th cut middle	Griddler model	Griddler model	Griddler model		
M1 (156 mm)	6th cut middle	Module cell model	Module cell model	Module cell model		
M1 (156 mm)	6th cut bottom	Griddler model	Griddler model	Griddler model		
M1 (156 mm)	6th cut bottom	Module cell model	Module cell model	Module cell model		
M2 (156.75 mm)	Full	Griddler model	Griddler model	Griddler model	Griddler model	Griddler IBC model

http://griddlersolar.com/index.php/cell-and-module-files-library/

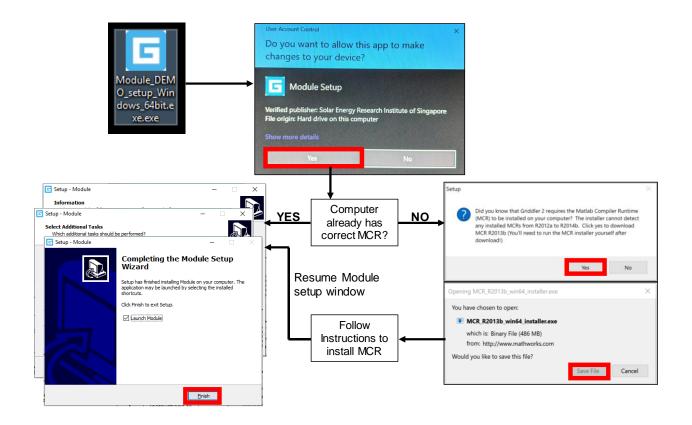
The file links called "Module cell model" are zip files that you can directly load into Module via File  $\rightarrow$  Open Session, or in the Cell Library of Module via "Add cells from another zip".

The file links called "Griddler model" and "Griddler IBC model" can be opened in Griddler 2.5 PRO and Griddler IBC, respectively. If you have the software bundle, then you can launch these cell simulation programs to load these files, edit them, and load them into Module for cell reduction.



#### 2.1 Installation

After you have downloaded the installer, double click it to initiate installation. The installation process is automatic and easy to follow and is described by the diagram below. Module is written in MATLAB and requires the Matlab compiler runtime (MCR R2013b) to run. The installer will autodetect the presence of the correct MCR version and download it if it is missing, but you will need to install the MCR separately. Once setup is complete, hit finish with the "Launch Module" checkbox checked, and Module will launch.

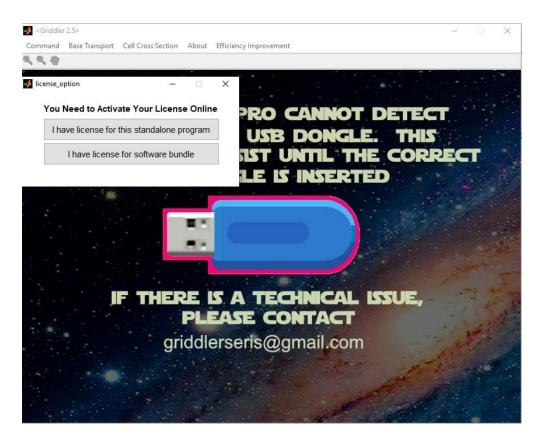


Module needs <u>either</u> a physical USB dongle provided by us or online activation to run. Either method requires periodic internet connection (for USB dongle about once a month; for online activation about once a day). The USB dongle looks like the one shown below and needs to be plugged into the computer while the program is running.



When you run the program for the first time, if it doesn't detect the USB dongle, then a pop up screen will show up with the following options. Select the appropriate (software bundle = Griddler 2.5 PRO + Griddler IBC + Module simulation program purchase; standalone = Module only).





Then you will be give the option below to enter a product key. Use the one provided to you and you can then continue to use the program.

		×
~	💦 TurboActivate	
	Activate Griddler now Your activation period has expired and Griddler is no longer working. To use your software you must activate this copy of Griddler.	
	$\rightarrow$ <u>A</u> ctivate Griddler online now	
	$\rightarrow$ <u>B</u> uy a new product key online	
	$\rightarrow$ <u>R</u> etype your product key	
	$\rightarrow$ Other <u>options</u>	
	Canc	el



## 2.2 Module Quick Guide

Here's Module's main screen. In it, you can define the module layout, set the temperature, access the cell and diode libraries, subcircuits library, conductive backsheet, and coarsely adjust the cell parameters of the cells inside the module. Of course, you can also run simulations.

🛃 <module> — 🗆 🗙</module>	Module_figure	– 🗆 X
File About Import Sunsolve 🏻	€, S, ₩	Ľ
RODULE	Cells Cell connections resistors C nodes node (x,y) Subcircuit	details Circuit V Rescale Refresh
Override layout pattern with custom netlist	960.5mm	
Module Dimensions		
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2		
Margin to frame (mm) Top 20 Side 5 Bottom 10 +- dist (mm) 100		
Cell Connecting Ribbons         String Connecting Ribbons           width (mm)         1         sheet res (mohm/sq)         0.07         width (mm)         6         sheet res (mohm/sq)         0.05		
Ribbons optical scatter 0.2 Cables connectors 0 Calculator		
Temperature (C)         25         Two parallel halves		
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	l li	
Cells Diodes Subcircuits Conductive Backsheet	1999 - 19	
Place cell type into positions		
Extra ribbon contact res (mohm)		
Extra shunt cond (1/(kohm-cm2)) 0		
Front 1-Sun Jsc Rear 1-Sun Jsc 1		
J01 multiplier 1 J02 multiplier 1 N Front Illumination 1 N (Suns) 0 N		



Let's start by choosing File  $\rightarrow$  Open Session, and then choosing mono-SE-PERC-cell\_M2.zip downloaded from the online library.

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width 1 sheet res 0.07 width (mm)		Date modified	Туре	Size
Vesterday (1)				
Ribbons optical scatter 0.2 Cables conner resistance (mg	ell_M2.zip	12/9/2020 11:36 pm	Compressed (zipp	8,078 KB
Temperature (C) 25 Two para V Last week (2)				
Cells, Bypass Diodes, Subcircuits, Co	- 1	10/9/2020 4:45 pm	Compressed (zipp	254 KB
Cells Diodes Subcircuits Cond	J-10_16-45-49	10/9/2020 4:45 pm	File folder	
Place cell type into positions	E E			
Extra ribbon contact Front 0 N Rear 0				
Extra shunt cond (1/(kohm-cm2)) 0				
Front 1-Sun Jsc Rear 1-Sun Jsc 1 M multiplier				
J01 multiplier 1 🗾 J02 multiplier 1 🛒				
Front Illumination Rear Illumination 0				

As soon as the zip file has been loaded and there is information of the solar cell, the module shown in the Module\_figure will be populated by the first solar cell type by default. You can make a lot of changes---populating the module with different cell models, changing the details of the cell (if user has access to Griddler 2.5 PRO or Griddler IBC), etc. These will be explained later on in the manual.

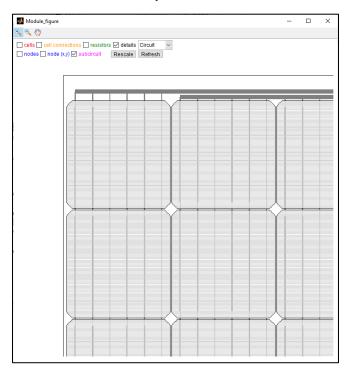
📣 <module> — 🗆 🗙</module>	Modul	e figure				_		×
File About Import Sunsolve 📽	. 🔍 🔍 🥎	)						
RODULE	Cells	] cell co					ircuit Refresh	~
Override layout pattern with custom netlist				(simlation )				
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Cell Connecting Ribbons String Connecting Ribbons		3 [1]	19 [1]	23 [1]	39 [1]	43 [1]	[1]	
width 1 sheet res 0.07 width 6 sheet res (mm) 0.05			18		38		58	
Ribbons optical scatter 0.2 Cables connectors 0 Calculator	ŀ	4 [1]	[1]	24 [1]	[1]	44 [1]	[1]	
Temperature (C) 25 Two parallel halves	Ļ		17	Ļ	37	ļ	57	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet		5 [1]	[1]	25 [1]	[1]	45 [1]	[1]	
Cells Diodes Subcircuits Conductive Backsheet	639 5mm		16	ļ	36	<u> </u>	56	
Cells Diodes Subcircuits Conductive Backsneet	16.3	6 [1]	[1]	26 [1]	[1]	46 [1]	[1]	
Place cell type into positions			15		35		55	
Extra ribbon contact Front 0 Rear 0 N	ſ	7 [1]	[1]	27 [1]	[1]	47 [1]	[1]	
Future shuret and (1/(kohm am2))			14	<u> </u>	34	<u> </u>	54	
Front 1-Sun Jsc Rear 1-Sun Jsc		8 [1]	[1]	28 [1]	[1]	48 [1]	[1]	
multiplier 1 N multiplier 1 N	l		13	<u> </u>	33	<u> </u>	53	
J01 multiplier 1 💉 J02 multiplier 1 💉	ſ	9 [1]	[1]	29 [1]	[1]	49 [1]	[1]	
Front Illumination Rear Illumination			12		32		52	
(Suns) UN	ſ	10 [1]	[1]	30 [1]	[1]	50 [1]	[1]	
	Ļ		11	<u> </u>	31		51	



The Module\_figure window can be resized. After resizing the window, pressing "Resize" will cause the program to redraw the module in the correct aspect ratio.

	Module_figure											-	×
	<b>€</b> €												
	cells cell connections				-								
🛃 <module> — — X</module>	🗌 nodes 🗌 node (x,y) 🗹 subci	ircuit	Re	scale		resh m (simlat <u>io</u> n	mach	eount -	33704)				
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Margin to frame (mm) Top 20 Side 5 Bottom 10 +- dist 100		3	[1]	[1	1	23 [1]		[1]	43 [1]	[1]			
Cell Connecting Ribbons String Connecting Ribbons width sheet res 0.07 width sheet res 0.07				18			38			58	J		
(mm) (mohm/sq) (0.07 (mm) (mohm/sq) (0.05		4	[1]	[1	1	24 [1]		[1]	44 [1]	[1]			
Ribbons optical scatter 0.2 Cables connectors 0 Calculator				17	_		37			57			
Temperature (C) 25 Two parallel halves		5	[1]	[1	1	25 [1]		[1]	45 [1]	[1]			
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet				16			36			56			
Cells Diodes Subcircuits Conductive Backsheet		6	[1]	[1	1	26 [1]	Î	[1]	46 [1]	[1]			
Place cell type into positions				15			35			55			
Extra ribbon contact Front 0 M Rear 0 M		7	[1]	[1	ı î	27 [1]	î	[1]	47 [1]	(1)	1		
Extra shunt cond (1/(kohm-cm2)) 0				14			34			54			
Front 1-Sun Jsc Rear 1-Sun Jsc 1 Multiplier		8	[1]	<u>را</u>		28 [1]	ŕ	[1]	48 [1]	(1)	1		
J01 multiplier 1 🔟 J02 multiplier 1 🛒													
Front Illumination Rear Illumination 0		9		13	{	29 [1]	33			53	{		
		1	11	[1	1	29 [1]		[1]	49 [1]	[1]			
				12	_		32			52	Į		
		10	[1]	[1	1	30 [1]		[1]	50 [1]	[1]			
				11			31			51	J		
		_								-	1		

There is a variety of options of what to display for the module, which will be explained later in the Subcircuit Library section because that is where these options become useful. For now, we demonstrate for instance, if you press "details", then the full details of the module down to cell ribbons and fingers will be displayed, and then you can use the zoom tool to look closely at sections of the module.





To run simulations, the Module interface resembles Griddler and Griddler IBC. Click "Find Jsc Voc MPP" and Module will run the I-V curve, focusing on finding the main I-V parameters.

Module> - 🗆 X	Module_figure - 🗆 🗙
File About Import Sunsolve 🔉	🔍 🔍 🖑
RODULE	I-V v
Override layout pattern with custom netlist	10
Module Dimensions	
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Margin to frame (mm) Top 20 Side 5 Bottom 10 + - dist (mm) 100	€ 6 FF = 79.39% Pmax = 314.29 W
Cell Connecting Ribbons String Connecting Ribbons	Image: Control of the state of the
width 1 sheet res 0.07 width 6 sheet res 0.05 (mohm/sq)	₩ 4 Imp = 9.11 A Rs = 0.162 ohm
Ribbons optical scatter 0.2 Cables connectors 0 Calculator	2-
Temperature (C) 25 Two parallel halves	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	0 10 20 30 40 50 Voltage (V)
Cells Diodes Subcircuits Conductive Backsheet	350
Place cell type into positions	300 -
Extra ribbon contact Front 0 N Rear 0 N	250 -
Extra shunt cond (1/(kohm-cm2)) 0	€ 200
Front 1-Sun Jsc Rear 1-Sun Jsc 1	
multiplier N multiplier N	100-
J01 multiplier 1 J02 multiplier 1 N Front Illumination Rear Illumination	
(Suns)	50 -
	0 10 20 30 40 50 Voltage (V)

Find Jsc Voc MPP stops after the maximum power point has been found, so the I-V curve might not look very smooth. If you want the I-V curve to be smooth, you can press "JV sweep", and specify additional voltages to run the simulation. As long as you have not made changes to the module simulation parameters, Module will add the newly simulated I-V points onto the existing I-V curve.

🛃 <module> — — X</module>	Module_figure	- 🗆 ×
File About Import Sunsolve	× 🔍 🔍 🖑	
RODULE		I-V 🗸
Override layout pattern with custom netlist	10	
Module Dimensions		•
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2 (mm) 2 (mm) 2	8 - Voc = 41.08 V Isc = 9.64 A	<u>}</u>
frame (mm) Top 20 Side 5 Bottom 10 (mm) 100	€ 6 FF = 79.39% Pmax = 314.29 W	
Cell Connecting Ribbons String Connecting Ribbons	6 6 FF - 73.39% Pmax = 314.29 W Vmp = 34.49 V 4 Imp = 9.11 A	<b>↓</b>
width 1 sheet res 0.07 width 6 sheet res (mohm/sq) 0.05	3 4 - Imp = 9.11 A Rs = 0.006 ohm	
Ribbons optical scatter 0.2 Cables connectors 0 Calculator	2 -	
Temperature (C) 25 Two parallel halves	0	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	0 10 20 30 Voltage (V)	40 50
Cells Diodes Subcircuits Conductive Backsheet	350 350	
Place cell type into positions	300 -	<b>* </b>
Extra ribbon contact res (mohm) Front 0 N Rear 0	250 -	<b>}</b> -
Extra shunt cond (1/(kohm-cm2)) 0	200- 150- *	4 -
	- 8 150 -	
SWEEP RANGE CO	100-	t l
35 to 41 step 1 V RUN DONE		
	50 -	
	0 10 20 30 Voltage (V)	40 50



To visualize the voltage distribution, you can press "MAP" and then specify what to map (here we chose Cell front voltage) and what operating condition to map (here we chose 34.49V which is the maximum power point. You can also enter "OC" to simulate open circuit condition).

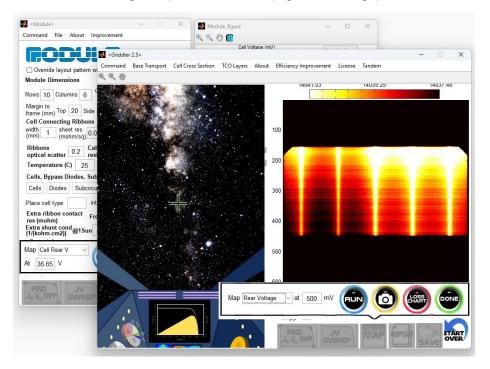
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File About Import Sunsolve 2	۹ 🔍 🖑		
RODULE	Cell 559.74	I Voltage (mV) 595.62 591.50 Rescale	Map (hot) 🗸
Override layout pattern with custom netlist			
Module Dimensions			
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2			
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100			and the second second
Cell Connecting Ribbons         String Connecting Ribbons           width         1         sheet res (mom/sq)         0.07         width         6         sheet res (mom/sq)         0.05			
Cables connectors optical scatter         0.2         Cables connectors resistance (mohm)         0         Calculator			
Temperature (C) 25 Two parallel halves			
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	a state of		
Cells Diodes Subcircuits Conductive Backsheet			
Place cell type into positions			and the second second
Extra ribbon contact Front 0 Rear 0 N			
Extra shunt cond (1/(kohm-cm2)) 0			
Map Cell Front V			
At 34.49 V			
			а 1 н н

(New Since March 2023) For detailed simulation of a cell inside the module, after a MAP simulation, press the icon in the Module Figure and enter the cell number to zoom. Press OK and Griddler will launch to calculate the detailed voltage distribution for that particular cell inside the module.

🛃 <module> — 🗆 X</module>	Module_figure	– 🗆 🗙
Command File About Improvement	🔍 🔍 🖤 🛄	
RODULE	Cell Voltage (mV) 2:49 1.28 0.07	Map (hot) V
Override layout pattern with custom netlist Module Dimensions		
Rows     10     Columns     6     Cell gap 2 (mm)     2     (mm)     2       Margin to frame (mm)     Top     20     Side     5     Bottom     10     + - dist 100       Cell Connecting Ribbons     String Connecting Ribbons     String Connecting Ribbons       width     4     sheet res     0.02	Select Cell Number to Zoo	
(mm) 1 (mohm/sq) 0.07 (mm) 6 (mohm/sq) 0.05 Ribbons optical scatter 0.2 Cables connectors 0 Calculator	24 OK Close	
Temperature (C) 25 Two parallel halves Cells, Bypass Diodes, Subcircuits, Conductive Backsheet		
Cells Diodes Subcircuits Conductive Backsheet		
Place cell type into positions Extra ribbon contact res (mohm) Front 1548. Rear 0 Extra shunt cond [1/(kohm-cm2]) @1Sun 0 @0Sun 4 Param 5.5		
Map Cell Rear V V At 36.65 V		



Note: user needs to choose the right map inside Griddler (e.g. Rear voltage).



You can save the I-V curve and I-V parameters information by pressing REPORT.

🚺 <module></module>	- 🗆 🗙 🛃 Module_figure	– 🗆 X	mono-SE-PERC-cell_M2_IV.txt - Notepad	– – ×
File About Import Sunsolve	save file name	×	<u>F</u> ile <u>E</u> dit Format <u>V</u> iew <u>H</u> elp	
	$\leftarrow \rightarrow \checkmark \uparrow$ $\rightarrow$ This PC $\rightarrow$ OS (C:) $\rightarrow$ Module	v 🖏 Search Module 🔎	<pre>mono-SE-PERC-cell_M2_IV.txt</pre>	
Override layout pattern with custom net	Organize 🔻 New folder	III 🕶 🕐	IV Parameters front Suns 1.000000	
Module Dimensions	SolarEYE Files fo ^ Name ^	Date modified Type	rear Suns 0.000000	
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Margin to frame (mm) Top 20 Side 5 Bottom	OneDrive     Module_content_jd8h2euh	13/9/2020 12:12 am File folder	FF 79.390803 % Pmax 314.288897 W	
Cell Connecting Ribbons String Co	This PC Griddler_directory.txt	7/9/2020 11:57 pm File folder 8/9/2020 1:12 pm Text Documer	Vmp 34.491961 V	
width 1 sheet res 0.07 width 6 (mm) 6	3D Objects Griddler_IBC_directory.txt	8/9/2020 1:12 pm Text Documer	Imp 9.111946 A Rs 0.006138 ohm	
Ribbons Cables connecto	Desktop     homepath_mat.txt     Documents     homepath_zip.txt	12/9/2020 11:52 pm Text Documer 13/9/2020 12:12 am Text Documer	JV Curve	
optical scatter 0.2 resistance (mohr Temperature (C) 25 Two parallel	Josephilia jd82jh8ueihdd2.txt	7/9/2020 10:56 pm Text Documer	V I Power (V) (A) (W)	
Cells, Bypass Diodes, Subcircuits, Cond	b Music		0.000000 9.636411 8.216248 9.636374	0.000000 79.174833
Cells Diodes Subcircuits Conduct	Pictures		16.432495 9.635837 24.648743 9.627574	158.340841 237.307606
Place cell type into positions	S (C:)		32.864990 9.400918 33.730155 9.277793	308.961087
Extra ribbon contact		>	34.491961 9.111946	314.288897
res (mohm) I rom I III III IIII IIII IIII IIIII IIIIIII	File name: mono-SE-PERC-cell_M2_IV.txt	~	34.595320 9.083906 35.000000 8.958421	314.260630 313.544748
Front 1-Sun Jsc Rear 1-S multiplier 1 m	Save as type: (*.txt)	~	36.000000 8.511167 37.000000 7.787628 38.000000 6.675271	306.402029 288.142223 253.660285
J01 multiplier 1 J02 mu	∧ Hide Folders	Save Cancel	39.000000 5.074273	197.896665
Front Illumination 1 Rear Illum (Suns) (Suns)	nination 50	ii.	40.000000         2.929256           40.670426         1.184758           41.000000         0.241032	117.170243 48.184625 9.882300
	EPORT SAVE	30 40 50 e (V)	41.081238 0.000000	0.000000



After changes have been made, you can also save the session back into a zip folder, either through the SAVE button in the main screen, or via File  $\rightarrow$  Save New or File  $\rightarrow$  Save.

📣 <module></module>	- 🗆 🗙 🛃 Module_figure		- 🗆 🗙	
File About Import Sunsolve	save Session			×
	$\leftrightarrow$ $\rightarrow$ $\checkmark$ $\uparrow$ $\blacklozenge$ > This PC > Download	ads 🗸 🗸	Search Downloads	Ą
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Ribbons optical scatter 0.2 Cables connecto resistance (mohr	OneDrive     Vast month		25/8/2020 5:49 pm	Compres
Temperature (C) 25 Two parallel	3D Objects Trina+data		25/8/2020 3:49 pm 25/8/2020 8:35 am	Compre
Cells, Bypass Diodes, Subcircuits, Cond Cells Diodes Subcircuits Conduct Place cell type into positions	Desktop     Documents     Sample A	a-0824.zip urements-0825-F102-L1 (1)	24/8/2020 8:16 pm 27/8/2020 3:47 pm 25/8/2020 5:52 pm	Compres File folde File folde
Place cell type into positions Extra ribbon contact res (mohm) Front	Downloads     Music     File name: modified_PERC_modu	lo		>
Extra shunt cond (1/(kohm-cm2)) 0 Front 1-Sun Jsc Rear 1-S multiplier 1 m m	Save as type: (*.zip)			~
Jo1 multiplier 1 J02 m Front Illumination 1 Rear Illum (Suns) JEND JEND SWEEP MAP		10 20 30 Voltage (V)	Save Ca 40 50	ancel



## 2.3 Update Notifications

We roll out periodic updates, and you'll be notified of one upon program start (below). Please be diligent, and click "Take Me to the Download Page" and download the latest installer. You can simply run the installer and it will overwrite the previous version from your computer.

File     About     Import Sunsolve       Import Sunsolve     Import Sunsolve	s Circuit	
	s Circuit	-
Override layout pattern with custom netlist Module Dimensions	Refresh	
Rows 10       Columns 6       Cell gap       2       (mm)       2         Margin to       Ton       20       Side       5       Bottom 10       + - dist       100         Ci       A new version of Module (version 1.00032, vors)       vors       yons       yons       yons         Vi       January 1, 2021) is available.       0.05       vors       yons       yons         T       Take Me to the Download Page!       veet       veet       veet       veet         C       No thanks       veet       veet       veet       veet       veet         Place cell type       into positions       veet       veet       veet       veet       veet         Front 1-Sun Jsc       1       Rear 1-Sun Jsc       1       multiplier       veet       veet         J01 multiplier       1       J02 multiplier       1       veet       veet<		

You can always check your version numbers by clicking "About" on the top menu bar. Hit "Download Release Notes" to see the changes made in each version.

<module> —</module>	$\times$	Modu	le_figure		_		$\times$
ile About Import Sunsolve	''	ب کې کې	)				
Module version 1.00032 Released on January 1, 2021 For inquiries or to report bugs, please write to johnson@gridd	le le	Cells Contraction Contraction	-	ubcircuit	 	ircuit Refresh	
Module Change Log from January 1 2021 (version 1.00032)	-						
<ol> <li>Introduced conductive backsheet loading and interconnection 2. Extra ribbon conductive backsheet solder contact points con a spatially resolved manner.</li> <li>Remembers directories now (before does not upon reload)</li> </ol>	it						
Module Change Log from November 2 2020 (version 1.00030) 	-	1639 5mm					
Module Change Log from September 12 2020 (version 1.0002	5						
<ol> <li>Recalls the last directories user navigated to assess Modul</li> <li>Added a button link to the Griddler cell and Module cell file li</li> </ol>							
Module Change Log from September 7 2020 (version 1.00028	0						
1. Some IBC cells reduction did not converge. Now this is fixe	×						
Download Release Notes Clos	e						1

## 3 Detailed Operations on the Main Screen

## 3.1 Introduction

- X	Module_figure — 🗆 >	×
File About Import Sunsolve 🔉	• • • • •	'N
RODULE	Cells       cell connections       resistors       details       Circuit         nodes       node (x,y)       subcircuit       Rescale       Refresh	
Override layout pattern with custom netlist Module Dimensions	960.5mm	
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2 (mm)		
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100		
Cell Connecting Ribbons         String Connecting Ribbons           width         1         sheet res (mohm/sq)         0.07         width         6         sheet res (mohm/sq)         0.05		
Ribbons optical scatter 0.2 Cables connectors 0 Calculator		
3 Temperature (C) 25 Two parallel halves		
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet           Cells         Diodes         Subcircuits         Conductive Backsheet		
1 Place cell type into positions		
Extra ribbon contact res (mohm)		
Extra shunt cond (1/(kohm-cm2)) 0		
Front 1-Sun Jsc Rear 1-Sun Jsc Multiplier		
J01 multiplier 1 J02 mu		

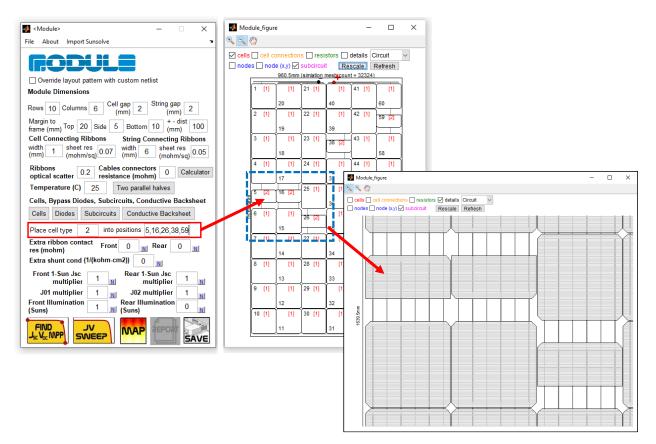
The main screen has the above categories of option groups 1) module layout options (for commonly encountered, rectangular patterns; for arbitrary patterns see Subcircuits Library Section), 2) Ribbons and cables connectors, 3) Temperature, 4) Illumination and cell diode properties.

#### 3.2 Module Layout Options

This group of options allows you to quickly change the layout of a rectangular module. For more arbitrary layouts, see the subcircuits library section.

Here we show for illustrative purposes a module that consists of two cell types. To show this clearly we create a module that is a mixture of full size cells and half cut cells, but of course usually you want to create module with similar sized cells. For this to work, your module session has to have more than one cell type in the cell library (see Cell Library). To repopulate parts or all of the module with another cell type, see below. Enter the cell type number and positions of the module (which can be seen in the Module\_figure) you wish to insert that cell type. If you want to place that cell type into all the positions, enter "all".





Note that all the cells within the module must have the same number of ribbons. Here we show what happens, for example, if we have a third cell type that has 5 busbars, when the existing cells inside the module have 6 busbars. If we try to place cell type 3 into certain positions of the module, an error message will appear and you won't be able to do it.

🛃 <module> — 🗆 X</module>	🛃 Module_figure — 🗆 🗙
File About Import Sunsolve 🏻 📽	• 🔍 🔍 🥙
Coverride layout pattern with custom netlist Module Dimensions	cells _ cell connections _ resistors _ details Circuit ↓ nodes _ node (x,y) Ø subcircuit Rescale Refresh 960.5mm (similation mestacount = 32324)
Rows     10     Columns     6     Cell gap (mm)     2     String gap (mm)     2       Margin to     -     -     -     -     -       Warning     -     -     X	
Cell Type 3 has 5 busbars. Cell number 1 inside the module has 6 busbars. This is not allowed OK	
Temperature (C) 25 Two parallel halves	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	
Cells Diodes Subcircuits Conductive Backsheet	
Place cell type 3 into positions	
Extra ribbon contact res (mohm)	
Extra shunt cond (1/(kohm-cm2)) 0	
Front 1-Sun Jsc Rear 1-Sun Jsc 1 M multiplier	
J01 multiplier 1 J02 multiplier 1 J Front Illumination Rear Illumination	
(Suns)	┋╴┝╾┽╾┽╾┽╼┽╼┥



For rectangular layouts, you can easily change the dimensions of the module via the options in red below.

🛃 <module> — 🗆 🗙</module>	🛃 Module_figure — 🗆 🗙
File About Import Sunsolve 🏻 🗨	
<b>CODULE</b>	vells       cell connections       resistors       details       Circuit       v         nodes       node (x,y)       Subcircuit       Rescale       Refresh
Module Dimensions	
Rows 5 Columns 4 Cell gap 2 String gap 2 (mm) 2	787.0mm (similation mesh count = 10702)
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100	
Cell Connecting Ribbons         String Connecting Ribbons           width         1         sheet res (mm)         0.07         width (mohm/sq)         6         sheet res (mm)         0.05	
Ribbons optical scatter 0.2 Cables connectors 0 Calculator	2 [1] [1] 12 [1] [1]
Temperature (C) 25 Two parallel halves	9
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	
Cells Diodes Subcircuits Conductive Backsheet	3         (1)         13         (1)         (1)           8         8         18         18         18
Place cell type 0 into positions	
Extra ribbon contact Front 0 Rear 0 N	
Extra shunt cond (1/(kohm-cm2)) 0	
Front 1-Sun Jsc Rear 1-Sun Jsc 1 M multiplier	
J01 multiplier 1 N J02 multiplier 1	
Front Illumination (Suns) Rear Illumination 0	

Because it is common to layout half cut cells into two symmetrical, parallel/series connected halves of the module, we have also added this as a quick option. Here we show for an example, a module consisted of entirely half cut cells. Press "Two parallel halves" and then check "two parallel strings" and module will layout the cells as shown in the Module\_figure below.

File       About       Import Sunsolve         File       About       Import Sunsolve         Import Sunsolve       Import Sunsolve       Import Sunsolve         Import Sunsolve       Import Sunsolve       Import Sunsolve         Import Sunsolve       Import Sunsolve       Import S	🐠 <module> — 🗆 🗙</module>	Module_figure — 🗆 🗙
Image: string options       Image: string option         Image: string option       Image: string option         Image: string options       Image: string option         Image: string option       Image: string option         Image:	File About Import Sunsolve 🏻 🕈	🔍 🔍 🖑
res (mohm)       Front       0       Rear       0       N         Extra shunt cond (1/(kohm.cm2))       0       N       1	File       About       Import Sunsolve         Import Sunsolve       Import Sunsolve	Cells cell connections resistors details       Circuit         nodes node (x,y)       subcircuit       Rescale         787.0mm (similation mesh count = 10792)         24       [2]       [27         23       [2]       [28         23       [2]       [28         22       [2]       [29         21       [2]       [30         21       [2]       [30         1       [2]       [10         10       [2]       [11         20       [2]
Front 1-Sun Jsc multiplier 1 J02 multiplier 1 J02 multi		
Front 1-Sun Jsc 1 Rear 1-Sun Jsc 1 J J01 multiplier 1 J02 multiplier 1 J Front Illumination 1 Rear Illumination 0 J	Extra shunt cond (1/(kohm-cm2)) 0	
John Multiplier 1 J02 multiplier 1 Front Illumination 1 (Suns)		
	Front Illumination	

### 3.3 Shingled Cells Module

Shingled cells can easily be defined by simply setting the cell gap value to a negative number. To give ane example, we will start from scratch and build a module that consist of 6<sup>th</sup> cut mono-PERC cells laid out as shingles.

We download from the online Module cell library the following Module cell files: mono-SE-PERCcell\_M2\_6THCUTTOP.zip, mono-SE-PERC-cell\_M2\_6THCUTMID.zip, mono-SE-PERCcell\_M2\_6THCUTBOTTOM.zip and load them into Module via Cell Library  $\rightarrow$  Add cells from another zip

Below we show the difference between arranging these cells with positive cell gap versus negative cell gap (shingling).

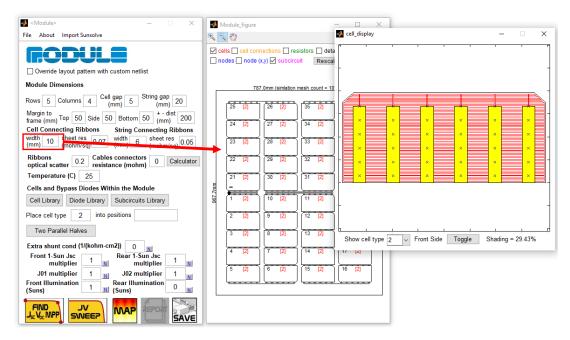
Module> — 🗆 X	Module_figure — 🗆 🗙
File About Import Sunsolve	
RODULE	cells       cell connections       resistors       details       Circuit         nodes       node (x,y)       subcircuit       Rescale       Refresh
Override layout pattern with custom netlist	Indes inde (,) ( subtreak intestate) Relesh
Module Dimensions	166.8mm (simlation mesh count = 1014)
Rows 6 Columns 1 Cell gap 2 String gap 2 (mm) 2	
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100	1 [1]
Cell Connecting Ribbons String Connecting Ribbons	
(mm) 1 sheet res 0.07 (mm) 6 sheet res (mohm/sq) 0.05	2 [2]
Ribbons optical scatter 0.2 Cables connectors 0 Calculator	3 [2]
Temperature (C) 25 Two parallel halves	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet Cells Diodes Subcircuits Conductive Backsheet	
	<sup>™</sup> 4 [2]
Place cell type into positions Extra ribbon contact Front 0 Post	
res (mohm)	5 [2]
Extra shunt cond (1/(kohm-cm2)) 0	
Front 1-Sun Jsc Rear 1-Sun Jsc 1 N multiplier	6 [3]
J01 multiplier 1 💉 J02 multiplier 1 📢	
Front Illumination 1 Rear Illumination 0 N	· · · · · · · · · · · · · · · · · · ·
✓ <module> — — X File About Import Sunsolve •</module>	Module_figure - 🗆 🗙
-	
File About Import Sunsolve ~	Setting the set of
File About Import Sunsolve ~	Setting the set of
File About Import Sunsolve	Image: Construction in the second
File About Import Sunsolve	Image: Construction in the second
File About Import Sunsolve	Image: Cells     Cell connections     resistors     details     Circuit       Inodes     node (x,y)     Subcircuit     Rescale     Refresh
File About Import Sunsolve	Image: Cell connections     resistors     details     Circuit     Image: Circuit       Image: node (x,y)     Subcircuit     Rescale     Refresh
File About Import Sunsolve > Constraints of the second sec	Image: Cells     Cell connections     resistors     details     Circuit       Inodes     node (x,y)     Subcircuit     Rescale     Refresh
File About Import Sunsolve	Image: Construction of the second of the
File About Import Sunsolve >	Cells     cell connections     resistors     details     Circuit       nodes     node (x,y)     subcircuit     Rescale     Refresh
File About Import Sunsolve >	Image: Cells     Cell connections     resistors     details     Circuit       Inodes     node (x,y)     Subcircuit     Rescale     Refresh
File About Import Sunsolve	Image: Cells     Cell connections     resistors     details     Circuit       Inodes     node (x,y)     Subcircuit     Rescale     Refresh
File About Import Sunsolve	Image: system of the system
File About Import Sunsolve	Image: Cells _ cell connections _ resistors _ details     Circuit
File About Import Sunsolve >	Image: system of the system
File About Import Sunsolve >	Image: system of the system



Firstly, the Griddler cell design page enables shingle cell type of grids to be defined. See Griddler\_and\_PRO\_manual section 2.4. Assuming that you have the right kinds of shingled cells in the cell library of Module, simply set the Cell gap to a negative number, and you're all set. Now the cells are shingled with an overlap equal to the magnitude of the cell gap. The decrease in current of any cell due to the overlap shading is automatically calculated, for both front and rear illumination cases.

#### 3.4 Ribbons and Cable Connectors

You can adjust both ribbon width and sheet resistance in the options below. Here we show what happens if you adjusted ribbon width to 10mm. The module figure will be updated, and there will also be a window that shows you the shading on the cell. You can choose which cell type to show. Here for cell type 2 the shading is 29.43%.

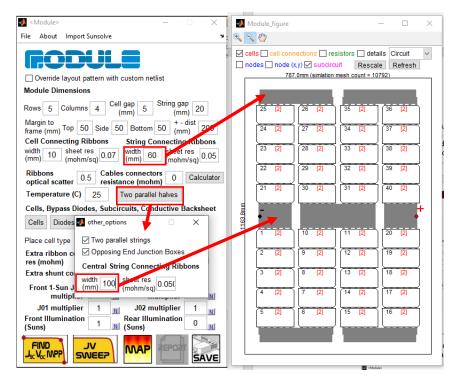


The shading depends not only on the ribbon width, but also on the ribbon optical scattering properties. Some ribbons are designed to scatter more light inside the module, resulting in higher cell light absorption. To reflect this, you can adjust "ribbon optical scatter". Value of 0 means that any light falling on the ribbon is not scattered back into the cell. Value of 1 means that all light falling on the ribbon scatters back onto the cell. You can see that adjusting this number results in a different shading percentage.



🛃 <module> — 🗆 🗙</module>	Module_figure	
File About Import Sunsolve 🛥	R Cell_display	- 🗆 ×
RODULE	Ø cells     cell connections     resistors     de       nodes     node(x,y)     subcircuit     Resc	· · ]
Override layout pattern with custom netlist		
Module Dimensions		
Rows 5 Columns 4 Cell gap 5 String gap 20 (mm)	787.0mm (similation mesh count = 1	
Margin to frame (mm) Top 50 Side 50 Bottom 50 (mm) 200		< × 1
Cell Connecting Ribbons         String Connecting Ribbons           width         10         sheet res (mom)         0.07         width         6         sheet res (mom)         0.05		
Ribbons O.5 Cables connectors O Calculator		
Temperature (C) 25 Two parallel halves		× 📃 ×
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet		
Cells Diodes Subcircuits Conductive Backsheet		_
Place cell type into positions		
Extra ribbon contact Front 0 N Rear 0 N		ا ب ب ب
Extra shunt cond (1/(kohm-cm2)) 0		ading = 19.02%
Front 1-Sun Jsc Rear 1-Sun Jsc 1		
J01 multiplier 1 📊 J02 multiplier 1 📊		
Front Illumination Rear Illumination 0		

Similarly you can adjust the width and sheet resistance of string connecting ribbons. To illustrate an exaggerated example, below we adjust them to really large values.



By default, cables and junction box related resistances are zero. If you wish to simulate their effects, you can click "Calculator" next to this field and a screen pops up which allows you to calculate the wire resistance for all kinds of copper wire gauge and lengths, as well as junction box resistance. Hitting "Apply" will enter the total resistance into the cable connections resistance field.



🛃 <module> — 🗆 🗙</module>	Module_figure — 🗆 🗙
File About Import Sunsolve	
COULS	Cells       cell connections       resistors       details       Circuit          nodes       node (x,y)       subcircuit       Rescale       Refresh         787.0mm (similation mesh count = 10792)
	Cables_connections_resistance_calculator
Rows       5       Columns       4       Cell gap (mm)       5       Sing gap (mm)       20         Margin to frame (mm)       Top       50       Side       50       Bottom       5)       + - dist (mm)       200         Cell Connecting Ribbons       String Contecting Ribbons       String Contecting Ribbons       width       10       sheet res (mchm/sq)       0.05         Ribbons       0.5       Cables connectors       7.55       Calculator         Temperature (C)       25       Two parallel h       10	Internal and contact junction box (mohm) Contact resistance per jack (mohm) Cable wire gauge (AWG) 10
Cells, Bypass Diodes, Subcircuits, Condu <sub>lle</sub> Cells Diodes Subcircuits Conductive_ibrary Place cell type into positions Extra ribbon contact Front 0 R Extra shunt cond (1/(kohm-cm2)) 0 with	Cable wire diameter (mm) 2.58826 Cable wire resist- 1.72386 Cable length (m) 1.0 Cople length
Front 1-Sun Jsc multiplier 1 General Sun Jsc 1 multiplier 1 J01 multiplier 1 J02 multiplier 1 General Sun Jsc 1 multiplier 1 General Sun Jsc 1 multiplier 1 mult	Reset to Default

## 3.5 Temperature

The temperature can be adjusted from the default value of 25°C as shown below. Module will adjust the diode recombination parameters in the cell but the user will be reminded to adjust cell current density and resistors (if there is any temperature dependence) manually.

Nodule> — 🗌 X	🛃 Module_figure — 🗆 🗙
File About Import Sunsolve 🕿	€
RODULE	Cells       cell connections       resistors       details       Circuit         nodes       node (x,y)       Subcircuit       Rescale       Refresh
Override layout pattern with custom netlist	787.0mm (simlation mesh count = 10792)
Module Dimensions	
Rows 5 Columns 4 Cell gap 5 String gap 20 (mm) 5 (mm)	25 (2) (26 (2) 35 (2) (36 (2)
Warning – 🗆 🗙	24 [2] [27 [2] [34 [2] [37 [2]
User is responsible for adjusting the cell current density and resistive elements according to the temperature set point	
ОК	22 [2] 29 [2] 32 [2] 39 [2]
Temperature (C)         50         Two parallel halves	21 [2] 30 [2] 31 [2] 40 [2]
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	
Cells Diodes Subcircuits Conductive Backsheet	
Place cell type into positions	
Extra ribbon contact Front 0 Rear 0 N	2 [2] 9 [2] 12 [2] 19 [2]
Extra shunt cond (1/(kohm-cm2)) 0	3 [2] 8 [2] 13 [2] 18 [2]
Front 1-Sun Jsc multiplier	
J01 multiplier 1 J02 multiplier 1 J Front Illumination Rear Illumination 0 J	

Module makes adjustments to the cell recombination parameters (expressed by the two diode model) according to

$$J_{01}(T) = J_{01}(25^{\circ}C) \times (n_i(T)/n_i(25^{\circ}C))^2$$
$$J_{02}(T) = J_{02}(25^{\circ}C) \times (n_i(T)/n_i(25^{\circ}C))^1$$
$$n_i(T) = 9.15 \times 10^{19} \left(\frac{T + 273.15}{300}\right)^2 exp\left(\frac{-6880}{T + 273.15}\right)$$

Where  $J_{01}$  and  $J_{02}$  are the saturation current densities of the n=1 and n=2 diodes respectively (saturation current per area values from the  $I_{01}$  and  $I_{02}$  explained in section 1.2), *T* is temperature in Celsius,  $n_i$  is the intrinsic carrier concentration in silicon. The above equations basically mean that the thermal equilibrium carrier concentration, and therefore recombination currents, increase with temperature. This leads to opencircuit voltage ( $V_{oc}$ ) and efficiency drops as temperature rises. The above equations capture most of the negative temperature coefficient in solar cell  $V_{oc}$  and efficiency. However Module does not model the comparatively minor temperature coefficient in short-circuit current density ( $J_{sc}$ ) that is due to increased absorption of infrared photons as the silicon bandgap decreases with increasing temperature.

#### 3.6 Illumination and cell diode properties

The illumination condition from the front and the rear (in units of Suns) can be adjusted in this option group. As well, without needing to access the original Griddler cell model, you can make adjustments to the cell diode properties by setting multipliers for the front and rear 1 Sun short-circuit current density ( $J_{sc}$ ), and the diode recombination current densities  $J_{01}$ ,  $J_{02}$ . You can also add additional cell level shunt conductance. For more details on the definition of these parameters and the two diode model of solar cells, refer to the Griddler and PRO manual, section 1.2 Griddler Core Model. By default, all multipliers are set to 1 and the extra shunt conductance is set to zero, meaning that there is no alteration to the diode properties of the cell model.

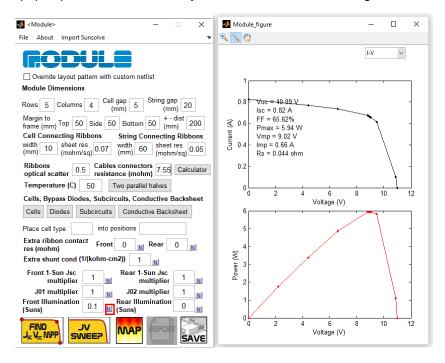
Below we illustrate the case where we set the extra shunt conductance to 1 (inverse kohm-cm<sup>2</sup>) and plot the I-V curve under low light condition of 0.1 Sun from the front.



🛃 <module> — 🗆 🗙</module>	Module_figure - 🗆 X
File About Import Sunsolve 🏻	R R 8
RODULE	FA ~
Override layout pattern with custom netlist	1,
Module Dimensions	
Rows 5 Columns 4 Cell gap 5 String gap 20	0.8 <del>Voc = 10.99 V</del> Isc = 0.82 A
Margin to frame (mm) Top 50 Side 50 Bottom 50 (mm) 200	€ 0.6 FF = 65.62% Pmax = 5.94 W
Cell Connecting Ribbons         String Connecting Ribbons           width         10         sheet res (mohm/sq)         0.07         width (mohm/sq)         60         sheet res (mohm/sq)         0.05	3         0.6         Pmax = 5.94 W           Fmax = 5.94 W         Vmp = 0.02 V           5         0.4         Imp = 0.66 A           Rs = 0.044 ohm         Rs = 0.044 ohm
Ribbons optical scatter 0.5 Cables connectors 7.55 Calculator	0.2
Temperature (C) 50 Two parallel halves	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	U 2 4 6 6 10 12 Voltage (V)
Cells Diodes Subcircuits Conductive Backsheet	6
Place cell type into positions	5-
Extra ribbon contact Front 0 N Rear 0 N	54
Extra shunt cond (1/(kohm-cm2)) 1	
Front 1-Sun Jsc Rear 1-Sun Jsc 1	
J01 multiplier 1 J02 multiplier 1 N Front Illumination 0.1 Kear Illumination 0 N	1.
	0 2 4 6 8 10 12 Voltage (V)

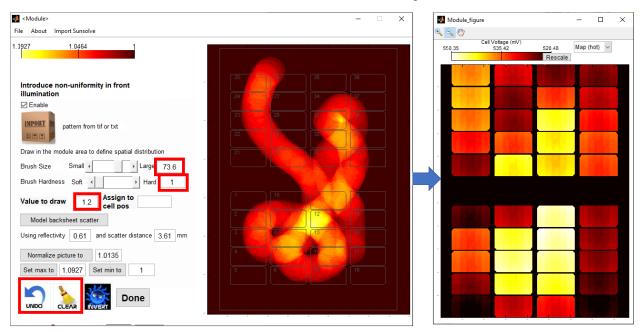
#### 3.7 Non-uniform Cell Parameters

If you have used Griddler the solar cell simulation program before, you will recognize that next to certain parameters there are <u>blue N</u> buttons (shown below). That means that for these parameters you can define spatially non-uniform distributions. Let's click on the <u>blue N</u> button next to "Front illumination". An interactive screen pops up with tools that allow you to create a non-uniform light field.





You can directly draw the light field by selecting the value to draw (specified in Suns), and then painting over the module schematic just like using paint tool. Below we show an example of such a free style illumination field definition and the resultant simulated front cell voltage near MPP:



You can also select "Import" to load a picture that represents the light field. The picture is always resized to fit right inside the module frame. If you select a greyscale tif, the grey scale will be translated into numbers representing the nonuniform parameter; if you select an RGB jpg, the R, G, B values will be translated into numbers according to number =  $sqrt(Rvalue^2 + Gvalue^2 + Bvalue^2)$ .

Module> File About Import Sunsolve				- 🗆 X	]
1.0927 1.0464 1					-
	🜏 Select file to open				×
Introduce non-uniformity in front	← → 👻 🕇 📙 « mar	uals > Module manual	5 V	Search Module manual	م
illumination	Organize 👻 New folder				
C Enable	👧 share with Spark ^	Name		Date modified	Туре
INPORT P pattern from tif or txt	<u>@</u> SolarEYE Files fo	light_field.txt		11/3/2019 11:45 am	Text Docume
	at website	👔 tree shading.jpg		13/9/2020 6:29 pm	JPG File
Draw in the module area to define spatial distri	OneDrive				
Brush Size Small (	💻 This PC				
	3D Objects				
Brush Hardness Soft	E Desktop				
Value to draw 2.0269 Assign to cell pos	🔮 Documents				
	🕂 Downloads				
Model backsheet scatter	b Music				
Using reflectivity 0.61 and scatter distance	Pictures				
	😽 Videos				
Normalize picture to 1.0135	🟪 OS (C:)				
Set max to 1.0927 Set min to 1	DATA (D:)	c I I I I I I I I I I I I I I I I I I I			>
	File nar	ne: tree shading.jpg	~	All image formats (*.jp	ar*.tifr*.k ∨
					Cancel
		1 1 1			

After loading the picture, you can make adjustments to the intensity by setting the maximum and minimum levels of the imported image as shown below. Here we set the maximum to 1 (Sun) and minimum to 0.8 (Suns). To the right is the resultant simulated front cell voltage near MPP.



🛃 <module></module>			×	Module_figure			- 0	×
File About Import Sunsolve			(	۹ 🔍 👏				
1 0,9 0,8	14 M 15	0.		Ce 562.63	I Voltage (mV) 513.96	465.29 Rescale	Map (hot) 🗸	
Introduce non-uniformity in front		35 <b>7</b> 6	-	-				
☑ Enable		28-28 PAN				A > N		
INPORT Pattern from tif or txt	23 28 29 29	32 39						
Draw in the module area to define spatial distribution		31 40		a table				
Brush Size Small								
Brush Hardness Soft <u>+</u> Hard 1		[11] [20]						
Value to draw 2.0260 Assign to cell pos								
Model backsheet scatter	2 9	12 19		$\sqrt{-1}$	$\mathbf{A}$	N POV		
Using reflectivity 0.61 and scatter distance 3.61 mm -	3 8	13 18	-				1	
Normalize picture to 0.96327	4 7	14 17		-				
Set max to 1 Set min to 0.8	5 6	15 16						
Dono						NH		
						N HV		
								-

There is a more precise way to import picture representing a nonuniform pattern, by importing a text file that has within in an N x M matrix of numbers. In this case, Module will assign these numbers exactly to the nonuniform picture inside the module frame.

0,9 0,8	10 ST 62 THE R 20 ST 10	6		
	A Select file to open			>
Introduce non-uniformity in front	← → ∨ ↑	~ Ō	Search Module manual	P
illumination	Organize 🔻 New folder			
Enable	🧟 share with Spark ^ Name ^		Date modified	Туре
IMPORT Depattern from tif or txt	SolarEYE Files fo		11/3/2019 11:45 am	Text Docur
	🐲 website 📄 tree shading.jpg		13/9/2020 6:29 pm	JPG File
Draw in the module area to define spatial distril	<ul> <li>OneDrive</li> </ul>			
Brush Size Small ∢ ► Lar	💻 This PC			
Brush Hardness Soft	3D Objects			
	Desktop			
Value to draw 1.926	Documents			
Model backsheet scatter	Downloads			
	Music ■ Pictures			
Using reflectivity 0.61 and scatter distanc	Videos			
Normalize picture to 0.96327	S (C:)			
Set max to 1 Set min to 0.8	DATA (D:)		_	
	File name: light_field.txt	~	All image formats (*.jp	nit tifet k. 🗸
🗠 🍾 🎆 Done	Inght_held.oct	Ť	An image ronnats ( .jp	g, ani, az +



Module>				- 🗆	×	Module_figure				×
File About Import Sunsolve						م 🔍 🔍				
1.3505 1.0035 0.65648						Cell V 587.19	oltage (mV) 199.65	412.12 Rescale	Map (hot)	~
Introduce non-uniformity in front					-					
INPORT pattern from tif or txt					2 -					
									r	7
Draw in the module area to define spatial distribution				40						
Brush Size Small										
Value to draw 1.926£ Assign to cell pos				20	-	-				
Model backsheet scatter		9	12	19		-		<u> </u>		
Using reflectivity 0.61 and scatter distance 3.61 mm -		8	13	18	- 1					
Normalize picture to 1.0038	4		14	17					Î	
Set max to 1.3505 Set min to 0.65648	5	6	15	16	- 1	-				
🔄 🍾 🎆 Done						-				
	1 1		<u> </u>	L L	_					

In this example we imported a text file called light\_field.txt. If we open it in excel, we see that it is a 100 x 100 array of numbers. The upper left corner of the matrix has a value of 0.657. This is exactly the number which has been assigned to the upper left corner of the module frame.

Auto	Save 💽													8	ook1 - Exce										Sam Nachar 🖽	
File	Home	Insert	Page	Layout	Formulas	Data	Review	View	Help	₽ Tel	me what you	want to d	0												년 Share	Comme
2	X Cut		Calibri		11 - A"	. = -	*	ab u	irap Text		General		1999		Normal		ad	Good		Neutral	0	alculation			I AutoSum + Arr (	0
ste	Copy		e anon									10 m	Conditiona	E Format as		-	xolanatory	-		Linked Co		ote	•	Insect De	iete Format	48
	S Form	at Painter	BI		Ø - A	e = 3	8-8 12	些 EBN	lerge & Cent	er •	\$ - % 9	*30 -00	Formatting		Children of the		xpiunatory	Imput		Dinked Ci		ote	Ŧ	*	Clear + Filter + Sel	
	lipboard	19		Font		6	A	Vignment		6	Number	- 15						Styles						0	ells Editing	
3		1.0	~ 1	0.72	16																					
5				* 0.72	3.5																					
	E	F	G	н	1	1	K	L	м	N	0	P	Q	R	S	т	U	V	W	X	Y	Z	AA	AB -		
	0.667	0.6695	0.672	0.6745	0.677	0.6795	0.682	0.6845	0.687	0.6895		0.6945	0.697	0.6995	0.702	0.7045	0.707	0.7095	0.712	0.7145	0.717	0.7195	0.722	0.724	Queries & Connections	
	0.6715	0.674	0.6765	0.679	0.6815	0.684	0.6865	0.689	0.6915	0.694		0.699	0.7015	0.704	0.7065	0.709	0.7115	0.714	0.7165	0.719	0.7215	0.724	0.7265	0.7:	Queries Connections	
	0.676	0.6785	0.681	0.6835	0.686	0.6885	0.691	0.6935	0.696	0.6985		0.7035	0.706	0.7085	0.711	0.7135	0.716	0.7185	0.721	0.7235	0.726	0.7285	0.731	0.73		
	0.6805	0.683	0.6855	0.688	0.6905	0.693	0.6955	0.698	0.7005	0.703		0.708	0.7105	0.713	0.7155	0.718	0.7205	0.723	0.7255	0.728	0.7305	0.733	0.7355	0.7	1 query	
-	0.685	0.6875	0.69	0.6925	0.695	0.6975	0.7	0.7025	0.705	0.7075		0.7125	0.715	0.7175	0.72	0.7225	0.725	0.7275	0.73	0.7325	0.735	0.7375	0.74	0.74:	ight_field	
	0.6895	0.692	0.6945	0.697	0.6995	0.702	0.7045	0.707	0.7095	0.712		0.717	0.7195	0.7265	0.7245	0.727	0.7295	0.732	0.7345	0.737	0.7395	0.742	0.749	0.74	100 rows loaded.	
	0.694	0.6965	0.7035	0.7015	0.704	0.7065	0.709	0.7115	0.714	0.7165		0.7215	0.724	0.7265	0.729	0.7315	0.734	0.7365	0.739	0.7415	0.744	0.7465	0.749	0.75		
-	0.703	0.7055	0.7033	0.7105	0.7085	0.7155	0.7155	0.7205	0.7183	0.7255		0.7305	0.7285	0.7355	0.7333	0.7405	0.743	0.7455	0.748	0.7505	0.7463	0.7555	0.758	0.76		
-	0.7075	0.71	0.7125	0.715	0.7175	0.72	0.7225	0.725	0.7275	0.72		0.735	0.7375	0.7355	0.7425	0.745	0.7475	0.75	0.7525	0.755	0.7575	0.76	0.7625	0.70		
-	0.712	0.7145	0.7125	0.7195	0.722	0.7245	0.727	0.7295	0.732	0.7345		0.7395	0.742	0.7445	0.747	0.7495	0.752	0.7545	0.757	0.7595	0.762	0.7645	0.767	0.765		
-	0.7165	0.719	0.7215	0.724	0.7265	0.729	0.7315	0.734	0.7365	0.735		0.744	0.7465	0.749	0.7515	0.754	0.7565	0.759	0.7615	0.764	0.7665	0.769	0.7715	0.7		
	0.721	0.7235	0.726	0.7285	0.731	0.7335	0.736	0.7385	0.741	0.7435		0.7485	0.751	0.7535	0.756	0.7585	0.761	0.7635	0.766	0,7685	0.771	0.7735	0,776	0.771		
	0.7255	0.728	0,7305	0.733	0.7355	0.738	0.7405	0.743	0.7455	0.748		0.753	0.7555	0.758	0.7605	0.763	0.7655	0.768	0,7705	0,773	0.7755	0.778	0.7805	0.78		
	0.73	0.7325	0.735	0.7375	0.74	0.7425	0.745	0.7475	0.75	0.7525		0.7575	0.76	0.7625	0.765	0,7675	0.77	0.7725	0.775	0.7775	0.78	0.7825	0,785	0.78		
	1.7345	0.737	0.7395	0.742	0.7445	0.747	0.7495	0.752	0.7545	0.757		0.762	0.7645	0.767	0.7695	0.772	0.7745	0.777	0.7795	0.782	0.7845	0.787	0.7895	0.7		
	0.739	0.7415	0.744	0.7465	0.749	0.7515	0.754	0.7565	0.759	0.7615		0.7665	0,769	0.7715	0.774	0.7765	0.779	0.7815	0.784	0,7865	0.789	0.7915	0.794	0.79		
	0.7435	0,746	0,7485	0.751	0.7535	0.756	0.7585	0.761	0.7635	0.766	0.7685	0.771	0.7735	0.776	0.7785	0.781	0.7835	0.786	0.7885	0.791	0.7935	0.796	0.7985	0.8(		
	0,748	0.7505	0.753	0.7555	0.758	0.7605	0,763	0.7655	0,768	0.7705	0.773	0.7755	0.778	0.7805	0.783	0.7855	0,788	0.7905	0.793	0,7955	0,798	0.8005	0,803	0.805		
	1.7525	0.755	0,7575	0.76	0.7625	0.765	0.7675	0.77	0.7725	0.775	0.7775	0.78	0,7825	0.785	0.7875	0.79	0.7925	0,795	0.7975	0.8	0.8025	0.805	0.8075	0.8		
	0.757	0.7595	0.762	0.7645	0.767	0.7695	0.772	0.7745	0.777	0.7795	0.782	0.7845	0.787	0.7895	0.792	0.7945	0.797	0.7995	0.802	0.8045	0.807	0.8095	0.812	0.814		
	0.7615	0.764	0.7665	0.769	0.7715	0.774	0.7765	0.779	0.7815	0.784	0.7865	0.789	0.7915	0.794	0.7965	0.799	0.8015	0.804	0.8065	0.809	0.8115	0.814	0.8165	0.8		
	0.766	0.7685	0.771	0.7735	0.776	0.7785	0.781	0.7835	0.786	0.7885	0.791	0.7935	0.796	0.7985	0.801	0.8035	0.806	0.8085	0.811	0.8135	0.816	0.8185	0.821	0.82		
	0.7705	0.773	0.7755	0.778	0.7805	0.783	0.7855	0.788	0.7905	0.793	0.7955	0.798	0.8005	0.803	0.8055	0.808	0.8105	0.813	0.8155	0.818	0.8205	0.823	0.8255	0.8		
	0.775	0.7775	0.78	0.7825	0.785	0.7875	0.79	0.7925	0.795	0.7975	0.8	0.8025	0.805	0.8075	0.81	0.8125	0.815	0.8175	0.82	0.8225	0.825	0.8275	0.83	0.83		
1	0.7795	0.782	0.7845	0.787	0.7895	0.792	0.7945	0.797	0.7995	0.802	0.8045	0.807	0.8095	0.812	0.8145	0.817	0.8195	0.822	0.8245	0.827	0.8295	0.832	0.8345	0.8		
	0.784	0.7865	0.789	0.7915	0.794	0.7965	0.799	0.8015	0.804	0.8065	0.809	0.8115	0.814	0.8165	0.819	0.8215	0.824	0.8265	0.829	0.8315	0.834	0.8365	0.839	0.84:		
	0.7885	0.791	0.7935	0.796	0.7985	0.801	0.8035	0.806	0.8085	0.811	0.8135	0.816	0.8185	0.821	0.8235	0.826	0.8285	0.831	0.8335	0.836	0.8385	0.841	0.8435	0.84		
	0.793	0.7955	0.798	0.8005	0.803	0.8055	0.808	0.8105	0.813	0.8155		0.8205	0.823	0.8255	0.828	0.8305	0.833	0.8355	0.838	0.8405	0.843	0.8455	0.848	0.850		
1	0.7975	0.8	0.8025	0.805	0.8075	0.81	0.8125	0.815	0.8175	0.82		0.825	0.8275	0.83	0.8325	0.835	0.8375	0.84	0.8425	0.845	0.8475	0.85	0.8525	0.85		
	0.802	0.8045	0.807	0.8095	0.812	0.8145	0.817	0.8195	0.822	0.8245		0.8295	0.832	0.8345	0.837	0.8395	0.842	0.8445	0.847	0.8495	0.852	0.8545	0.857	0.855		
1	0.8065	0.809	0.8115	0.814	0.8165	0.819	0.8215	0.824	0.8265	0.829		0.834	0.8365	0.839	0.8415	0.844	0.8465	0.849	0.8515	0.854	0.8565	0.859	0.8615	0.8		
	0.811	0.8135	0.816	0.8185	0.821	0.8235	0.826	0.8285	0.831	0.8335		0.8385	0.841	0.8435	0.846	0.8485	0.851	0.8535	0.856	0.8585	0.861	0.8635	0.866	0.86	A support folder to establish	
1	0.8155	0.818	0.8205	0.823	0.8255	0.828	0.8305	0.833	0.8355	0.838		0.843	0.8455	0.848	0.8505	0.853	0.8555	0.858	0.8605	0.863	0.8655	0.868	0.8705	0.8	A synced folder is missing.	
	0.82	0.8225	0.825	0.8275	0.83	0.8325	0.835	0.8375	0.84	0.8425		0.8475	0.85	0.8525	0.855	0.8575	0.86	0.8625	0.865	0.8675	0.87	0.8725	0.875		Backup and Sync is trying to sync "Deskto	
1	0.8245	0.827	0.8295	0.832	0.8345	0.837	0.8395	0.842	0.8445	0.847		0.852	0.8545	0.857	0.8595	0.862	0.8645	0.867	0.8695	0.872	0.8745	0.877	0.8795		the folder has either been moved or delete	HO.
	0.829	0.8315	0.834	0.8365	0.839	0.8415	0.844	0.8465	0.849	0.8515		0.8565	0.859	0.8615	0.864	0.8665	0.869	0.8715	0.874	0.8765	0.879	0.8815	0.884	0.88		-
-	0.8335	0.836	0.8385	0.841	0.8435	0.846	0.8485	0.851	0.8535	0.856	0.8585	0.861	0.8635	0.866	0.8685	0.871	0.8735	0.876	0.8785	0.881	0.8835	0.886	0.8885	0.8	STOP SYNCING THIS DIRECTORY	LOCATI
		Sheet2	Sheet1	(+)																				1		

Besides using the brush, you can also set the value to draw, and then put the cell numbers to assign the value to. In this example we assign 1.5 to cell positions 1,6,32,40:



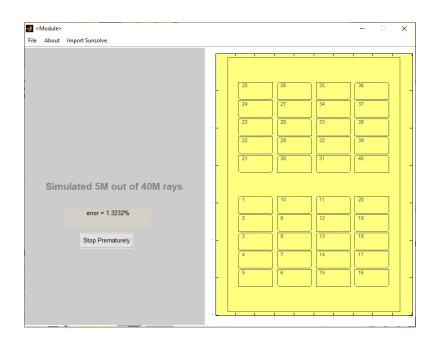
Amodule>					×						
File About Import Sunsolve											
1.3505 1.0035 0.65648											
Introduce non-uniformity in front	25 24				]   -						
Import	23										
	22			39					32	39	
Draw in the module area to define spatial distribution Brush Size Small  Large 73.6	21			40						40	
Brush Hardness Soft  Hard 1 Value to draw 1.5 Assign to cell pos 1,6,32,40				20	1 -	-	1	10			
Model backsheet scatter			12	19	<u>j</u>		2	2		19	
Using reflectivity 0,61 and scatter distance 3,61 mm -	3	8	13	18		•				18	-
Normalize picture to         1.0038           Set max to         1.3505         Set min to         0.65648	4		14	17					14	17	

Let's go back to the example where we imported a jpg representing leaf shading. We hit "Done" to go back to the main screen, and we can hit MAP to run a simulation (at this example at 37V) to see the impact of the shading on the cell voltage near MPP condition. Of course, you can also re-run the I-V curve on your own.

With illumination light fields, you'll notice that there is an additional tool to define non-uniform light distribution, called "Model backsheet scatter". This is a rough tool that calculates the enhanced light absorption in the solar cell due to light incident on the backsheet, in the gaps between cells or gap between cell and the module frame. The user must enter the backsheet total reflectance, as well as the scatter distance, which describes the point spread function of the light scattering laterally inside the module. Feel free to explore this calculator on your own and run some simulations. Here, first we clear the shaded pattern light field by pressing "Clear" in the non-uniform spatial distribution page for Front illumination, and then pressing "Model backsheet scatter" using the default reflectivity and scatter distance. You see that the light intensity falling near cell edges is enhanced because of the backsheet scattering.



<module> le About Import Sunsolve</module>					_	
		<u> </u>	<u> </u>	<u> </u>	<u> </u>	
Introduce non-uniformity in front illumination		25	26	35	36	
✓ Enable		24	27	34	37	
DIPORT In action from til ocht	-	23	28	33	38	
pattern from tif or txt		22	29	32	39	
Draw in the module area to define spatial distribution		21	30	31	40	
Brush Size     Small      →     Large     73.6       Brush Hardness     Soft      →     Hard     1						
Assign to cell pos		1	10	11	20	
Model backsheet scatter		2	9	12	19	
Jsing reflectivity 0.61 and scatter distance 3.61 mm		3	8	13	18	
Normalize picture to 1		4	7	14	17	
Set max to 1 Set min to 1	-	5	6	15	16	





<module> ile About Import Sunsolve</module>			-	
1869 1.0934 1				
Introduce non-uniformity in front	26	35	36	
	27	34	37	
INPORT pattern from tif or txt	28	33	38	
	29	32	39	
Draw in the module area to define spatial distribution	30	31	40	
Brush Size Small	ليسميها ال	اعصا ا	مسجعها ا	
Brush Hardness Soft				
Value to draw 1.5 Assign to cell pos	10		20	
Model backsheet scatter	9	12	19	
Using reflectivity 0.61 and scatter distance 3.61 mm -	8	13	18	
Normalize picture to 1.0096	7	14	17	
Set max to 1.1869 Set min to 1	6	15	16	
UNDO CLEAR	لمحقد) ال			

For the diiode parameter multipliers (1 Sun Jsc and J01, J02), one can also model cell to cell variability within the module. In this example below, press the <u>blue N</u> button next to "J01 multiplier", which is a modification factor to the J01 (recombination) of the cell type at the positions within the module.

🛃 <module> — 🗆 🗙</module>	Module_figure — 🗆	$\times$
File About Import Sunsolve 🗣	Q Q ∅	
	✓ cells _ cell connections _ resistors _ details Circuit _          □ nodes _ node (x,y)	
Override layout pattern with custom netlist		
Module Dimensions		
Rows 5 Columns 4 Cell gap 5 String gap 20	25 [2] 26 [2] 35 [2] 36 [2]	
Margin to frame (mm) Top 50 Side 50 Bottom 50 + - dist 200	24 [2] 27 [2] 34 [2] 37 [2]	
Cell Connecting Ribbons         String Connecting Ribbons           width         10         sheet res (mohm/sq)         0.07         width (mohm/sq)         60         sheet res (mohm/sq)         0.05	23 [2] [28 [2] [33 [2] [38 [2]	
Ribbons optical scatter 0.5 Cables connectors 7.55 Calculator		
Temperature (C) 50 Two parallel halves		
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet		
Cells Diodes Subcircuits Conductive Backsheet		
Place cell type into positions		
Extra ribbon contact Front 0 Rear 0 N		
Extra shunt cond (1/(kohm-cm2)) 1		
Front 1-Sun Jsc Rear 1-Sun Jsc IIII multiplier		
J01 multiplier 1 📕 J02 multiplier 1 関		
Front Illumination CSuns)		

In the window to define the spatial distribution of the J01 multiplier, press "Model cells variability" using mean 1 and standard deviation of 0.1. You can see that each cell will be randomly assigned a value according to normal distribution of mean 1 and standard deviation 0.1. Below we show this and the resultant front cell voltage at open-circuit conditions.



🛃 <module></module>				- 0	×	📣 Module_figure	– 🗆 X
File About Import Sunsolve						🔍 🔍 🖑	
1.2095 1.0271 0.84472						Cell Voltage (mV) 632.93 627.97	623.00 Map (hot) V
Introduce non-uniformity in J01	-		35	36	_		
☑ Enable	24	27	34	37			
DIPORT In pattern from tif or txt	- 23	28	33	38	_		
	22	29	32	39			
Draw in the module area to define spatial distribution	21	30	31	40			
Brush Size Small							
Brush Hardness Soft						-	
Value to draw 2 Assign to cell pos	-	10	11	20	-		
Model cells variability	2	9	12	19			
Using mean 1 and std deviation 0.1	- 3	8	13	18	-		and the second s
Normalize picture to 1.0096	4	7	14	17			
Set max to 1.2095 Set min to 0.84472	- 5	6	15	16	_	-	

#### 3.8 Extra Ribbon Solder Point Contact Resistance

🛃 <module> — 🗆 🗙</module>	Modu	ıle_figu	re			-		×
File About Import Sunsolve 🔷	€, €, ₹	ŋ						
RODULE			connection de (x,y) 🗹			<sup>letails</sup> Ci Rescale	rcuit ~	·
Override layout pattern with custom netlist			956.0mm	(simlation	has			
Module Dimensions		1 [1	1 [1]	21 [1]	<b>(</b> 1)	41 [1]	[1]	
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2			20	<u> </u>	40		60	
Margin to frame (mm) Top 20 Side 5 Bottom 10 + - dist (mm) 100		2 [1	] [1] 19	22 [1]	[1] 39	42 [1]	[1] 59	
Cell Connecting Ribbons         String Connecting Ribbons           width 1         sheet res (mm)         0.07           (mm) 1         (mohm/sa)         0.05		3 [1		23 [1]	[1]	43 [1]	[1]	
Ribbons O.2 Cables connectors O. Calculator		4 [1	18 ] [1]	24 [1]	38 [1]	44 [1]	58 [1]	
			17		37		57	
Temperature (C) 25 Two parallel halves	.	5 [1	1 [1]	25 [1]	[1]	45 [1]	[1]	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet			16		36		56	
Cells Diodes Subcircuits Conductive Backsheet	1632	6 [1	] [1]	26 [1]	[1]	46 [1]	[1]	
Place cell type into positions			15		35		55	
Extra ribbon contact Front 0 Rear 0		7 [1		27 [1]	[1]	47 [1]	[1]	
Extra shunt cond (1/(kohm-cm2)) 0		8 [1	14	28 [1]	34	48 [1]	54	
Front 1-Sun Jsc Rear 1-Sun Jsc 1 Multiplier 1 N			13	20 [1]	33	40 [1]	53	
101 multiplier 1 102 multiplier 1		9 [1	1 [1]	29 [1]	[1]	49 [1]	[1]	
Front Illumination (Suns) 1 M (Suns) 0 N			12	Ļ	32	ļ	52	
		10 [1	] [1] 11	30 [1]	[1] 31	50 [1]	[1] 51	

There is much interest in the investigation of whether a certain interconnection scheme is robust against imperfect solder joint/conductive adhesive joint contacts, or deterioration of contacts as the module is used in the field over time. In section 4.5, we will illustrate a very precise way of modelling nonzero ribbon joint contact resistance, by editing the Griddler cell model and then introducing the cell model into Module.



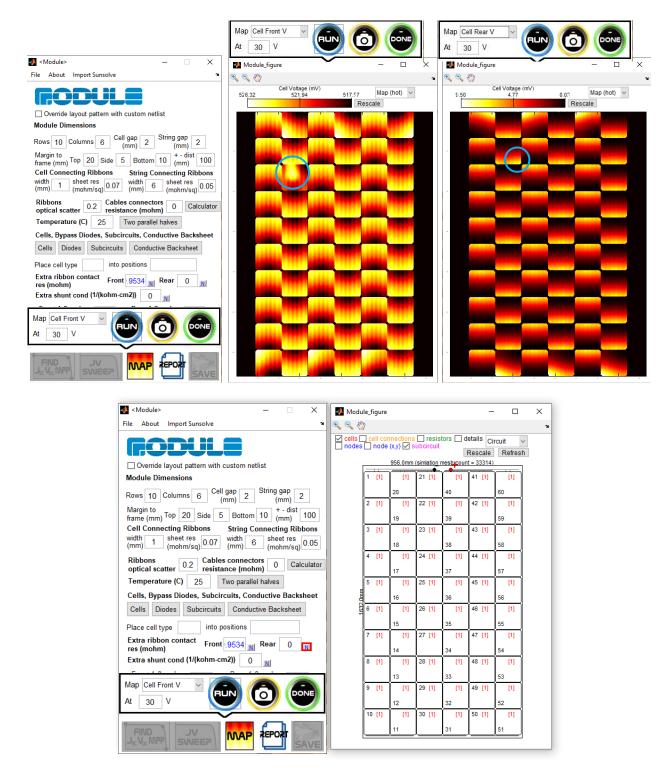
However, this method is time consuming because the cell analysis process takes a long time, and also, only users with software bundle license has access to Griddler 2.5 PRO for cell level editing. So, we have also introduced a much quicker way to allow the user to directly define joint contact point resistance in Module itself.

To introduce front side ribbon contact resistance, you can either directly enter a non-zero number into the box next to Extra ribbon contact res Front. This will assign that number in mohms to all front ribbon solder joint points in the module. Very frequently, one might want to investigate the impact of incidental bad contact resistance that occur locally in certain areas of the module. To do that press the blue N button next to "Extra ribbon contact res (mohm) Front". As above, this will bring you to the interactive screen to define the nonuniform front ribbon contact resistance, where, as before, you can either import a picture describing the spatial pattern, or use the drawing tool to define areas with high contact resistance, as shown below.

Module>		- 🗆 X
File About Import Sunsolve	Grey dots are the front ribbon solder points	
Introduce non-uniformity in extra front ribbon contact res		
Draw in the module area to define spatial distribution Brush Size Small  Large Brush Hardness Soft Value to draw 200 Assign to		Use drawing tool to define areas with high contact resistance
Model cells variability		
Using mean 1 and std deviation 0 Normalize picture to 0.81407 Set max to 200 Set min to 0 UNDO CLEAR WITH DONE	22 -	

Once done, the average front ribbon contact resistance will be displayed as a blue number in the main screen, and the simulations will incorporate these additionally added contact resistance. In the example below, we show the cell front and rear voltage drops at 1 Sun illumination and 30V. One can see that the extra contact resistance has caused the voltage to swell locally, and has also slightly altered the rear side voltage pattern of the neighbouring cell.

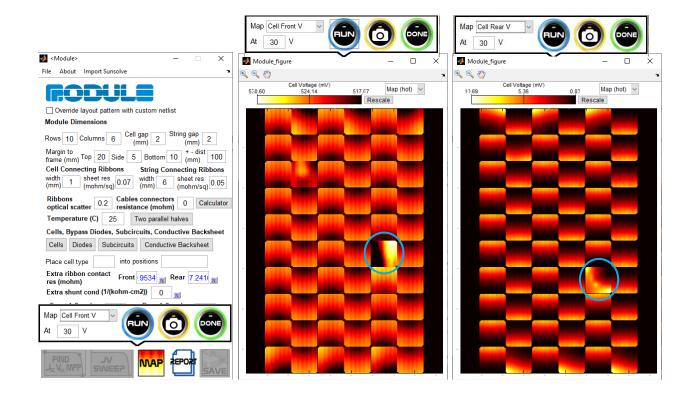




Similarly, to introduce rear side ribbon contact resistance, you can either directly enter a non-zero number into the box next to Extra ribbon contact res Rear, or introduce a spatial pattern by pressing the blue N button next to "Extra ribbon contact res (mohm) Rear". Once done, the average rear ribbon contact resistance will be displayed as a blue number in the main screen, and the simulations will incorporate these additionally added contact resistance.



🛃 <module></module>			×
File About Import Sunsolve			R
1000 500 0	Grey dots are the rear ribbon solder points		
Introduce non-uniformity in extra rear ribbon contact res	-		
Draw in the module area to define spatial distribution		Use drawing tool to define areas	
Brush Size     Small ✓     →     Large       Brush Hardness     Soft     ✓     →     Hard       Value to draw     1000     Assign to cell pos	10 100	with high contact resistance	
Model cells variability	0.02 -		
Normalize picture to 6.7446 Set max to 1000 Set min to 0	-		_
	-		_





## **4** Cell Library

#### 4.1 Introduction

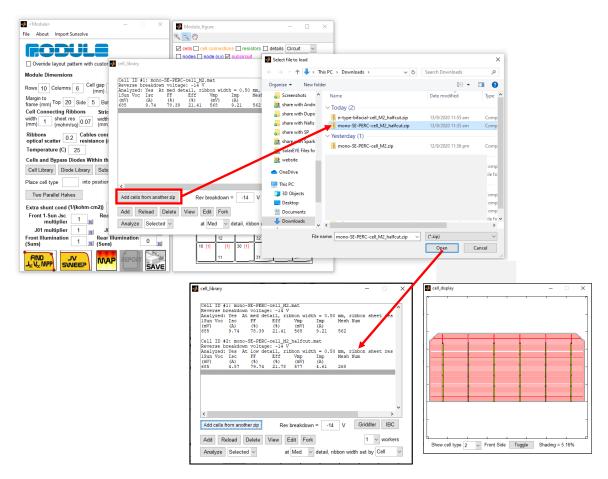
The cell library stores different cell models ready to be placed into the module. Here we start from the beginning and click File  $\rightarrow$  Open  $\rightarrow$  and load mono-SE-PERC-cell\_M2.zip. Click Cell Library to open it. There is one cell type in the library. Click view to look at the schematic of this cell.

🛃 <module></module>	– 🗆 X	Module_figure	– 🗆 🗙	1		
File About Import Sunsolve		€				
Override layout pattern with custor	cell_library	Cells       cell connections       resistors         nodes       node (x,y)       subcircuit       F		cell_display		- 🗆 X
Module Dimensions	Cell ID #1: mono-SE-					
Rows         10         Columns         6         Cell gap (mm)           Margin to frame (mm)         Top         20         Side         5         Bot           Cell Connecting Ribbons         Stefn         Stefn         Mathematical steps         Stefn           width         1         sheet res         0.07         (mth         (mchnr/sq)         0.07         (mth	Reverse breakdown vo Analyzed: Yes At me ISun Voc Isc FH (mV) (A) (4	ltage: -14 V d detail, ribbon width = 0.50 mm, r Eff Vmp Imp Mesh	ibbon sheet res			
Ribbons 0.2 Cables conr optical scatter 0.2 Cables conr resistance (r Temperature (C) 25				×.		-
Cells and Bypas Diodes Within th Cell Library Diode Library Subo Place cell type into position	<		, i			-
Two Parallel Halves	Add cells from another z	p Rev breakdown = -14 V	Griddler IBC			
Extra shunt cond (1/(kohm-cm2)) Front 1-Sun Jsc multiplier J01 multiplier 1 NJ J(	Add Reload Dele Analyze Selected ~	te View Edit Fork at Med v detail, ribbon wi	1 v workers dth set by Cell v	Show cell type 1 Frc	nt Side Toggle Sl	hading = 5.24%
Front Illumination Rear IIIC (Suns)		12 32 10 [1] [1] 30 [1] [ 11 31	52 50 (1) (1) 51			

There are two ways to add more cell types into this session:

## 4.2 Adding Cells from Zip File

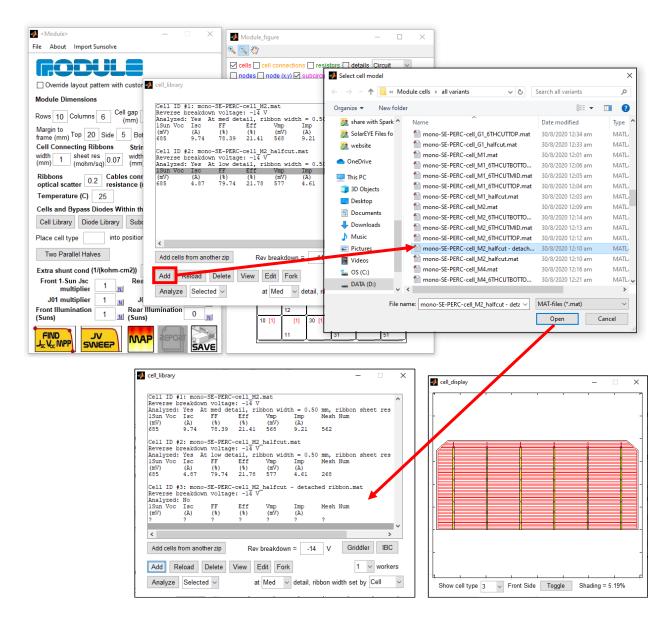
Clicking "Add cells from another zip" will load cell types that exist in other zipped session files. This cell type can be readily inserted into the Module and used in simulation.



# 4.3 Adding Cells from Griddler Files (For users with bundled software license)

**[For users with bundled software license]** Clicking "Add" allows you to load Griddler cell models (multiple selection is permitted). Because the cell model is in the Griddler format with a high number of FEM nodes, this cell type cannot be immediately used in Module simulation. First it needs to go through a reduction process, where a smaller Module cell model with fewer number of FEM nodes is generated based on the Griddler cell model.



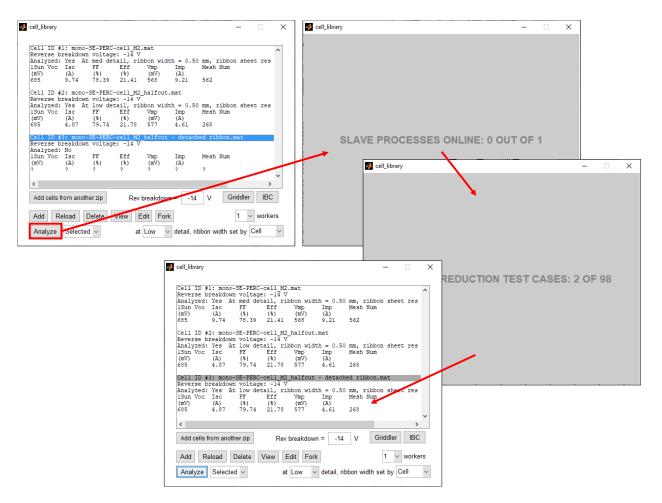


# 4.4 Analyzing Griddler Cells Files (For users with bundled software license)

**[For users with bundled software license]** Choose the newly imported Griddler cell model. Choose the level of detail you wish to generate the reduced Module cell model. We recommend "Medium" for full size cell, "Low" for half cut cells, and "very low" for 5<sup>th</sup> or 6<sup>th</sup> cut cells. Click "Analyze" and a process of Griddler simulation and analysis will take place to generate the reduced Module cell model. This process will take a few minutes.

It is also possible to analyze multiple loaded Griddler cell models. To do so, in the popup menu that says "Selected", choose "Cell #s" and then an edit box will appear allowing you to enter the Cell IDs in the library you wish to simultaneously analyze. In the popup menu that says "1" workers, you can choose up to 8 Griddler workers to run the reduction process in parallel.

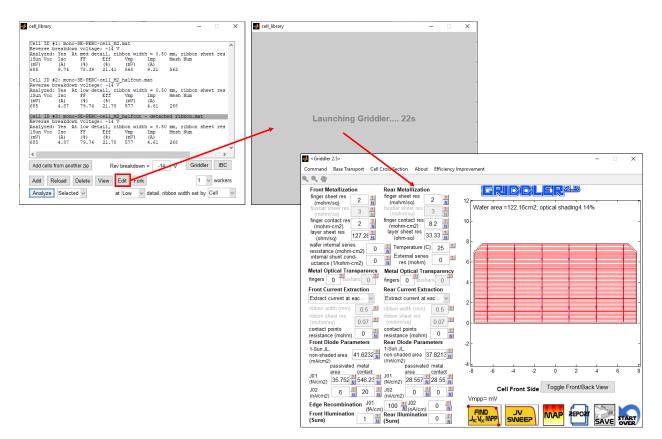




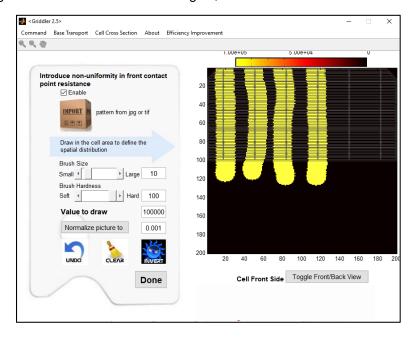
# 4.5 Editing Griddler Cell Files in Detail (For users with bundled software license)

**[For users with bundled software license]** For cell types loaded from Griddler models, it is always possible to load the original Griddler model in Griddler 2.5 PRO (or if it is an IBC model, in Griddler IBC), edit it in great detail, save it and then re-analyze the cell type in Module. To do so, select the cell type you wish to edit in the listbox, and then press "Edit".





**[For users with bundled software license]** In this example, we edit the Griddler cell model at a level of detail not possible in Module: we introduce very large solder point contact resistance at 4 of the 6 busbars, thereby simulating 4 detached ribbons. After doing so, we resave the Griddler model

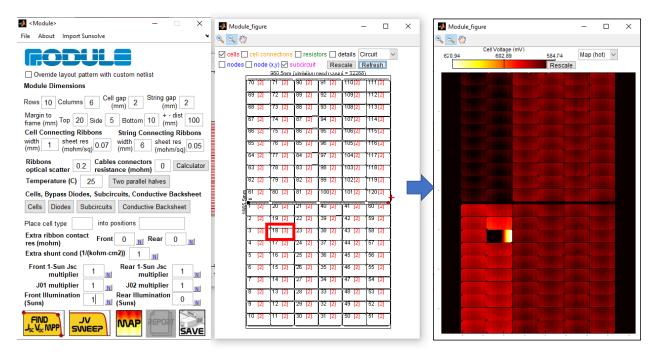




Back in Module, we click "Analyze" to re-analyze this cell type. You can see now the resultant cell FF has dropped from 79.74% (before simulating the detached ribbons) to 60.16% (after simulating the detached ribbons).

cell_library							-		$\times$
Cell ID #	1: mono-	SE-PERC-	-cell M2.	mat					^
Reverse b	reakdown	voltage	e: −14 V						
Analyzed:	Yes At	med det	tail, rib	bon widt	h = 0.50	mm, ribb	on shee	et res	
1Sun Voc			Eff	Vmp		Mesh Num			
(mV)	(A)	(%)	(%)	(mV)	(A)				
		78.39		568	9.21	562			
Cell ID #	2: mono-	SE-PERC-	-cell M2	halfcut.	mat				
Reverse b	reakdown	voltage	e: -14 V	-					
Analyzed:	Yes At	low det	tail, rib	bon widt	h = 0.50	mm, ribb	on shee	et res	
1Sun Voc	Isc	FF	Eff	Vmp	Imp	Mesh Num	1		
(mV)	(A)	(%)	(%)	(mV)	(A)				
685					4.61	268			
Cell ID #					<ul> <li>detach</li> </ul>	ed ribbon	.mat		
Reverse b									
Analyzed:								et res	
1Sun Voc		FF	Eff	Vmp		Mesh Num	1		
(mV)	(A)	(%)	(%)		(A)				
685	4.87	60.16	16.43	472	4.25	268			
									×
<								>	
Add cells f	rom anoth	erzip	Rev b	oreakdown	-14	V	Griddler	IBC	
Add Re	eload C	)elete	View	dit Fork			1 ~	worke	rs
Analyze	Selected	$\sim$	at	Low ~	detail, rit	obon width	set by	Cell	$\sim$

Now, if we created a module where every cell position is populated with cell type 2 (halfcut cell with no detached ribbon) except for position 18 which is populated with cell type 3 (halfcut cell with detached ribbon), we can simulate the effects of such a detached ribbon cell within the module. The picture to the right below shows the front cell voltage distribution near MPP.



## 4.6 Reverse Breakdown Voltage

If the imported cell type does not have its own reverse breakdown behavior defined (i.e. hotspots and edge breakdown), you can add a reverse breakdown voltage in the process shown below. If the imported cell type has its own reverse breakdown characteristics, then Module will emulate it during the cell analysis process (See next section 4.7)

Analyzed:	reakdowr	SE-PERC voltage med det	e: -14 V		lth = 0.5	0 mm, ri	bbon she	et res	'
1Sun Voc			Eff	Vmp		Mesh N	um		
(mV) 685	(A) 9.74	(%) 78.39	(%) 21.41	(mV) 568	(A) 9.21	562			
Cell ID #	2: mono-	SE-PERC-	-cell_M2	halfcut	.mat				
Reverse b									L
Analyzed: 1Sun Voc	Isc	FF	Eff	Vnp	Imp	0 mm, ri Mesh N		et res	
		(%) 79,74		(m7) 57	(A) 4.61	268			
Cell ID # Reverse b Analyzed:	reakdowr Yes At	n voltage ; low det	e: -14 V tail, ri	- bbon wid	lth = 0.5	0 mm, ri	bbon she	et res	
1Sun Voc (mV)			Eff		Imp (A)	Mesh N	um		
(mv)		(*) 60.16				268			
685									
								>	
			_						-
685	rom anoth	ier zip	Rev	breakdov	/n = -20	v	Griddler	IBC	

In the example above, we have set cell type 2 reverse breakdown voltage to be -20V. We can see the effect of this setting by running a simulation in which one of the cell is current limiting, and there are no bypass diodes in the module. Below, if we map the module front plane voltage, we can see a step at the current limiting cell, and the step in the voltage is about 20V, meaning that the current limiting cell is revers biased at approximately the breakdown voltage.

🛿 <module> — 🗆 X</module>	Module_figure	– 🗆 X
File About Import Sunsolve 🗣	e e	
RODULE	Voltage (V) 10.01 -1.35 -12	71 Map (hot) V
Override layout pattern with custom netlist		
Module Dimensions		
Rows     10     Columns     6     Cell gap     2     String gap     2       Margin to frame (mm)     Top     20     Side     5     Bottom     10     (mol)       Cell Connecting Ribbons     String Connecting Ribbons     String Connecting Ribbons       width     1     sheet res (mohn/sq)     0.05		Current limiting cell in module without bypass
Ribbons optical scatter 0.2 Cables connectors 0 Calculator Temperature (C) 25 Two parallel halves		diodes
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet		
Cells Diodes Subcircuits Conductive Backsheet		
Place cell type into positions Extra ribbon contact res (mohm) Front 0 IN Rear 0 IN		
Extra shunt cond (1/(kohm-cm2)) 1		
Map Cell Front V V At 10 V		



## 4.7 Detailed Reverse Breakdown Simulations

Griddler manual section 6.8 covers the definition of hotspots and wafer edge breakdown on the cell level. Once done, one can as usual add the cell model into the Module cell library to analyze it.

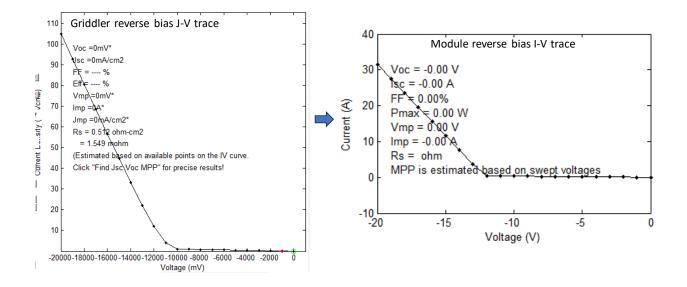
Module>	-					-	
Command File About Improvement			lule_figure			- 0	×
		- 🔍 🔍	-				-
		<ul> <li>cells</li> <li>node</li> </ul>	cell col s 🗌 node	nnections ( (x,y) 🗹 su	] resistor bcircuit	s details Circuit ~ Rescale Refresh	
Override layout pattern with custom net	cell_library					- 0	×
Module Dimensions							
Rows 10 Columns 6 Cell gap 2	Cell ID #1: 202 Reverse breakdo Analvzed: No				ky edge.	mat	
Margin to frame (mm) Top 20 Side 5 Bottom	ISun Voc Isc (mV) (A)	FF (%) 2	Eff (%) 2	Vmp (mV)	Imp (A)	Mesh Num	
Cell Connecting Ribbons         String Cc           width (mm)         1         sheet res (mohm/sq)         0.07         width (mm)         6	£ £	2	2	1	2	2	l I
Ribbons 0.2 Cables connector resistance (moh							
Temperature (C) 25 Two paralle							
Cells, Bypass Diodes, Subcircuits, Con							
Cells Diodes Subcircuits Conduct							
Place cell type into positions							
Extra ribbon contact res (mohm) Extra shunt cond	Add cells from an	other zip	Rev	breakdow	n = -14	V Griddler IBC	
Extra shunt cond (1/(kohm-cm2)) @1Sun 0 M @0Su					_		_
Front 1-Sun Jsc Rear 1-S	Add Reload	Delete	View	Edit For	< .	1 v worke	rs
	Analyze Selec	:ted $\sim$	а	t Med 🕓	detail, ri	ibbon width set by Cell	$\sim$
Front Illumination (Suns) 1 M (Suns) 1 J02 m				12	32	52	
	SAVE						

The analysis will result in a reverse breakdown voltage that is consistent with the cell level reverse bias characteristics.

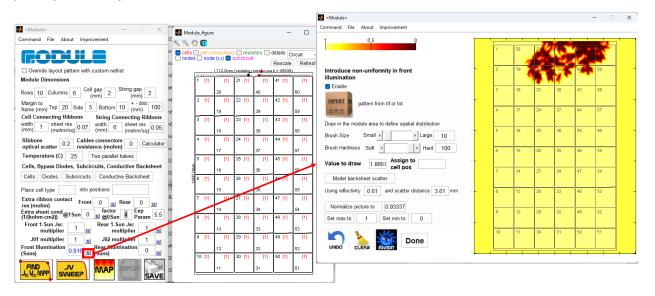
Rever Analy 1Sun	se br zed: Voc	eakdown Yes At Isc	voltag med de FF	e: -11.3 tail, r: Eff	3921 V ibbon wid Vmp	ky edge.m th = 2.00 Imp			sheet	res
(mV) 700		(A) 12.19			(mV) 592	(A) 11.63	824			
Add	cells fr	om anothe	ər zip	Rev	/ breakdow	n =14	V	Gric	ldler	IBC



The module reduced cell will have the same reverse bias characteristics as the full Griddler model. Note in the below, the left J-V curve (Griddler, with current density in units of mA/cm<sup>2</sup> and voltage in units of mV) and the right I-V curve (Module, with current in units of A and voltage in units of V) have identical results, after accounting for the cell area of 330.69 cm<sup>2</sup>.



To illustrate a realistic module cell reverse bias condition, below we will simulate a partial shading condition where the front illumination pattern is 1 Sun except at the top section of the module where a few cells are partially shaded by a tree.





Below is the I-V characteristics under this partial shading condition (the module has three bypass diodes).

🛃 <module> — 🗆 🗙</module>	Module_figure — 🗆 🗙
Command File About Improvement	Q, Q, 🖑 🔟
RODULE	V-1
Override layout pattern with custom netlist	12,
Module Dimensions	10
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2	8
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100	(4) 6
Cell Connecting Ribbons String Connecting Ribbons width sheet res out width sheet res out	<u>ل</u> وال المراجع
(mm) 1 (mohm/sq) 0.07 (mm) 6 (mohm/sq) 0.05	2
Ribbons optical scatter         0.2         Cables connectors resistance (mohm)         0         Calculator	0-
Temperature (C) 25 Two parallel halves	-20 10 20 30 40 50
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	0 10 20 30 40 50 Voltage (V)
Cells Diodes Subcircuits Conductive Backsheet	
Place cell type into positions	0.8
Extra ribbon contact res (mohm)	
Extra shunt cond @1Sun 0 factor 4 Exp (1/(kohm-cm2)) @1Sun 0 @0Sun 4 Param 5.5	0.6
	0.4-
SWEEP RANGE	-
0 to 42 step 1 V	0.2 -
	0 0.2 0.4 0.6 0.8 1 Voltage (V)

Below are the cell voltages and module cell voltage progression, at the voltage at MPP of 27V:

	× polication	/U5 KB				
	🐪 🚺 Module_fi	igure		-		×
Command File About Improvement	🔍 🔍 🥙 🚺	n an				
	1	Cell Voltage (mV)				
	696.03	565.68	<=435 33	Map (	(hot) 🗸	
	1,4		Res	cale		
Override layout pattern with custom netlist						
Module Dimensions	12					
	23		1.1			
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2			1000			
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100						
Cell Connecting Ribbons String Connecting Ribbon	s					
width 1 sheet res 0.07 width 6 sheet res 0.0						
(mm) (mohm/sq) (0.07 (mm) (mohm/sq) (0.0	5					
Ribbons Cables connectors						
optical scatter 0.2 resistance (mohm) 0 Calcula	tor					
Temperature (C) 25 Two parallel halves			· · · ·			
Two parallel haives						
Cells, Bypass Diodes, Subcircuits, Conductive Backshee	et 👘					
Cells Diodes Subcircuits Conductive Backsheet			1 N			
Place cell type into positions						
			· · · ·		-	
Extra ribbon contact Front 0 N Rear 0 N						
Extra shunt cond (1/(kohm-cm2)) @1Sun 0 M @0Sun 4 Param 5.	5		<del> </del>		-	
Map Diode V 🗸 🦳 🦳						
		1 1 1		1		
At 27 V						
		1. 17. 1		1		
Jsc Voc MPP SWEEP SWEEP SAV	E		11 44			
				-	-	-



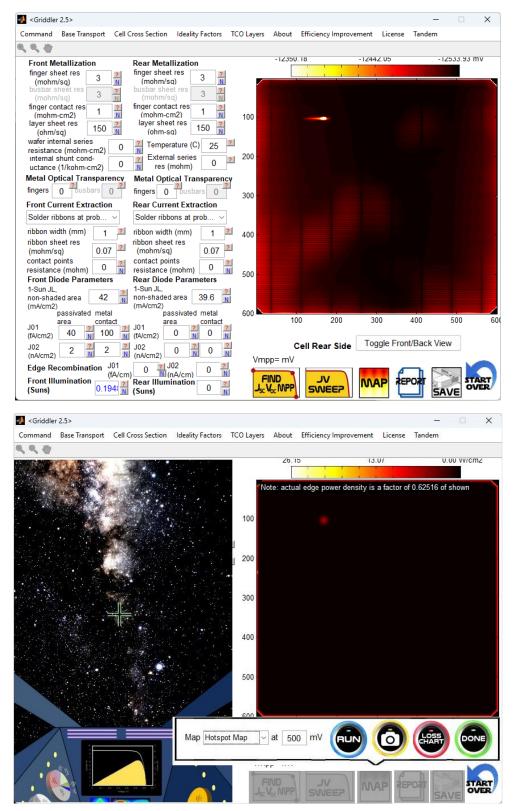
All	polication	705 KB		_	_	
Command File About Improvement	Module_figure			-		×
Command File About improvement	- 🔍 🔍 🖑 🔟					
RODULE	27.02	Voltage (V) 13.84	0.67		hot) 🗸	
Override layout pattern with custom netlist			1.00	Jaire		
Module Dimensions	v					
Rows 10 Columns 6 Cell gap 2 String gap 2 (mm) 2	2)					
Margin to frame (mm) Top 20 Side 5 Bottom 10 (mm) 100						
Cell Connecting Ribbons         String Connecting Ribbons           width         1         sheet res         0.07         width         6         sheet res         0.05           (mm)         1         (mohm/sq)         0.07         width         6         (mohm/sq)         0.05						
Ribbons 0.2 Cables connectors 0 Calculator	]					
Temperature (C) 25 Two parallel halves						
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet						
Cells Diodes Subcircuits Conductive Backsheet						
Place cell type into positions						
Extra ribbon contact res (mohm) Extra shunt cond exter o factor t Exp						
Extra shunt cond @1 Sun 0 factor Exp 5.5 (1/(kohm-cm2)) 6.5						
Map Front plane V 🗸 🦱 🦱						
At 27 V RUN O ONE						

As in P.10 of section 2.2, one can select a cell to zoom in on with detailed Griddler simulation:

Command File About Improvement  Command File About Improvement	×
Columns       6       Cell gap       2         String gap       2	
Module Dimensions Rows 10 Columns 6 Cell gap 2 String gap 2	
Rows 10 Columns 6 Cell gap 2 String gap 2	
Rows 10 Columns 6 2 2 2 2 2 2	
(mm) (mm) Select Cell Number to Zoom	
Margin to frame (mm) Top 20 Side 5 Bottom 10 + - dist 100	
Cell Connecting Ribbons String Connecting Ribbons	
width 1 sheet res 0.07 width 6 sheet res 0.05 41 OK Close	
Ribbons 0.2 Cables connectors 0 Calculator resistance (mohm) 0 Calculator	
Temperature (C) 25 Two parallel halves	
Cells, Bypass Diodes, Subcircuits, Conductive Backsheet	
Cells Diodes Subcircuits Conductive Backsheet	
Place cell type into positions	
Extra ribbon contact Front 0 N Rear 0 N	
Extra shunt cond (1/(kohm-cm2)) @1Sun 0 @0Sun 4 Param 5.5	
Map Front plane V V RN RN RN RN I V V	
At 27 V	



We pick on the shaded and reverse biased cell 41. Here are the detailed Griddler simulation of the shaded cell voltage and hotspot distributions:





Now, in Griddler, when one clicks on report, there will be a record of the hotspot and edge breakdown power dissipation information at the bottom of the report.

2023-09-16 ce	ell number 41 at MPP.	×	+		
File Edit Vie	ew.				
1090.00000 1100.00000 1110.00000 1120.00000 1130.00000 1140.00000 1150.00000 1160.00000 1170.00000 1180.00000 1190.00000	61.643766 54.680582 48.355694 41.085728 34.423950 25.981904 19.287929 12.843966 7.138521 2.197424 1.222553				
1200.000000	0.748758				Two botcoots location
Hotspots:					Two hotspots location
x y (cm) (cm)	radius power ( (um) (W)	dissi	pation		and power dissipation
-4.000000 -9.100000	6.000000 2.000000		.000000	 32974 93094	
Edge reverse b	reakdown: 55.607	518	W 👞	Edg	e breakdown total
x y (cm) (cm)	power dissipat (W) 9.100000	ion	.91921	-	ver dissipation
0.000000 -0.285658 -0.571315 -0.856973 -1.142630	9.100000 9.099999 9.099999 9.099999	0.1 0.1 0.1 0.1	.91939 .91831 .91889 .92016	-	preakdown ed power ation
4 400000	0.00008	0.1	00005	distrib and po	ution (position ower)



### **5 Diode Library**

The diode library lists the bypass diodes. By default there is one bypass diode type. The bypass diode is characterized by a two diode model with recombination currents  $I_{01}$ ,  $I_{02}$ , series resistance  $R_s$  and shunt conductance in units of 1/(kohm). You can change these parameters and then click "Set Changes" to apply the changes, or Add to define more bypass diode types.

In the next section we will show how to insert bypass diodes into the module.

🛃 <module> — 🗆 🗙</module>	Module figure — 🗆 X
File About Import Sunsolve	
Coverride layout pattern with custom netlist	Cells       cell connections       resistors       details       Circuit         nodes       node (xy)       Subcircuit       Rescale       Refresh         900.5mm (simistion mestr usual = 32266)
Module Dimensions	70 (2) 71 (2) 90 (2) 91 (2) 110(2) 111(2)
Rows 10 Columns 6 Cell gap 2 String conditioned diode_li	ibrary – – ×
Margin to frame (mm) Top         20         Side         5         Bottom         10         + (n         Diode           Cell Connecting Ribbons width         1         Sheet res (mm)         5         String Connectin (fA)         101 (fA)           0.07         (mm)         6         met         1000         1000	ID #1: IO2 Rs shunt cond (nA) (mohm) 1/(kohm) 0 100.00 0.00
Cables connectors     0       optical scatter     0.2     Cables connectors     0       Temperature (C)     25	
Cells and Bypass Diodes Within the Module           Cell Library         Diode Library         Celd control to the module           Place cell type         2         into positions	
Two Parallel Halves	¥
Front 1-Sun Jsc Rear 1-Sun Jsc multiplier 1 J01 multiplier 1 J02 multiplier 5 Front Illumination Serie	t conductance = 0.0 nA Set Changes Add Delete se resistance = 10.0 mohm

## 6 Subcircuits Library

#### **6.1 Introduction**

The subcircuit library offers the ultimate flexibility in defining cell layout patterns in the module, insertion and deletion of connections, and other micro operations. It is also the window in which you can insert bypass diodes. To access it, press Subciruits Library in the main screen. As a start, each cell type in the cell library is one subcircuit, as shown below.

🛃 <module> —</module>	X Module_figure — 🗆 X
File About Import Sunsolve	
Override layout pattern with custom netlist	R, R, (*)
Module Dimensions	Subcircuits
Rows       10       Columns       6       Cell gap (mm)       2       String gap (mm)       2         Margin to frame (mm)       Top       20       Side       5       Bottom       10       + - dist (mm)         Cell Connecting Ribbons       String Connecting Rib       String Shet res (mm)       6       sheet res (mohm/sq)	<pre>1 mono-SE-PERC-cell M2.mat W=156.75mm H=156.75mm no of cells=1 no of nodes= 2 mono-SE-PERC-cell M2_halfcut.mat W=156.75mm H=78.38mm no of cells=1 no of nodes= 3 mono-SE-PERC-cell M2_halfcut - detached ribbon.mat W=156.75mm H=78.38mm no of cells=1 no of nodes=</pre>
Ribbons       0.2       Cables connectors       0       Calc         optical scatter       0.2       resistance (mohm)       0       Calc         Temperature (C)       25       25       Cells and Bypass Diodes Within the Module	
Cell Library Diode Library Subcircuits Library Place cell type 2 into positions Two Parallel Halves	Rename       Delete       Save       (Save Current Module Circuit as Subcircuit)       Other micro operations (on main page circuit)         Place in Module       (Place chosen subcircuit into Module)       Other micro operations (on main page circuit)         View operations       0 modes       1 and 1         with a ribbon       of       1 mohm/sq
Extra shunt cond (1/(kohm-cm2)) 0 Front 1-Sun Jsc multiplier 1 J01 multiplier 1 Front Illumination 0.996 Suns FIND JV	As an array of Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Num Spacing (mm) Set or Deactivate node 1 as a + v terminal Create node at (0, 0)mm, or Remove Num Spacing Create Num Spacing (x,y) = (0, 0) mm Create Nudge Subcircuit Clear Dangling Nodes Clear diodes
	Clear Ungrounded Parts Clear All UNDO REDO

To illustrate the use of the various functions in the subcircuit library, we will start from scratch and build a module that consist of 6<sup>th</sup> cut mono-PERC cells.

We download from the online Module cell library the following Module cell files: mono-SE-PERCcell\_M2\_6THCUTTOP.zip, mono-SE-PERC-cell\_M2\_6THCUTMID.zip, mono-SE-PERCcell\_M2\_6THCUTBOTTOM.zip and load them into Module via Cell Library  $\rightarrow$  Add cells from another zip

### 6.2 Save Current Module Circuit As Subcircuit

In the Module main page, we use the "Place cell type X into positions X" method, and adjust the module dimensions, to first create a 6 cell shingled module, as shown below.



X	Module_figure – 🗆 🗙
File About Import Sunsolve	<b>€ €</b> <i>(</i> <sup>1</sup> / <sub>2</sub> )
	✓ cells _ cell connections _ resistors _ details       Circuit _ ∨         □ nodes _ node (xy) ✓ subcircuit       Rescale       Refresh
Module Dimensions	
Rows       6       Columns       1       Cell gap (mm)       1       String gap (2)         Margin to frame (mm)       Top       20       Side       5       Bottom       10       + - dist       100         Cell Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       width       1       sheet res       0.07       (mm)       6       sheet res       0.05         Ribbons       0.2       Cables connectors       0       Calculator         Temperature (C)       25       Cells and Bypass Diodes Within the Module	166.8mm (similation mesh count = 1014)
Cell Library       Diode Library       Subcircuits Library         Place cell type       3       into positions         Two Parallel Halves       Extra shunt cond (1/(kohm-crm2))       0       10         Front 1-Sun Jsc       1       Mathematical Strain Schematical Strain Schema	

Press Subcircuits Library to view it. You see that as a start, each cell type is a subcircuit.

File       About Import Sunsolve         Import Sunsolve       Import Sunsolve	
○ Verride layout pattern with custom netlist         Module Dimensions         Rows 6       Columns 1       Cell gap (mm) -1       String gap (mm) -2         Margin to frame (mm) Top 20       Side 5       Bottom 10       (mm) (mm) (mm) (mm) -2         Weils 6.75mm       H=26.13mm       no of cells=1       no of nodes=         mono-SE-PERC-cell M2 ofHCUTIOP.mat       Ferles 6.75mm       H=26.13mm       no of nodes=         winstein (mm) Top 20       Side 5       Bottom 10       (mm) (mm) (mm)       String Connecting Ribbors         Cell Connecting Ribbors       String Connecting Ribbors       String Connecting Ribbors       No of cells=1       no of nodes=	
□ Override layout pattern with custom netlist         Module Dimensions         Rows 6       Columns 1       Cell gap1       String gap2 (mm)1       Subcircuits         Margin to frame (mm) Top 20       Side 5       Bottom 10       + - dist 10 (mm)       Imomo-SE-PERC-cell M2 GTHCUTIOP.mat H=156.75mm       no of cells=1       no of nodes= no of cells=1         We string Ribbons       String Connecting Ribbon       String Connecting Ribbon       H=26.13mm       no of cells=1       no of nodes= H=26.75mm	×
Module Dimensions       String gap (mm)       String (	
Rows       6       Columns       1       Cell gap (mm)       2         Margin to frame (mm)       Top       20       Side       5       Bottom       10       +- dist 10 (mm)       10       clist 10       no of cells=1       no of nodes=         Cell Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       No of cells=1       no of nodes=	
width 1 sheet res 0.07 width 6 sheet res (mm) 6 (mohm/sq) 0.0	
Ribbons optical scatter       0.2       Cables connectors       0       Calcula         Temperature (C)       25       Cells and Bypass Diodes Within the Module       >         Cell Library       Diode Library       Subcircuits Library       >	-
Rename Delete Save (Save Current Module Other micro operations (on main page circuit)	
Place certifyipe       3       into positions       Connect       or       1       and       1         Two Parallel Halves       Place in Module       (Place chosen subcircuit into Module)       with a ribbon       of       1       mohm/sq       >	
Extra shunt cond (1/(kohm-cm2))       0       0         Front 1. Sun Jsc multiplier       1       Rear 1-Sun Jsc multiplier       1       Num Spacing       ower left       corner is at (mm)       with width       1       mm, thickness       NA         J01 multiplier       1       J02 multiplier       1       1       (x,y) = (0, 0)       0)       mm         Front Illumination (Suns)       1       J02 multiplier       1       Then rotate about center by 0       Cols       1       Then rotate about center by 0       Set or Remove cell       1       to be type       1         FIND Swieger       JV Swieger       State       Sa       Sa       Num Spacing       Clear Dangling Nodes       Clear diades         Clear Ungrounded Parts       Clear All       UNDO       Clear All       UNDO       Rest	

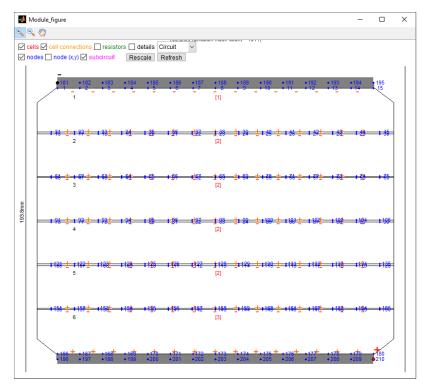


Press Save to save the current module layout as a subcircuit which you can edit and reuse as a part. A dialog box pops up asking you to give this subcircuit a name. We call it "6 cell block".

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Subcrouis 1 mono-SE-PERC-cell_M2_6THCUTTOP.mat W=156.75mm H=26.15mm no of cells=1 2 mono-SE-PERC-cell M2_6THCUTHOI.mat W=156.75mm H=26.15mm no of cells=1 3 mono-SE-PERC-cell M2_6THCUTBOTTOM.mat W=156.75mm H=163.75mm no of cells=6 W=156.75mm H=163.75mm no of cells=6	no of nodes- no of nodes- no of nodes- no of nodes-
< <tr>          Rename         Delete         Save (Save Current Module (Cricut as Subcircuit))           Place in Module         (Place chosen subcircuit into Module)           As an array of Num Spacing Rows 1         Iower left v corner is at (x,y) = (0, 0, 0) mm Then rotate about center by 0 degrees Nudge Subcircuit</tr>	Other micro operations (on main page circuit)         Connect or Disconnect nodes 1 and 1         with a ribbon of 1 mohm/sq v         with width 1 mm, thickness NAmm         Set or Deactivate node 1 as a + v terminal         Create node at (0,0 mm, or Remove node 0         Set or Remove cell 1 to be type 1         Clear Dangling Nodes         Clear All         UNDO REDO

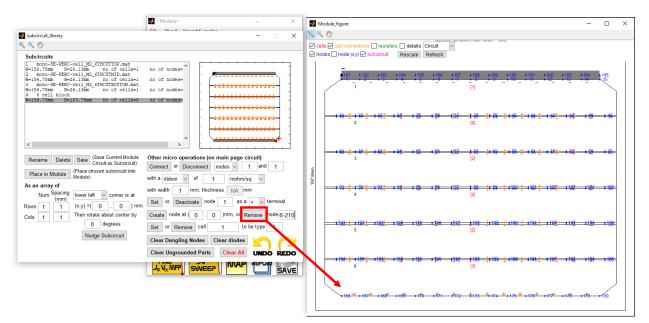
## 6.3 Removing nodes and deactivating terminals

We can also make edits to the existing module layout before saving as a subcircuit. First, in the module figure, check "nodes" to show the ID of each node in the connection diagram. You can resize the window, use zoom, and hit "refresh" to get a clear view of the parts you would like to do editing on.

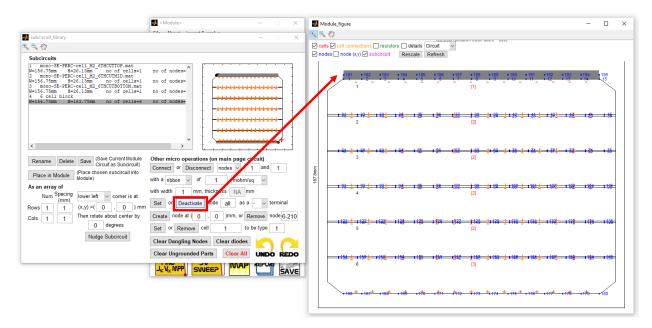




Let's remove the bottom ribbon from this circuit. To do so, in the subcircuit library window, type 196-210 next to "node" and click "remove". You can see now that these nodes, as well as all ribbon connections associated with them, are removed.



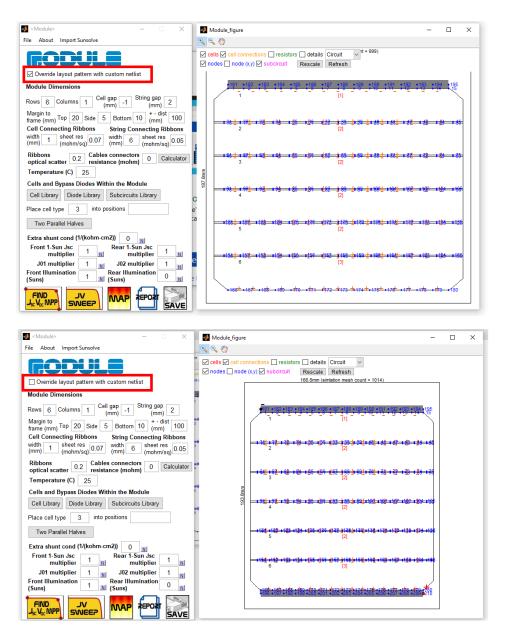
Let's deactivate also all terminal connections. To do so, set node to "All" and the popupmenu to "-" next to terminal, and click deactivate. You can see now the node 181 is no longer a negative terminal.



We can now save this circuit as a subcircuit called "6 cell block no bottom ribbon".

Note that as soon as you do any editing to the circuit, Module will check the box in the main page "Override layout pattern with customer netlist". This means that the edited circuit is shown in the Module\_figure instead of the original rectangular layout as defined in the main page. If you uncheck this box, then the original rectangular layout (with terminals and the bottom ribbon) are displayed again, and you can then use this as a starting point to create other edited subcircuits.





We do so and with more editing, create other subcircuits called "6 cell block no top ribbon" and "6 cell block no top or bottom ribbons".



## 6.4 Place Subcircuits into Module

Now we are ready to layout the subcircuits we created into the module. To start, in the subcircuit library, press "Clear All" and the Module\_figure becomes a blank canvas.

	<module> —</module>	— <b>П</b>	×
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€ € *			
Subcircuits           1         mono-SE-PERC-cell H2_GTHCUTTOP.mat           M=156.75mm         H=26.13mm         no of cells=1           2         mono-SE-PERC-cell H2_GTHCUTTOP.mat           3         sco.5mm         H=26.13mm           3         sco.5mm         H=26.13mm           4         sco.5mm         H=26.13mm           4         sco.5mm         H=26.13mm           5         sco.5mm         H=63.75mm           6         scoll block no bottom ribbond         scollsed           6         cell block no robottom ribbond         scollsed           6         cell block no robottom ribbond         scollsed	no of nodes= no of nodes]	s details Circuit v Rescale Refresh	
7 6 cell block no top or bottom ribbons F=156.75mm B=151.75mm no of cells=6 < Rename Delete Save (Save Current Module Place in Module (Place chosen subcircuit) Place in Module (Place chosen subcircuit into Module)	no of nodese     Implementation       Other micro operations (on main page circuit)       Connect of Disconnect Indes v 1 and 1       with a ribbon v of 1		
As an array of Num Spacing (mm)         Iower left         comer is at           Rows         1         1         (x,y) = (0         0         0         mm           Cols         1         1         Then rotate about center by 0         0         gerees	with width 1 mm, thickness NA mm Set or Deactivate node all as a + v terminal Create node at (0,0)mm, or Remove node 6-210 Set or Remove cell 1 to be type 1		
Nudge Subcircuit	Set     of     remove     clear     clear     of     clear     cle		

We select "6 cell block no top or bottom ribbons", and then we create the right settings in the Array section, i.e. layout subcircuit as an array of 2 rows by 1 column, row spacing of -1 mm (for the shingling), and we place the lower left corner of the subcircuit at (x,y) = (0,0). Then we press "Place in Module".

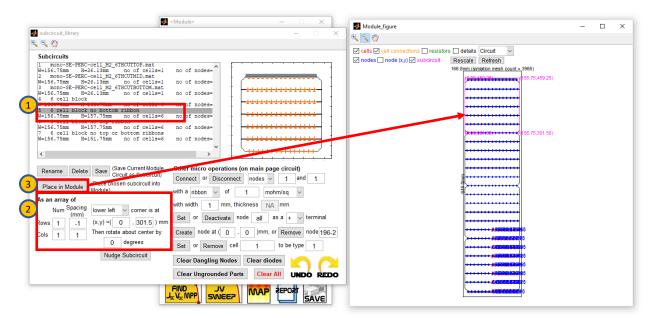
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Đ	- • • *			
	Subcircuits 1 mono-SE-PERC-cell M2 6THCUTTOP.mat H=16.75m H=26.15m no of cells=1 2 mono-SE-PERC-cell M2 6THCUTHOP.mat H=16.75m H=26.15m no of cells=1 3 mono-SE-PERC-cell M2 6THCUTHOTION.mat H=16.75m H=26.15m no of cells=1 4 6 cell block H=16.75m no of cells=6 5 6 cell block no bottom ribbon H=16.75m no of cells=6 6 6 cell block no top ribbon H=16.75m no of cells=6 7 6 cell block no top ribbon H=16.75m no of cells=6 7 6 cell block no top or bottom ribbon H=16.75m no of cells=6 7 6 cell block no top or bottom ribbon H=16.75m no of cells=6 7 6 cell block no top or bottom ribbon H=16.75m no of cells=6	no of nodes no of nodes	Cells Connections resistors details Circuit Condes node (x,y) subcircuit (Rescale) Refresh 168.8mm (similation mesh count = 1988) (156.75,302.50)	
3	<     Rename Delete Save (Save Current Module Circuit as Subcircuit) (Place documentum 100	Other micro operations (on main page circuit)		
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	Rows         2         -1         (x,y) =(         0         ,         0         ) mm           Cols         1         1         Then rotate about center by         0         degrees	Create         node at (         0         )mm, or         Remove         node         196-2           Set         or         Remove         cell         1         to be type         1		
	Nudge Subcircuit	Clear Dangling Nodes Clear diodes		
			56.75,0.00)	

We select "6 cell block no top ribbon", and then we create the right settings in the Array section, i.e. layout subcircuit as an array of 1 row by 1 column, and we place the top left corner of the subcircuit at (x,y) = (0,1). Then we press "Place in Module". This will place this subcircuit below the existing laid out circuit with an overlap of 1mm. Note that if you made a mistake, you can always click Undo, or enter new coordinates and press "Nudge Subcircuit" to re-place.



X	– – ×	
☐ cells ☐ cell connections ☐ resistors ☐ details Circuit ✓		
	R2 effective       no of nodese         m no of cells=1       no of nodese         m no of cells=6       of nodese         m no of cells=6       no of nodese         m no of cells=6       of nodese         m no of cells=6       no of nodese         m no of cells=6       of nodese         udde subcircuit       Ceare of Disconnect         udge Subcircu	

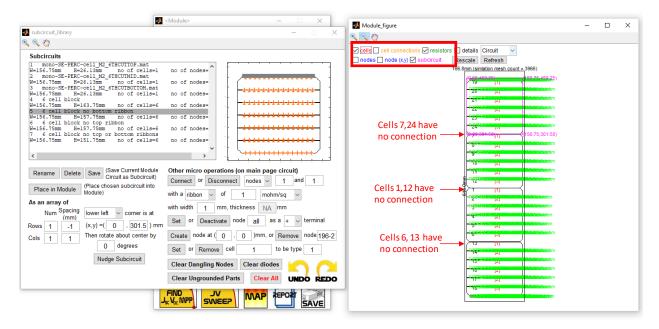
We select "6 cell block no bottom ribbon", and then we create the right settings in the Array section, i.e. layout subcircuit as an array of 1 row by 1 column, and we place the bottom left corner of the subcircuit at (x,y) = (0,301.5). Then we press "Place in Module". This will place this subcircuit above the existing laid out circuit with an overlap of 1mm. Note that if you made a mistake, you can always click Undo, or enter new coordinates and press "Nudge Subcircuit" to re-place.



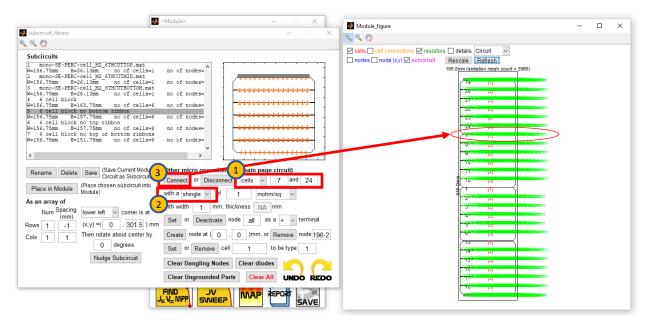


### 6.5 Making Connections

Now, if we go to Module\_figure and check "resistors", we can see the resistor values of every connection in the circuit, shown in green numbers. We can see that there is no connection between cells 7,24, between cells 1,12, and between cells 6,13.



To connect cells 7,24, set "cells" to be 7 and 24, set connection to be "shingle" and then click "connect". Module will search for nearest neighbours of + and - cell terminals and connect them with shingle connections (which have near zero resistance).



We continue on to connect all adjacent cells with shingle connections.



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		<u>≪</u> ≪ *		
Subcircuits		Cells Cell connections ✓ resistors details Circuit ✓     nodes node (x,y) ✓ subcircuit Rescale Refresh		
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		1990-200		

We save this entire subcircuit and call it "string".

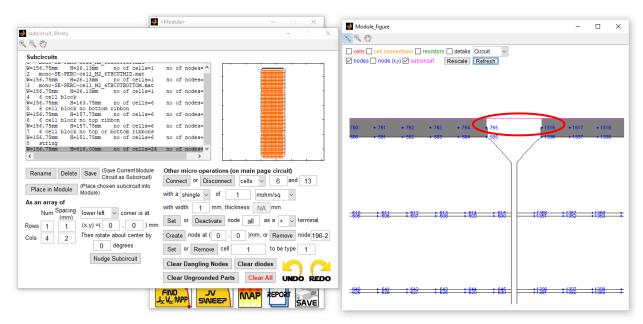
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Subcircuits					
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Num Spacing (mm)     lower left or corner is at (x,y) = (0, 301.5) mm       Cols     1       Then rotate about center by 0 degrees       Nudge Subcircuit	Set or Remove cell 1 to be Clear Dangling Nodes Clear diodes	nove node 196-2 type 1	-1-12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/0000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/00000     -12/2014/0000     -12/2014/0000     -12/2014/0000       -12/2014/00000     -12/2014/00000     -12/2014/00000     -12/2014/00000       -12/2014/00000     -12/2014/00000     -12/2014/00000     -12/2014/00000       -12/2014/000000     -12/2014/000000     -12/2014/000000     -12/2014/000000       -12/2014/00000000000000000000000000000000		

As before, we now press "Clear All" to start with a blank canvas, and then we layout an array of 1 row by 4 columns of "string".



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meiles.rsmin       image: Sister in no of cells=1       no of nodes         mono-SE-ERC-cell Lyck       no of nodes       no of nodes         moto-SE-ERC-cell Lyck       no of nodes       no of nodes         moto-Second       no of nodes       no no declise (an indicid no indicid no indino indicid no indicid no indicid no indicid no indino indicid no in	Subcircuits		
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<sup>1</sup> 6 cell block no top or bottom ribbons           of node= <sup>2</sup> block no top or bottom ribbons           of node= <sup>2</sup> block no top or bottom ribbons           of node= <sup>2</sup> block no top or bottom ribbons           of node= <sup>2</sup> block no top or bottom ribbons           for dellate line <sup>2</sup> block no top or bottom ribbons           for dellate line <sup>2</sup> block no top or bottom ribbons           for dellate line             Place in Module           for dellate line             Place in Module           for dellate line             Mum Spacing         for dellate line           for dellate node             Num Spacing         for dellate line           set or leachtate node         all as a + + terminal             Clast All         O degrees           Set or Remove cell           tob be type             Nudge Subcircuit             Clear All         Undor Redoe           Undor Redoe             Lear Ungrounded Parts         Clear All         Undor Redoe             Undor Redoe	6 6 cell block no top ribbon	no of nodes=	
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Clear All Derived Concernance       Cells of and 13         Place in Module       Formation Concert or Disconnect (cells of and 13)         With a shingle of 1       motim/sq of motion concernance         Num Specific lower left or corner is at nome       set or Deactivate node all as a + v terminal         Cols 4       2         Num Specific lower left or corner is at nome       Create node at (0, 0) mm, or Remove node 196-2         Set or Remove cell       1         Nudge Subcircuit       Clear All Dubo REDO	W=156.75mm H=616.00mm no of cells=24	no or nodes- +	
Levalue       Delet       Variable       Circuit as connect       of       Disconnect       Oil       Disconnect       Disconnect	- (Save Current Module -	Swett micro operations (on main page circuit)	
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Rows 1       1       (x,y) = (0, 0) mm       0       mm       or an ode at (0, 0) mm, or Remove node 196.2         Cols       4       2       Then rotate about center by O degrees       Create node at (0, 0) mm, or Remove node 196.2       0         Nudge Subcircuit       Clear Dangling Nodes       Clear diodes       0       0         Clear Ungrounded Parts       Clear All       UNDO       REDO	Num <sup>Spacing</sup> lower left v corner is at		
All Service     O degrees     Set or Remove cell     1     to be type     1       Nudge Subcircuit     Clear Dangling Nodes     Clear diddes     Image: Clear All UNDO REDO			
Nudge Subcircuit     Clear Dangling Nodes     Clear All     UNDO     REDO	JUIS 4 Z	Create node at (0,0)mm, or Remove node 196-2	
Clear Dangling Nodes Clear diodes Clear All UNDO REDO		Set or Remove cell 1 to be type 1	
	Nudge Subcircuit	Clear Dangling Nodes Clear diodes	
		Clear Ungrounded Parts Clear All	

Again, there are no connections between the strings. For example, if you zoom into the top part, check "nodes" and click "refresh" to display the nodes, you'll find there needs to be ribbon connection between nodes 765 and 1516.

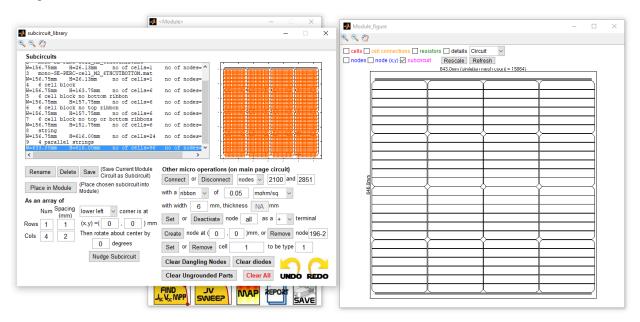


To establish the ribbon connection, set "nodes" to be 765 and 1516, then select "ribbon" of "0.05 mohm/sq" and width "6 mm", then press Connect.



	Module> - · · ×	Module_figure -		×
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Retraining     Detect     Save     Circuit as Subcircuit 3       Place in Module     (Place chosen subcircuit into Module)     (Place chosen subcircuit into Module)       As an array of Num Spacing Rows 1     1     (x,y) = (0, 0) mm	ther micro opsention 1 nain page circuit Connect or Disconnect modes 766 and 1516 with a mibbon of 0.05 mohm/sq v th width 6 mm, thickness NA mm Set or Deactivate node all as a + v terminal Create node at (0, 0) mm, or Remove node 196-2 Set or Remove cell 1 to be type 1	- <del>200 + 201 + 207 + 203 + 200 + 205</del> + <del>11367 + 1382</del>	<del>:1389</del> —	
	Clear Dangling Nodes Clear diodes Clear All UNDO REDO		:1381-	

We finish off all the needed ribbon cross connections, then save this subcircuit with the name "4 parallel strings".

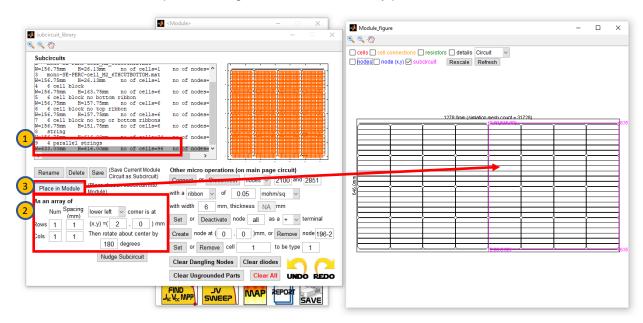


We press "Clear all" again to start with a blank canvas, and then we select the 4 parallel strings subcircujit, array of 1 by 1, and place the subcircuit with lower right corner at (x,y) = (0,0).



subcircuit_library	- X Module_figure	- 0
Subcircuis H=156.75mm H=26.13mm no of cells=1 no of nodes= 1 mon-SE-PERC-cell H2_CHECUBOITOM.mat H=156.75mm H=26.13mm no of cells=1 no of nodes= 4 cell block no bottor ribbon H=156.75mm H=157.75mm no of cells=6 no of nodes= 6 cell block no bottor ribbon H=156.75mm H=157.75mm no of cells=6 no of nodes= 7 cell block no topto bottor ribbons H=156.75mm H=157.75mm no of cells=6 no of nodes= 1 string H=151.75mm no of cells=6 no of nodes= 1 string H=151.05mm no of cells=9 no fr nodes= 1 string H=151.05mm no of cells=9 no fr nodes=	Cells Cell connections   resistors   details Circuit   Circuit   Disded mode (xy) / subcruit Rescale Refresh B43.0nm (siniskior mesh usau i = 15824) 	12,00,9
Num Spacing (mm)         Lower right         Connect         of         Disco           Num Spacing (mm)         Iower right         corner is at (mm)         with a fibbon         o         o           Solution         Individe         with width         6         mit           Num Spacing (mm)         Iower right         corner is at (mm)         o         0         mit           Solution         1         1         f.(-0, -0)         ) mm         Set or         Deactival           Cols 1         1         Then rotate about center by         Create node at ()         Create         node at ()	of         0.05         mohm/sq           im, thickness         NA         mm           ite         node         all         as a + v           0         0         mm, or Remove         node         196-2	
Nudge Subcircuit Clear Dangling No Clear Dangling No Clear Ungrounded	d Parts Clear All UNDO REDO	

Then we again select the 4 parallel strings subcircujit, array of 1 by 1, and place the subcircuit with lower left corner at (x,y) = (2mm,0) then rotate subcircuit about center by 180 degrees. This places a 180 degree rotated instance of the 4 parallel strings next to the one already placed.

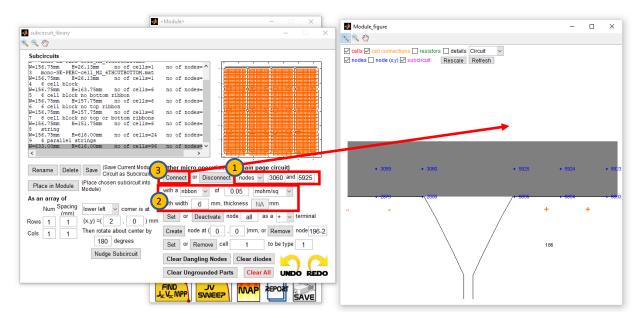


If we go to Module\_figure, choose "cell connections" and "cells", zoom into the upper part between the two 4 parallel strings and click refresh, we can see that establishing a ribbon connection in the red circled part below will create a series connection, as it connects the negative terminals of cell 91 to the positive terminals of cell 186.



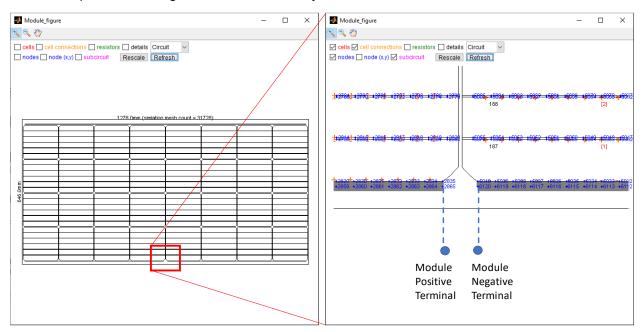
Module_figure		-		×
<ul> <li>€</li> </ul>				
✓ cells Ø cell connections □ resistors □ details Circuit         □ nodes □ node (x,y) Ø subcircuit				
1278.0mm (similation me	sh count = 31728)			
(2	00.646.001			
	185 131	++++	+ \	/ <mark>+</mark> 162
91 [1]	186 [3]		-γ	162
	*******	****	-	**
92 [2]	185 [2]			161
			_	
93 [2]	184 [2]		•	160

To establish the ribbon connection, we zoom in further and check "nodes" and hit "refresh" to see that the two nodes needing connection are 3060 and 5925. We set "nodes" to be 3060 and 5925, then select "ribbon" of "0.05 mohm/sq" and width "6 mm", then press Connect.

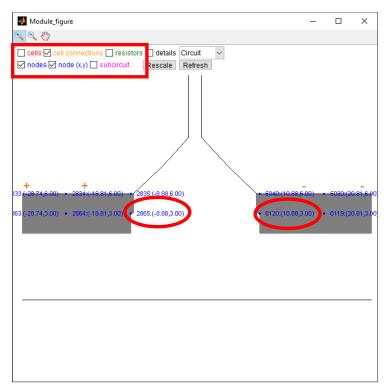


## 6.6 Creating New Nodes

Now, suppose we wish to Extend the ribbons as shown in the red rectangle region of the module to make the module positive and negative terminals, let's say 20mm.



In Module\_figure, we select "node(x,y)" and zoom in further, then click "refresh" to see that the two nodes we wish to extend the ribbons off of are nodes 2865 and 6120, with coordinates (-8.88, 3) and (10.88, 3) respectively.





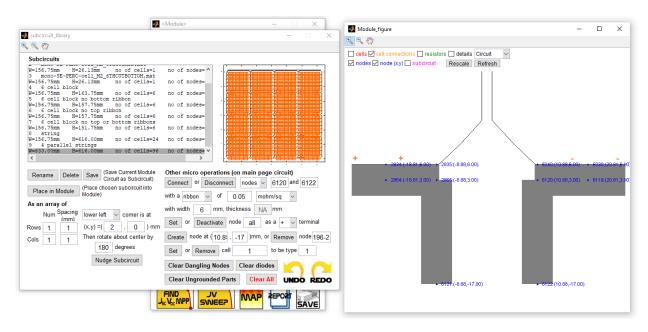
In the subcircuit library, make the coordinates (-8.88, -17) and press "Create" (node) and a new node appears at the coordinate specified. We can also make another node at (10.88,-17).

•	<module> — — X</module>	Module figure	. п	×
🛃 subcircuit_library	– 🗆 X			^
<b>€ € (</b> )				
Subcircuits		cells / cell connections resistors details Circuit      nodes / node (x,y) subcircuit Rescale Refresh		
W=155.75mm     Hb 22.15mm       B mono-SP-ERC-cell MA_CTRCUTBOTON.mat       W=155.75mm     H=26.13mm       No of cells=1       4 € cell block       W=155.75mm     H=163.75mm       No of cells=6       V=156.75mm     H=157.75mm       No of cells=6       F=156.75mm       H=157.75mm       No of cells=6       F=156.75mm       H=157.75mm       H=156.75mm       H=156.75mm       H=157.75mm       H=157.75mm       H=156.75mm       H=156.75mm       H=168.00mm	no of nodes= no of no no o	trouby inversion (x) = subsection     troub	+ 5030(5 + 6119(3	
	Clear Ungrounded Parts Clear All UNDO REDO	• 6121:(-8.88,-17.00)		
L		• 6121(-638,-17,00)		

As before, we establish ribbon connections.

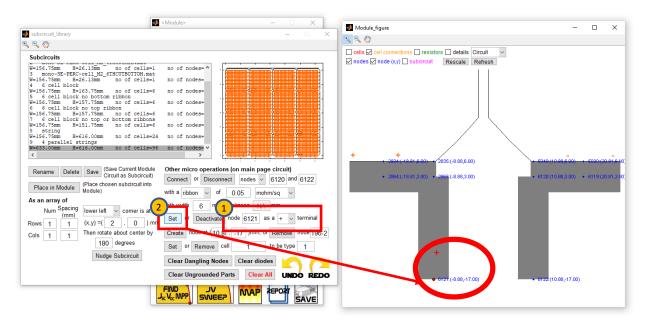
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● ●						
Subcircuits			Cells    Cell connections □ resistors □ details Circuit			
H=156.75mm       H=26.13mm       no of cell=1         B       mono-SP-FR-cell M2 cHUUTBOTCOL.ast         H       Gell=1       Simm       no of cell=1         H       Gell=1       block       no of cell=1         H       Simm       no of cell=1       Simm         H       Gell=1       block       no of cell=6         H       Gell>1       block       no of cell=6         G       Gell>1       block       no of cell=6         H       Gell>1       block       no of cell=6         H       Gell>6       Gell       block         H       Simm       H=157.75mm       no of cell=6         H       Gell>6       Gell>6       block         H=156.75mm       H=151.75mm       no of cell=6         H=156.75mm       H=16.175mm       no of cell=6         H=156.75mm       H=61.00mm       no of cell=6         H=26.75mm       H=61.00mm       no of cell=6         Kows       M       M       (X)Y = (Y)       (Y)	no of nodes= no of nodes= thermicro operation 1 noin pag Connect of Discount modes of with a mbon of 0.05 mon th width 6 mm, thickness NA Set or Deactivate node all a Create node at (10.8, -17) mm, or Set or Remove Cell 1 Clear Ungrounded Parts Clear A	2865 and 6121 mm s a + v terminal r Remove node 196-2 to be type 1 es UNDO REDO	+	2(10.88,400) + 2(10.88,400) + 2(10.88,47.00)	£030 (20 6119 (20	.01,0,10,
-		SAVE				



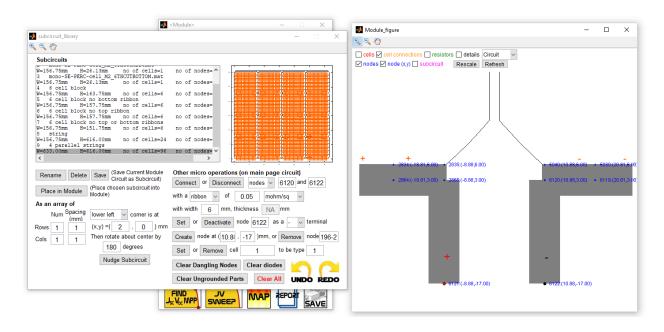


## 6.7 Setting Module Terminals

We select node "6121" as a "+" terminal, then press set. Similarly we select node "6122" as a "-" terminal, then press set.







### 6.8 Setting bypass diodes

After identifying the nodes we want to connect with a bypass diode using the zoom, we enter the nodes to be connected (node 751 being the positive terminal of the bypass diode, node 556 being the negative terminal of the bypass diode), select "diode" and type "1", then press connect.

Subcircuits I mono-SE-EERC-cell M2 SINCUTOP.mat imisSin Back.item no of celle=1 no of nodes= 2 mono-SE-EERC-clu A2 SINCUTOP.mat W=155.75mm H=26.15mm no of celle=1 no of nodes= 3 mono-SE-EERC-clu A2 SINCUTOP.mat	tell connections ] resistors ] details Circuit //
Subcircuis  mono-SE-EERC-cell M2 SINCUITOR.mat P=156.75m B-26.13m no of celle=1 no of nodes= 2 mono-SE-EERC-cell M2 SINCUITOR.mat W=156.75m B-26.13m no of celle=1 no of nodes= 3 mono-SE-EERC-cell M2 SINCUITOR.mat	
Subcircuis mono-SE-EERC-cell M2 SINCUTIOP.mat hei56.75m H=26.13m no of celle=1 no of nodes= 2 mono-SE-EERC-cell M2 SINCUTIOP.mat Hei56.75m H=26.13m no of celle=1 no of nodes= 3 mono-SE-EERC-cell M2 SINCUTION.mat	
H=154.75m       H=26.13m       no of colls=i       no of nodes         H=154.75m       H=13.75m       no of colls=i       no of nodes         H=154.75m       H=137.75m       no of colls=i       no of nodes         Reversion       H=137.75m       no of colls=i       no of nodes         Reversion       H=137.75m       no of colls=i       no of nodes         Reversion       H=138.75m       No of colls=i       no of nodes         Reversion       H=138.75m       No of colls=i       no of nodes         Rows 1 <t< th=""><th></th></t<>	

Similarly we create another bypass diode for the other half of the module.



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Subcircuits				connections [ de (x,y) [] sub							
I mono-SE-EERG-pell M2 diffutUTOP.mat [#=156.75m H=26.13m no of cells=1 2 mono-SE-PERC-cell M2 diffutUTMDI.mat [#=156.75mm H=26.13mm no of cells=1 3 mono-SE-PERC-cell M2 diffutUTBOTTOM.mat [#=156.75mm H=26.13mm no of cells=4 4 6 cell block [#=156.75mm H=163.75mm no of cells=6 5 6 cell block no bottom ribbon [#=156.75mm H=163.75mm no of cells=6	no of nodes= no of nodes= no of nodes= no of nodes= no of nodes=		iodes nor	ue (x,y) [] Suo		Omm (similation	mesh.count = 3	1730)			
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7 6 cell block no top or bottom ribbons W=156.75mm H=151.75mm no of cells=6 8 string	no of nodes=										
G string G String H-Si6 00mm po of celle-24 <	no of nodes-				ļ					E	3
Rename Delete Save (Save Current Module Circuit as Subcircuit) Place in Module Place chosen subcircuit into	Other micro operations (on main page circuit) Connect or Disconnect nodes v 3631 and 3616	mm0								E	
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180 degrees	Set or Remove cell 1 to be type 1			L	L			L			≝∣
Nudge Subcircuit	Clear Dangling Nodes Clear diodes					•	-				

Once we're done, we can simulate the I-V characteristics of the module (this example required module backsheet scatter to be calculated in order for the simulation to converge well).

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🐠 subcircuit_library	File About Import Sunsolve	R 🔍 🔍 🖑	
Subcircuits	RODULE		I-V v
<pre>1 mono-SE-PERC-cell M2 6THCUTOP.mat W=156.75mm H=26.13mm no of cells: 2 mono-SE-PERC-cell M2 6THCUTMID.mat W=156.75mm H=26.13mm no of cells: 3 mono-SE-PERC-cell M2 6THCUTBOTTOM.mw W=156.75mm H=26.13mm no of cells: 4 = 6 cell block W=156.75mm H=163.75mm no of cells: 5 = 6 cell block no bottom ribbon</pre>	Rows 6 Columns 1 Cell gap -1 String gap 2 (mm) -1	7 6 Voc = 32.75 V 5 Isc = 6.44 A FF = 79.29% 3 4 Pmov = 167.29 W	
W=156.75mm H=157.75mm no of cells: 6 6 cell block no top ribbon W=156.75mm H=157.75mm no of cells: 7 6 cell block no top or bottom ribbon W=156.75mm H=151.75mm no of cells: 8 string	Cell Connecting Ribbons String Connecting Ribbons width 1 sheet res 0.07 width 6 sheet res (mm) 6 (mohm/sq) 0.05	<pre></pre>	
Rename Delete Save (Save Current Modu	Ribbons optical scatter     0.2     Cables connectors resistance (mohm)     0     Calculator       Temperature (C)     25		25 30 35
Place in Module (Place chosen subcircuit into Module)	Cells and Bypass Diodes Within the Module Cell Library Diode Library Subcircuits Library	Voltage (V)	
As an array of Num Spacing (mm) Rows 1 1 (x,y) =( 2 , 0 )	Place cell type 3 into positions Two Parallel Halves	150 - - E	
Cols 1 1 Then rotate about center b	Extra shunt cond (1/(kohm-cm2)) 0 SWEEP RANGE 28 to 32 step 1 V RUN ONE	Domet (%)	
		0 5 10 15 20 Voltage (V)	25 30 35

# 7 Conductive Backsheet

#### 7.1 Introduction

Interdigitated back contact (IBC) and metal wrap through (MWT) are two solar cell types where both cathode and anode metallization patterns are on the rear side of the solar cell. For these cell types, there is the possibility of creating advanced module concepts that use conductive backsheets for interconnection, much like surface mount components on a printed circuit board.

In Module, now there is the option to use conductive backsheet interconnection---and it is not limited to IBC or MWT cell designs. It is also possible to combine ribbon connection elements with the conductive backsheet, offering a wide range of possibilities in the research realm.

To illustrate the use of conductive backsheet in Module simulation, we load an IBC cell model where both cathode (positive) busbars and anode (negative) busbars are on the rear side, as shown below. The design is similar to the Zebra solar cell technology invented by ISC Konstanz.



## 7.2 Conductive Backsheet Window

By default, Module always creates a rectangular module that is interconnected by ribbons. To replace that with conductive backsheet interconnection, set the cell connecting ribbons width to zero----this will remove any conducting elements along the busbars of the solar cell, other than the busbars themselves. Press "Conductive Backsheet" to open the conductive backsheet window.

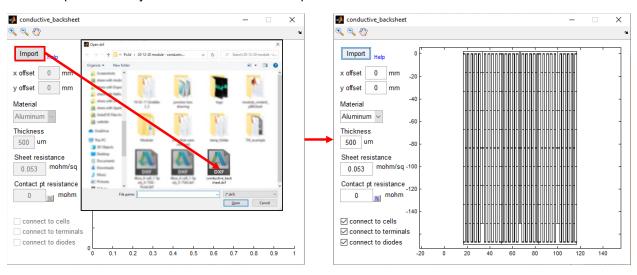


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Set ribb zero	soon width to		€ € ₩ Import Help						2
	Viargin to mame (mm) Top 20       Side 5       Bottom 10 (mm)       + - dist 100         Coll Connecting Ribbons       String Connecting Ribbons         Width 0       sheet res (mohm/sq) 0.07       width 6       sheet res (mohm/sq) 0.05         Ribbons optical scatter       0.2       Cables connectors (mohm/sq) 0.05       0       Calculator         Temperature (C)       25       Two parallel halves       Cells, Bypass Diodes, Subcircuits, Conductive Backsheet         Cells       Diodes       Subcircuits       Conductive Backsheet         Place cell type       into positions		x offset 0 mm 0.9 y offset 0 mm 0.8 Material 0.7 Aluminum 0.7 Thickness 0.6 500 um 0.5 Sheet resistance 0.5 Sheet resistance 0.4 Contact pt resistance 0.3 0 m mohm 0.2 connect to cells connect to cells						
	Front 1-Sun Jsc Rear 1-Sun Jsc 1 multiplier 1 J01 multiplier 1 J02 multiplier 1		connect to diodes	0.3	0.4	0.5 0.6	6 0.7	0.8 0.9	1
	Front Illumination       1    Rear Illumination    0      (Suns)    1    (Suns)    0      FIND    JV    SWEEP    FIND      Jx Vx    SWEEP    MAP    FPORT		12 32 10 [1] [1] 30 [1] [1] 50 11 31	52 [1] 51	[1]				

As of v33, Module does not have a native conductive backsheet design tool, so the user will have to import CAD designs (in dxf format) of the backsheet which are usually created in AutoCAD or Solid Works. You can press the "Help" button to view the design rules.

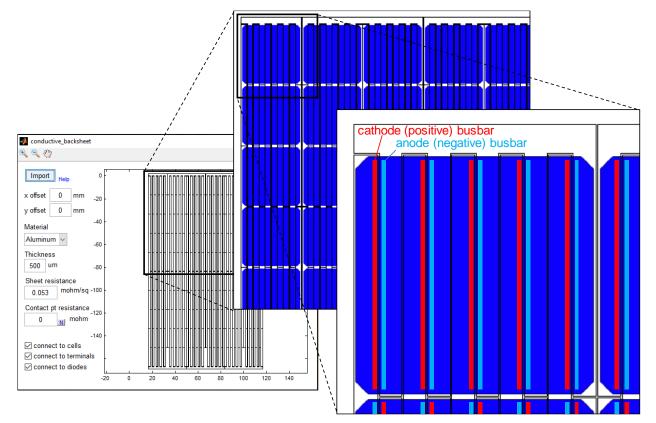
	conductive_backsheet	- 🗆 🗙
	🔍 🔍 🖑	
Connect to cells connect to diodes	AUTOCAD Design Rules 1. All units are in mm 2. Layers should be named as shown to the right 3. Draw all structures as closed polylines 4. Terminals (p and n) should be drawn as circles 5. Use PURGE and OVERKILL commands to clean up your drawing 6. Save as AUTOCAD DXF 2013 version. If that doesn't work, try other versions.	conductive_backsheet





Press "Import" to load your conductive backsheet pattern.

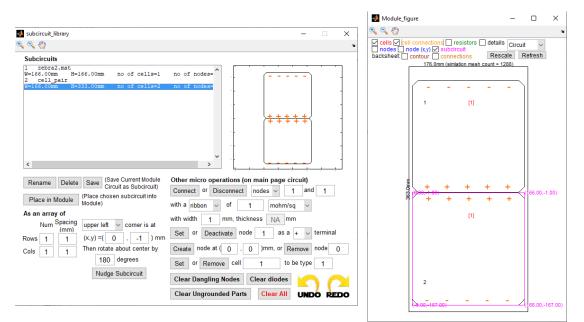
The conductive backsheet pattern deserves some explanation. Any shape within this pattern is considered to be a conductive foil. If we zoom in, we see that the backsheet consists of many interdigitated, but unconnected conductive foil sections. Here we show how the IBC cells are intended to be laid out on the conductive backsheet, showing the alignment of the busbars to the different foil sections. Notice that within a column, adjacent cells are rotated 180 degrees with respect to one another, so that a common foil section connects the anode busbars of one cell to the cathode busbars of the next cell.



#### 7.3 Conductive Backsheet Interconnection

The conductive backsheet pattern in this case requires that within a column, adjacent cells are rotated 180 degrees with respect to one another. We make use of the subcircuit library to make this kind of custom layout. See Section 6 Subcircuit Library for details. Here we simply show screenshots and brief descriptions of the steps.

Step 1: Create a subcircuit that consists of a pair of cells, spaced 1mm apart. The lower cell is rotated 180 degrees (see 6.4 Place Subcircuits into Module and 6.2 Save Current Module Circuit As Subcircuit).

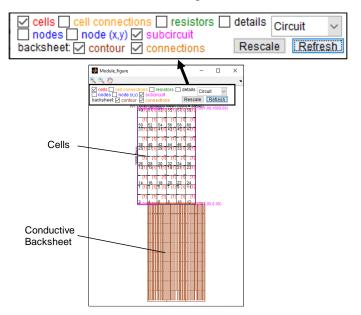


Step 2: Now insert a 5 rows x 6 columns array of the cell pair, with 1mm spacing. This creates the 60 cell module.

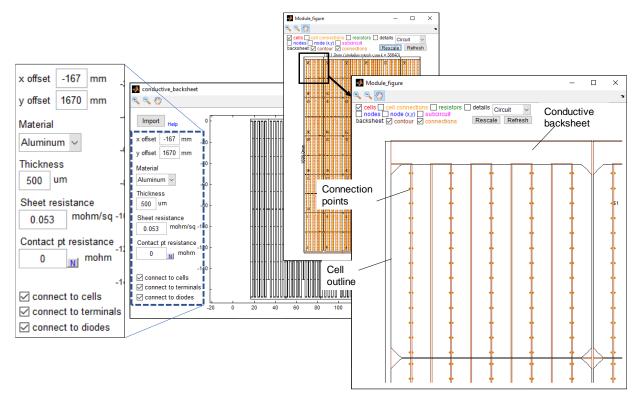
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Jubcircuit_library	– 🗆 X	e, e, 🖑	r
€	٢	✓ cells ✓ tell connections!       resistors       detai         □ nodes       node (x,y)       ✓ subcircuit         backsheet       contour       connections	Is Circuit ~
Subcircuits		1011.0mm (similation mesh count =	38640)
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<		│	
Rename     Delete     Save     (Save Current Module Circuit as Subcircuit)       Place in Module     (Place chosen subcircuit into Module)       As an array of Num Spacing (mm)     iower left v corner is at (x,y) = (0, 0), mm       Rows 5     1     (x,y) = (0, 0), mm       Cols     1     Then rotate about center by 0       degrees     Nudge Subcircuit	Other micro operations (on main page circuit)         Connect       or Disconnect         nodes       1         with a ribbon       of         1       mohm/sq         with width       1         1       mohm/sq         with width       1         1       mohm/sq         with width       1         1       mohm/sq         Set       or         Deactivate       node         1       as a + with terminal         Create       node at (0, 0) mm, or Remove       node 0         Set       or       Remove       cell         Clear Dangling Nodes       Clear diodes       Index       Index         Clear Ungrounded Parts       Clear All       Index       Index		

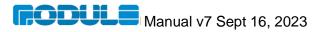


Step 3. When there is a conductive backsheet, the Module Figure allows you to select whether to view the backsheet contour or connections. Here we select contour and press "rescale". We can now see the conductive backsheet and also see that it is not at all aligned with the cells.

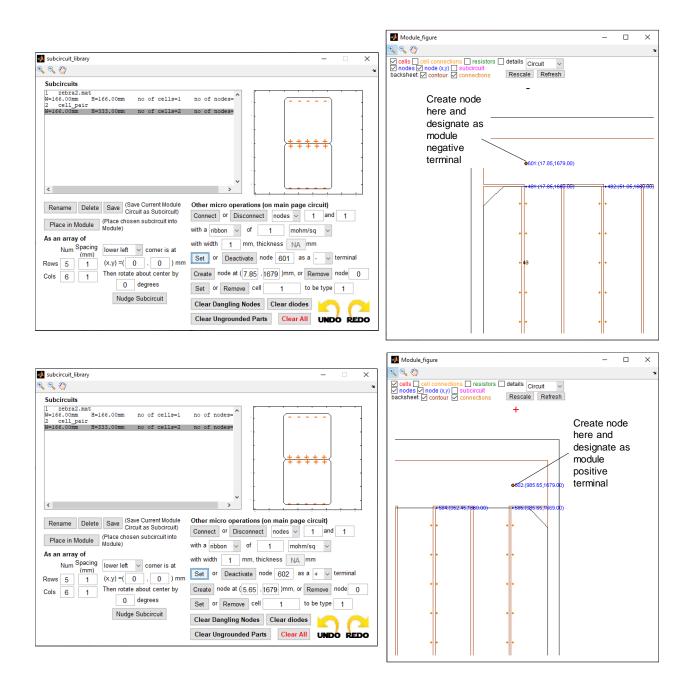


Step 4. Now open the conductive backsheet window. Adjust the x and y offset values to bring the conductive backsheet into alignment with the cells. If the box "connect to cells" is checked in the conductive backsheet window, then any solder point defined on the cell busbars which lie within the conductive backsheet, will be displayed as a connection points. In this design, we have perfect alignment when the positive busbar connection points and the negative busbar connection points are lying in different backsheet sections, as shown below.



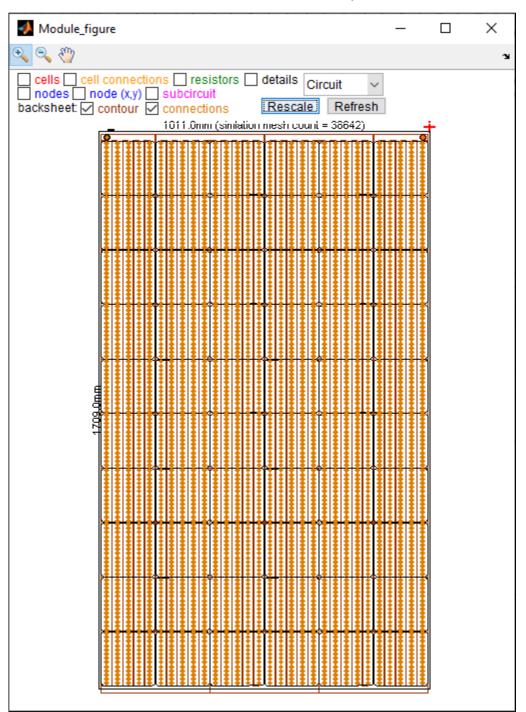


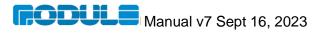
Step 5. Now that we have interconnected cells, we still need to define the module positive and negative terminals and connect them (see 6.6 Creating New Nodes and 6.7 Setting Module Terminals). If you go to the subcircuit library to create nodes and set them as positive/negative terminals, and these points are lying inside the conductive backsheet, and that the box "connect to terminals" is checked in the conductive backsheet window, then these points will be connected to the backsheet, as shown below.





We can now review the entire schematics. This module is now ready for simulation!



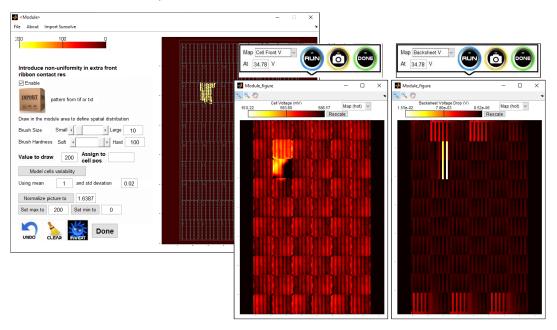


As with any module design, you can simulate the I-V characteristics, view the spatial distribution of cell voltages, etc. When there is a conductive backsheet, you can also choose to Map "Backsheet V" to see the voltage drop along each conductive backsheet section, as shown below.

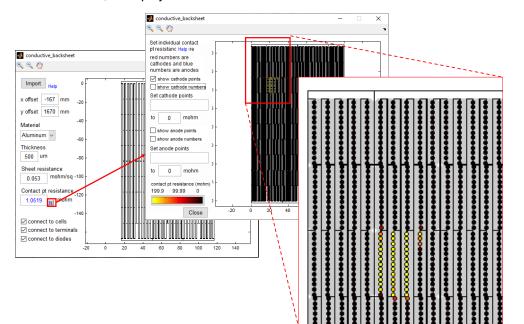
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Margin to frame (mm)         Top         20         Side         5         Bottom         10         + - dist (mm)         100						
Rows 10     Columns 6     (mm) 2     (mm) 4       Margin to frame (mm) Top     20     Side     5     Bottom     10     100       Cell Connecting Ribbons     String Connecting Ribbons     String Connecting Ribbons						
Margin to frame (mm) Top 20 Side 5 Bottom 10 + - dist Cell Connecting Ribbons     String Connecting Ribbons       width 1 sheet res     0.07						
Rows     10     Columns     6     (mm)     2     (mm)     2       Margin to frame (mm)     Top     20     Side     5     Bottom     10     100       Cell Connecting Ribbons     String Connecting Ribbons     String Connecting Ribbons     Width     6     mohm/seq     0.05       Ribbons     0.2     Cables connectors     0     Caluator						
Rows     10     Columns     6     (mm)     2     (mm)     2       Margin to frame (mm)     Top     20     Side     5     Bottom     10     model       Cell Connecting Ribbons     String Connecting Ribbons     width     6     sheet res     0.05       (mm)     1     (mohm/sq)     0.07     (midh     6     (mohm/sq)     0.05       Ribbons     optical scatter     0.2     Cables connectors     0     Calculator						
Robs 10       Columns 6       (mm) 2       (mm) 2         Margin to frame (mm) Top 20       Side 5       Bottom 10       (mm) 100         Cell Connecting Ribbons       String Connecting Ribbons       width 6       sheet res       0.05         (mm) 1       (mohm/sq) 0.07       (midh 6       (mohm/sq) 0.05       Ribbons       optical scatter       0.2       Cables connectors       0       Calculator         Temperature (C)       25       Two parallel halves       1       String Connecting Ribbons       1       Calculator						
Robs       10       Columns       6       (mm)       2       (mm)       2         Margin to frame (mm)       Top       20       Side       5       Bottom       10       model         Cell Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       width       6       sheet res       0.05         Ribbons       0.2       Cables connectors       0       Calculator         Temperature (C)       25       Two parallel halves         Cells, Bypass Diodes, Subcircuits, Conductive Backsheet						
Robs       10       Columns       6       (mm)       2       (mm)       2         Margin to frame (mm)       Top       20       Side       5       Bottom       10       model         Margin to frame (mm)       Top       20       Side       5       Bottom       100       100         Cell Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       width       6       mohers(a)       0.05         Ribbons       0.02       Cables connectors       0       Calculator         Temperature (C)       25       Two parallel halves         Cells, Bypass Diodes, Subcircuits, Conductive Backsheet       Cells       Diodes       Subcircuits       Conductive Backsheet         Place cell type       into positions						
Robs       0.2       Calculator         Grame (mm)       10       100         Cell Connecting Ribbons       String Connecting Ribbons       string Connecting Ribbons         width       1       sheet res       0.07         (mm)       1       (mohm/sq)       0.05         Ribbons       0.2       Cables connectors       0         optical scatter       0.2       Tesistance (mohm)       0       Calculator         Temperature (C)       25       Two parallel halves       Cells, Bypass Diodes, Subcircuits, Conductive Backsheet         Cells       Diodes       Subcircuits       Conductive Backsheet         Place cell type       into positions       Extra ribbon contact       Front       0       M         Extra ribbon contact       Front       0       M       Rear       0       M						
Robs       0       Calculator         Office       0       0         String       0       0         Cell Connecting Ribbons       String Connecting Ribbons         width       1       sheet res         0.07       width       6         mmh       1       (mohm/sq)         0.07       width       6         nohm/sq)       0.07       (minh         Ribbons       0.27       Cables connectors         optical scatter       0.2       Cables connectors         optical scatter       0.2       Tesistance (mohm)       0         Cells, Bypass Diodes, Subcircuits, Conductive Backsheet       Cells       Diodes       Subcircuits         Cells       Diodes       Subcircuits       Conductive Backsheet         Place cell type       into positions       Test ashunt cond (1/(kohm-cm2))       Mathematical scale scal						
Rows 10       Columns 6       (mm) 2       (mm) 2         Margin to frame (mm) Top 20       Side 5       Bottom 10       (mm) 100         Cell Connecting Ribbons       String Connecting Ribbons       string Connecting Ribbons         width 1       sheet res       0.07       (mm) 6       (mehn/sq)       0.05         Ribbons       0.2       Cables connectors       0       Calculator         Temperature (C)       25       Two parallel halves         Cells, Bypass Diodes, Subcircuits, Conductive Backsheet       Cells       Diodes       Subcircuits         Place cell type       into positions       Extra ribbon contact       Front       0       M         Extra ribbon contact       Front       0       M       Extra shunt cond (1/(kohm-cm2))       0       M						
Robs       10       Columns       6       (mm)       2       (mm)       2         Margin to frame (mm)       Top       20       Side       5       Bottom       10       (model)         Cell Connecting Ribbons       String Connecting Ribbons       String Connecting Ribbons       width       6       mehet res       0.05         Ribbons       0.27       cables connectors       0       Calculator         Temperature (C)       25       Two parallel halves       Cells, Bypass Diodes, Subcircuits, Conductive Backsheet         Cells       Diodes       Subcircuits       Conductive Backsheet         Place cell type       into positions       Extra ribbon contact       Front       0       M         Extra ribut cond (1/(kohm-cm2))       0       0       1       1       1						

### 7.4 Conductive Backsheet Connection Point Contact Resistance

You can simply follow the steps in section 3.8 to define extra connection point contact resistance between the cells and the backsheet. In this case, "extra front ribbon contact res" means extra contact resistance between cell positive busbar connection points and the conductive backsheet, and "extra rear ribbon contact res" means extra contact resistance between cell negative busbar connection points and the conductive backsheet. An example is shown below.



When there is conductive backsheet, an alternate way to view and edit the contact point resistance is in the conductive backsheet winow. Here, click on the blue N button next to "Contact pt resistance" to view the backsheet connections coloured by contact resistance. You can see that whatever spatial pattern was defined in the main screen, is displayed here as well.





If we check the box "show cathode numbers", then we can see the indices of the positive connection points to the backsheet as well.

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Set individual contact	3209	3196	337 <b>8</b>	3365	3352	3339	3326	3508	3495
pt resistanc Help :re red numbers are	3210 5 3211	3197 3198	3379 3380	3366 3367	3353 3354	3340 3341	3327 3328	3509 3510	3496 3497
cathodes and blue numbers are anodes	2392	2405	<b>4</b> 2483	2496	2509	2522	2535	2613	2626
show cathode points show cathode numbers	2391	2404	2482	2495	2508	2521	2534	2612	2625
Set cathode points	2390ر 2389	2403 2402	2481 2480	2494 2493	2507 2506	2520 2519	2533 2532	2611 2610	2624 2623
	2388	2401	2479	2492	2505	2518	2531	2609	2622
to 0 mohm	2387 52386	2400 2399	2478 2477	2491 2490	2504 2503	2517 2516	2530 2529	2608 2607	2621 2620
show anode points	2385	2398	2476	2489	2502	2515	2528	2606	2619
show anode numbers Set anode points	2384 2383	2397 2396	2475 2474	2488 2487	2501 2500	2514 2513	2527 2526	2605 2604	2618 2617
	02382	2395	2473	2486	2499	2512	2525	2603	2616
to 0 mohm	2381 2380	2394 2393	2472 2471	2485 2484	2498 2497	2511 2510	2524 2523	2602 2601	2615 2614
contact pt resistance (mohm)	2419	2406	2588	2575	2562	2549	2536	2718	2705
199.9 99.99 0	2420 2421	2407 2408	2589 2590	2576 2577	2563 2564	2550 2551	2537 2538	2719 2720	2706 2707
Close	2422	152409	25926	2578	25 <sup>2565</sup>	2552	2539	35 <sup>2721</sup>	2708
01030	2423	2410	2592	2579	2566	2553	2540	2722	2709

To make edits, you can set the value for the contact point resistance in mohm, then type a series of cathode points (or anode points), e.g. if we want to set another series of points 2614-2620 to value of 500 mohm, we simply set 500 and type "2614-2620" and hit enter, as shown below.

conductive_backsheet	– 🗆 🗙	conductive_backsheet	– 🗆 🗙
	لا د		
Set individual contact pt resistanc Heb re red numbers are cathodes and blue numbers are anodes         33         630         640         645         0465           show cathode numbers         5         653         6613         622         653         6613         622         653         6613         622         653         6613         622         653         6613         622         655         651         652         653         6613         622         655         656         657         650         656         652         656         648         647         652         653         651         652         653         651         652         653         651         652         653         656         652         656         651         652         656         656         652         656         656         657         650         656         652         656         656         657         650         656         652         656         656         657         650         657         650         657         650         657         650         657         650         657         650         657         650         657         653         651         652         656	445         643         642           645         634         626           646         644         627           665         743         675           666         744         672           666         744         775           666         743         775           666         734         775           666         736         771           656         734         775           656         734         775           656         735         774           656         734         775           655         735         774           656         734         775           655         734         774           655         734         774           656         634         732           656         634         635           656         844         836           656         854         837           656         855         837           656         855         837           656         855         837           656         855         837	Set individual contact pt resistanc Help rfe         532         6336         6432         6432         6432         6442         6442         6447           red numbers are cathodes and blue numbers are anodes         5         634         6322         6535         6432         6432         6442         6447         6447           show cathode numbers         652         6535         6433         6513         6452         6536         6552         6533         6552         6533         6552         6533         6551         6553         6543	0450         0630         0620           0457         6635         052           0456         664         622           0565         7743         6755           0562         6744         6722           0565         7741         6755           0562         6740         6773           0560         6736         6755           0555         6733         6746           0555         6733         6746           0555         6733         6746           0555         6733         6746           0556         6733         6746           0555         6733         6746           0556         6734         6742           0555         6733         6746           0556         6734         6742           0556         6733         6746           0556         6734         6742           0565         6733         6746           0565         6734         6742           0565         6734         6742           0565         6735         6744           0565         635         633



Now we can see that the updated spatial pattern of contact point resistance is reflected in the simulations.

