Photo Emission Tech., Inc.

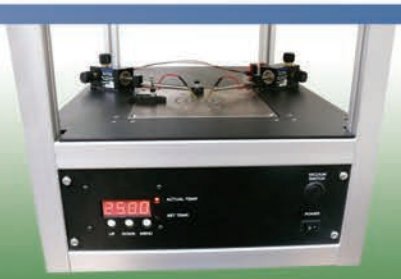
Your Best Source for:

- **CELL TESTERS**
  Integrated Solar Simulator & I-V Measurement System
- **STEADY STATE SOLAR SIMULATORS**
  Continuous Solar Simulators - Class AAA From 50mm x 50mm up to 300mm x 300mm Area of Illumination
  Larger areas of illumination available upon request
- **I-V MEASUREMENT SYSTEMS**
  From 1, 3, 5, 15, up to 20Amps and up to 60V Capability Systems
- **CALIBRATED REFERENCE CELLS (NREL TRACEABLE)**
- **SPECTRAL RESPONSE SYSTEMS/ QUANTUM EFFICIENCY SYSTEMS (EQE / IPCE, IQE)**
- **SPECTRO - RADIOMETERS**
- **FLEXIBLE DESIGN for easy customization**

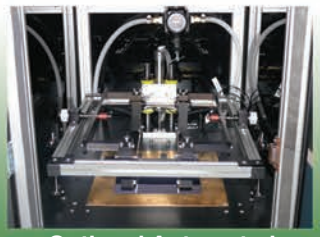
OPTIONAL ELECTRO-MECHANICAL CONTROL PANEL

STANDARD FLAT SCREEN (TOUCH) CONTROL PANEL

SS100 AAA Solar Simulator
Area of Illumination 100 mm x 100 mm
STANDARD FLAT SCREEN (TOUCH)
CONTROL PANEL



Typical Cell Testing Fixture for Cells up to 100mm X 100mm



Optional Automated Testing Fixture

Model CC-15 & CC-20
I-V System Console

CT150 AAA Cell Tester
Area of illumination 150 mm x 150 mm
Shown with standard flat screen
(touch Panel) Control Panel

SOLAR SIMULATORS

Solar Simulator – Introduction

A solar simulator is a xenon light source; however a xenon light source is not a solar simulator. Through the use of reflectors, special air mass filters and integrating optics, the properties of the light beam can be modified to meet the three main characteristics of light beam specified by international standards to make a xenon light source into a solar simulator. These international standards define three classes of solar simulators; Class A, Class B and Class C and the acceptable tolerance for the three main characteristics, namely spectral match to sunlight, non-uniformity of the light beam and stability of the light beam over time.

There are two types of solar simulators available in the market for cell testing. First is “Steady State”(SS) system and the second is the “Pulsed Simulator”(PS) system. Pulsed simulators can be single-pulse or multi-pulse type. PS systems have lamp life that is typically between 40,000 to 1 million flashes, whereas the SS systems have a typical lamp life of 1,000 -1,500 hours of continuous operation. Most PS systems typically have a flash duration of 2 ms to 10 ms; this means that the cell testing, i.e. I.V. measurement system must be able to perform the test within this short duration. Testing in this short duration is not a problem but generally means fewer data points for the I.V curve. It also means that the cell to be tested must be able to respond to the light in this short time duration. As a result it is important to know the response time of the device to be tested. All Photo Emission Tech, Inc. (PET) Solar Simulators are steady state systems based on xenon lamp technology, offering one of the closest matches to spectral irradiance of sun. We offer several models with different area of illumination. The models range from 50mm x 50mm to 300mm x 300mm area of illumination. All models have a standard one sun intensity that can be adjusted +/- 15%. If lower intensity values are required then neutral density filters can be used. Custom models with higher intensity are also available.

Standards for Solar Simulators

Three international organizations have defined the standards for solar simulators. These organizations and the standard for solar simulators are;

- American Standards for Test and Measurement (ASTM, standard reference # E927 – Standard Specifications for Solar Simulation for Terrestrial Photovoltaic Testing) has defined American standards.
- International Engineering Consortium (IEC, standard reference # IEC 60904-9 – Solar simulator performance requirements) has defined the European standards.
- Japanese Standards Association (JSA) has defined Japanese Industrial Standards (JIS C 8912 – Solar Simulators for Crystalline Solar Cells and Modules, and JIS C 8933 - Solar Simulators for Amorphous Solar Cells and Modules) for Japan.

All of these standards are very similar. Following is an overview of the three standards.

- There are three classes of systems defined • Class A • Class B • Class C

Each class defines the following properties of the light beam and how well it matches the properties of the sun light;

- Total Intensity in a specific range of wavelengths (400-1,100nm for AM1.5G)
- Non Uniformity of Total irradiance
- Temporal instability of irradiance
- Spectral match to sun light within a given range for each Air Mass

Table1: Solar Simulator International Standards Summary

Characteristic	ASTM E-927			IEC 60904-9			JIS C8912		
	Class of Solar Simulator			Class of Solar Simulator			Class of Solar Simulator		
	A	B	C	A	B	C	A	B	C
Spectral Match to All Intervals	±25% OR 0.75 – 1.25	±40% OR 0.60 – 1.40	+100% - 60% OR 0.40 – 2.0	±25% OR 0.75 – 1.25	±40% OR 0.60 – 1.40	+100% - 60% OR 0.40 – 2.0	±25% OR 0.75 – 1.25	±40% OR 0.60 – 1.40	+100% - 60% OR 0.40 – 2.0
Non-Uniformity of Total Irradiance (Small Area ≤ 300mm x 300mm)	≤2%	≤5%	≤10%	≤2%	≤3%	≤10%	≤2%	≤5%	≤10%
Non-Uniformity of Total Irradiance (Large Area > 300mm x 300mm)	≤3%	≤5%	≤10%	≤2%	≤3%	≤10%	≤2%	≤5%	≤10%
Number of Test Points For Non-Uniformity Testing	36	36	36	64	64	64	17	17	17
Short Term Temporal Instability of Irradiance (STI, 1ms Interval)	≤2%	≤5%	≤10%	≤0.5%	≤2%	≤10%	≤2%	≤5%	≤10%
Long Term Temporal Instability of Irradiance (LTI)	≤2%	≤5%	≤10%	≤2%	≤5%	≤10%	≤2%	≤5%	≤10%

In order to classify a Solar Simulator as a “Class A” system, it must meet all three requirements specified under Class A, i.e. the non-uniformity of the irradiance over the area of illumination must be ≤2%, and the Short Term Temporal Instability of irradiance must be ≤0.5% and the Long Term Temporal Instability (LTI) of irradiance must be ≤2%, and the spectral match in each wavelength interval must be ±25% or better. In addition, the total intensity must be 1,000W/m2 (100mW/cm2) for AM1.5G

All three standards allow the classification of a solar simulator with three letters, such as AAB etc, where the first letter in the class designation refers to the spectral match of the class of a system, second letter in the class designation refers to the system class for Spatial Non-uniformity of irradiance and the third letter in the class designation refers to the system class for Temporal Instability of Irradiance of the system. The standard also allows a single letter designation. For example a Class A signifies that the solar simulator meets all three requirements of class A and is the same as Class AAA.

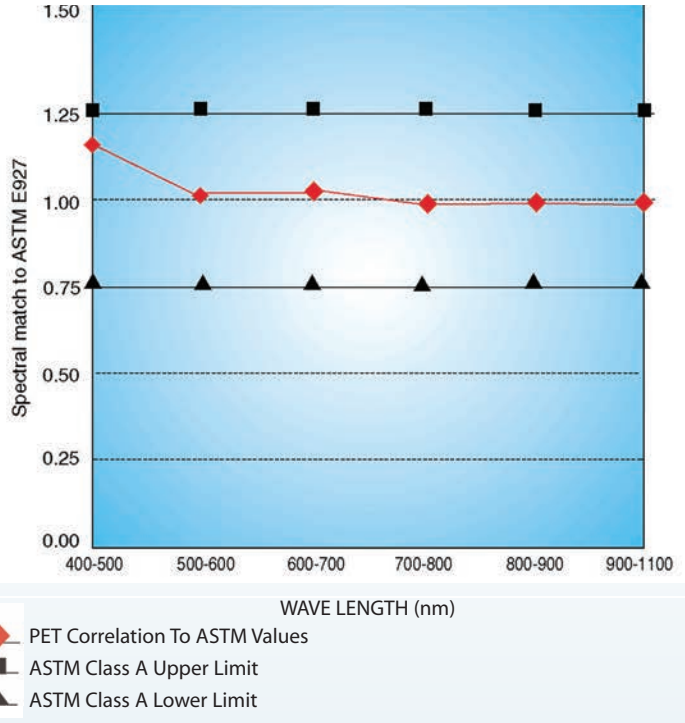
All PET Solar Simulators are class AAA meeting all three international standards. All systems are tested to the strictest of the three (3) International Standards. For example, European Standard IEC 60904-9 requires 64 test point measurement of Spatial Non-Uniformity as compared with 36 test points required by American Standard ASTM E927 or 17 test points required by Japanese Standard JIS C8912, PET Solar Simulators and Cell Testers are tested for using 64 test points to measure and calculate the Spatial Non-Uniformity. Similarly, European Standard IEC 60904-9 requires the Short Term Instability of Irradiance (STI) to be measured and reported. PET Solar Simulators and Cell Testers are tested for STI and LTI requirements of IEC 60904-9. A signed report is delivered with each system certifying the classification of the Solar Simulator or Cell Tester. See for our website for a sample report issued with our Soalr Simulators or Cell Testers.

SOLAR SIMULATORS

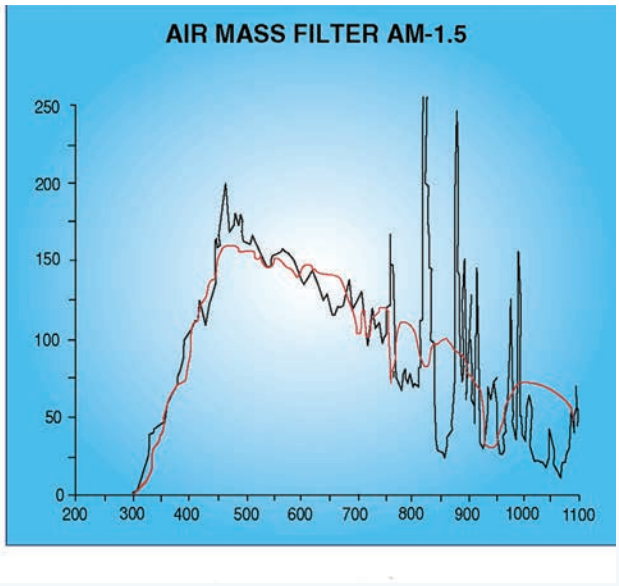
Applications

- Characterization of Solar Cells
- Lifetime testing to qualify materials, surface coatings/finishes etc. for space or on-the-ground applications. Since solar simulator can be powered on twenty four (24) hours a day, it accelerates the life testing. In addition to this life test acceleration, additional acceleration can be accomplished by increasing the light intensity of the solar simulator. A standard solar simulator is “one sun”, which is equivalent to a light intensity of 1,000W/m2 (100mW/cm2) for AM1.5G. If the intensity is increased to 2,000W/m2 (200mW/cm2) for AM1.5G, then the solar simulator would be classified as having an intensity of “two suns”.

TYPICAL ASTM SPECTRAL MATCH FOR CLASS A SOLAR SIMULATOR



TYPICAL SOLAR SPECTRAL IRRADIANCE FOR CLASS A SOLAR SIMULATOR



CELL TESTERS (Integrated I-V Measurement Systems)

Cell testers are integrated systems incorporating Solar Simulator and I-V Measurement systems. PET cell Testers are capable of measuring a diverse range of solar cell parameters, including cell conversion efficiency, complete light and dark I-V curves, Isc, Voc, Imax, Vmax, Pmax, FF, Rsh and Rs. All that needs to be done to test a cell is to load the cell, make electrical probes contact and press “Measure” icon on the I-V Measurement System software. The software will automatically open the Solar Simulator shutter, perform the test and close the shutter after the test is complete. The design is modular in nature and can be easily upgraded. Some options can added at a later time..

The CT series Cell Testers include Class AAA Solar Simulators and I-V System manufactured by PET. The system comes with an AM1.5G as a standard. Other AM filters are available. I-V Systems have a current range between 1A to 20A. Some of salient features of the Cell Testers are:

- High quality Solar Simulator
- Solar Simulator has intensity measurement and feedback control for long term stability
- Flexible cell test fixture configurations, including optional cell temperature control (5 to 70°C ±0.5°C or better)
- True four-probe cell contacting technique
- Temperature controlled chuck with vacuum hold
- Multiple cell contacting probes
- Premier I-V system has intensity measurement and temperature measurement with the ability to normalize the data points to Standard Test Conditions (STC) or other user specified conditions.
- Premier I-V software has the most powerful and advanced I-V curve software, including powerful curve fitting algorithms.

Various models of the available Cell Testers available are listed here. Customer needs to specify the solar cell size (area of illumination) and the maximum short circuit current (Isc) capability of the solar cell. Any of the Solar Simulator models listed herein can be integrated with any of the I-V Measurement systems. We can also provide custom chucks, usually at no extra charge.

CELL TESTER MODELS

	CT50AAA	CT80AAA	CT100AAA	CT150AAA	CT200AAA	CT300AAA
Lamp Type	Xenon Short ARC					
Lamp Power (W)	150W	300W	500W	1,000W	1,500W	3,000W
Max. Illumination Area	5 cm x 5 cm	8 cm x 8 cm	10 cm x 10 cm	15 cm x 15 cm	20 cm x 20 cm	30 cm x 30 cm
Light Source Type	Steady State					
Air Mass Filter	AM1.5G Std., AM1.5D, AM1 & AM0 Optional					
Lamp Life (Hours)	1,500h	1,000h	2,000h	1,500h	1,500h	1,500h
Intensity Adjustment Range	1000 W/m² ± 15% for AM1.5G (1,368 W/m² ± 15% for AM0)					
Spectral Match	±25% or Better					
Temporal Stability	≤2% or Better					
Non-Uniformity	≤2% or Better					
Dimensions (HxWxD) mm	896 x 365 x 530	974 x 365 x 530	1,308 x 365 x 530	1,755 x 416 x 618	2,060 x 416 x 618	3,056 x 616 x 771
Dimensions (HxWxD) in	35.5 x 14.5 x 21	38.5 x 38.5 x 14.5 x 21	51.5 x 51.5 x 14.5 x 21	69.1 x 69.1 x 16.4 x 24.3	81.1 x 81.1 x 16.4 x 24.3	120.3 x 120.3 x 24.3 x 30.4
Weight, Kg (Lbs.)	45 (99)	50 (110)	55 (121)	85 (187)	115 (253)	175 (385)
Phase	Single Phase					
Voltage (V)	110-220VAC				220VAC	
Frequency (Hz)	50-60-60HZ					
Max. Power Consumption (W)	650	800	1,000	1,700	2,200	4,000
	IV SYSTEM					
Electronic Load	Keithley for up to 5A Current: OEM for 10-20A Current					
Voltage Range (V)	up to 40V					
Voltage Resolution	1 Mv for 40V Range					
Current Ranges (A)	1, 3, 5,15, 20, (Please Specify)					
Duration of IV Measurement	~700ms (Depends on # of data points per IV curve					
D/A and A/D Resolution	16 Bit					
Max. # of Points Per Curve	1,064					
Max. Data Acquisition Time/Meas.	7 ms					
Dimensions (Console) (HxWxD) mm (in)	369 x 534 x 445 (14.5" x 21" x 17.5")					
Weight, Kg (Lbs.)	30 (66)					
Phase	Single Phase					
Voltage (V)	110 - 220VAC			20VAC		
Frequency (Hz)	50-60HZ					
Max. Power Consumption (with Temperature Control)	700W			1,050W		

SOLAR SIMULATORS CLASS AAA MODELS

	SS50AAA	SS80AAA	SS100AAA	SS150AAA	SS200ABA	SS300AAA
Lamp Type	Xenon Short ARC					
Lamp Power (W)	150W	300W	500W	1,000W	1.500W	3,000W
Max. Illumination Area	5 cm x 5 cm	8 cm x 8 cm	10 cm x 10 cm	15 cm x 15 cm	20 cm x 20 cm	30 cm x 30 cm
Light Source Type	Steady State					
Air Mass Filter	AM1.5G Standard, AM1.5D, AM1 & AM0 Optional					
Lamp Life (HOURS)	1500h	1000h	2000h	1500h	1500h	1500h
Intensity Adjustment Range	1000 W/m² ± 15% for AM1.5G (1,368 W/m² ± 15% for AMO)					
Spectral Match	±25% or Better					
Non-Uniformity	≤2% or Better					
Temporal Stability	≤2% or Better					
Dimensions (HxWxD) mm	896 x 365 x 530	974 x 365 x530	1,308 x 365 x 530	1,755 x 416 x 618	2,060 x 416 x 618	3,056 x 616 x 771
Dimensions (HxWxD) in	35.5 x 14.5 x 21	38.5 x 38.5 x 14.5	51.5 x 14.5 x 21	69.1 x 16.4 x 24.3	81.1 x 16.4 x 24.3	120.3 x 24.3 x 30.4
Weight , Kg (Lbs.)	35 (77) Kg	40 (88) Kg	45 (99) Kg	70 (154) Kg	100 (77) Kg	150 (330) Kg
Phase	Single Phase					
Voltage (V)	110-220VAC			220VAC		
Frequency (Hz)	50-60					
Max. Power Consumption (W)	400	550	750	1,250	1,750	3,250

STANDARD CELL TESTERS DESIGNED FOR SPECIAL NEEDS.
CUSTOM DESIGNS ARE AVAILABLE USUALLY AT NO ADDITONAL CHARGES.

Cell Tester with eight (8) ND filters (2 Filter Wheels with four (4) filters on each wheel) to provide intensity control from over one sun to 0.004 suns.

Cell Tester for use with Glove Box.
Test Fixture is separate and can be placed inside the Glove Box. Light Source is designed to be placed below the Glove Box to align with the quartz window in the Glove Box. The cell contacts are from the top and the light is incident on the cell from bottom of the cell. The Light Source can be made so that it can be placed at the top of a Glove Box.

Cell Tester with three (3) AM Filters: AM2.0G, AM1.5G and AM1G. The filter can be cycled manaully. The system also has automated simulation of a twelve (12) hour day as follows: First two (2) hours AM2G is in place and active, next two (2) hours AM1.5G is in place and active, next four (4) hours AM1G is in place and active, next two (2) hours AM1.5G is in place and active, and the last two (2) hours AM2G is in place and active.

LOW CONCENTRATION PHOTO-VOLTAIC (LCPV) & High Concentration Photo-Voltaic (HCPV) Cell Testing

Introduction

Testing of **LCPV** Cells require Solar Simulators that have intensity concentration of 2-10 suns (2,000-10,000w/m^2 or 200-1,000 mw/cm^2). Testing of **HCPV** Cells require Solar Simulators that have intensity concentration of ≥200 suns (≥200,000w/m^2 or ≥20,000mw/cm^2). These Solar Simulators deploy concentrating optics consisting of Fresnel lenses that concentrate Solar Simulator output to intensities that match the **LCPV** or **HCPV** Cell testing requirements. These **LCPV** or **HCPV** Solar Simulators are very useful for applications such as concentrated PV cell testing, accelerated photo-degradation studies and materials testing. Table below shows our standard systems modified to concentrate the light to smaller area to meet the **LCPV** and **HCPV** Cell testing needs or any other application that requires high flux Solar Simulators.

LCPV / HCPV Applications:

- Concentrated PV Cell testing
- Photo-biological studies of plants, animals, and cell cultures
- Semiconductor testing
- Photo-toxicity research
- Material degradation research
- Accelerated UV and solar exposure testing of color fastness and material stability for paints, textiles and plastics.
- Atmospheric photochemical pollution research

SS50AAA system shown with optional Fresnel Lens Assembly to provide ~10Suns with 1.5cm x 1.5cm area of illumination. Other areas of illumination and concentration levels are available. Contact your local distributor or the factory.

PET Solar Simulator Energy Output Table (Square Output Beam)

PET SS Model #	SS50	SS80	SS100	SS150	SS200	SS300
Square Beam: Original Size (cm)	5cm	8cm	10cm	15cm	20cm	30cm
Original Beam Area (cm^2)	25	64	100	225	400	900
Normal Intensity at working plane (w/m^2)	1,000 (1 Sun)	1,000 (1 Sun)	1,000 (1 Sun)	1,000 (1 Sun)	1,000 (1 Sun)	1,000 (1 Sun)
Concentrated Nominal Intensity At Working Plane for 2cm x 2cm Device (w/m^2)	6,250 (6.25 Suns)	16,000 (16.0 Suns)	25,000 (25.0 Suns)	56,250 (56.25 Suns)	100,000 (100.0 Suns)	225,000 (225.0 Suns)
Concentrated Nominal Intensity At Working Plane for 1cm x 1cm Device (w/m^2)	25,000 (25.0 Suns)	64,000 (64.0 Suns)	100,000 (100 Suns)	225,000 (225 Suns)	400,000 (400.0 Suns)	900,000 (900 Suns)
Concentrated Nominal Intensity At Working Plane for 0.5cm x 0.5cm Device (w/m^2)	100,000 (100.0 Suns)	256,000 (256.0 Suns)	400,000 (400.0 Suns)	900,000 (900 Suns)	1,600,000 (1,600.0 Suns)	3,600,000 (3,600.0 Suns)

Three device areas are shown in the above table, namely 2cm x 2cm, 1cm x 1cm and 0.5cm x 0.5cm. Other device areas and concentrations are available. Please contact the factory for your application by stating the device dimensions and the desired intensity in # of suns.

CELL TESTING FIXTURES
DESCRIPTION & FEATURES

TEST FIXTURES

Standard Test Fixture

Following is a description of the standard test fixture for silicon cells or other cells that have back contacts and have up to three (3) bus bars for the front contacts. The view shown here is that of an automatic cell contacting mechanism (optional), however all the features described here are also available in Manual Cell Contacting.

Top cell contacts are made by two bus bars, each bus bar can have up to twelve (12) pairs of spring loaded probes. One probe of each pair of probes is used to measure current and the other probe is used to measure voltage. The pairs of probes are equally distributed along the bus bar for most accurate current / voltage measurement.

Top cell contacting probes bars are aligned with the Y-Axis and have the provision to adjust the position of the bus bars in any location along the X-Axis. There is also a provision to adjust the pressure of the probes.

The top cell contacting assembly can be raised or lowered manually or automatically (optional). The assembly is raised to place the cell on the cell plate and then lowered to make top contacts with the cell. The manual frame is held down by spring loaded clasps during cell testing.

Optional temperature control of the cell is also available. The cell plate can be cooled or heated in the temperature range of 5-70°C using Peltier cells. The temperature is controlled within ±0.5°C or better. With the Advance software, the temperature of the cell plate is measured automatically and recorded during cell measurement. This is useful for measurement of thermal coefficients of various cell parameters as well as correcting the IV Curve to standard test conditions (STC) or user defined test conditions.

FIGURE 1: VIEW OF A TYPICAL CELL MEASURING TABLE

Typical Cell Testing Fixture for Cells up to 100mm X 100mm

Typical Cell Testing Fixture (Manual Contacting) for Cells 150mm X 150mm or larger

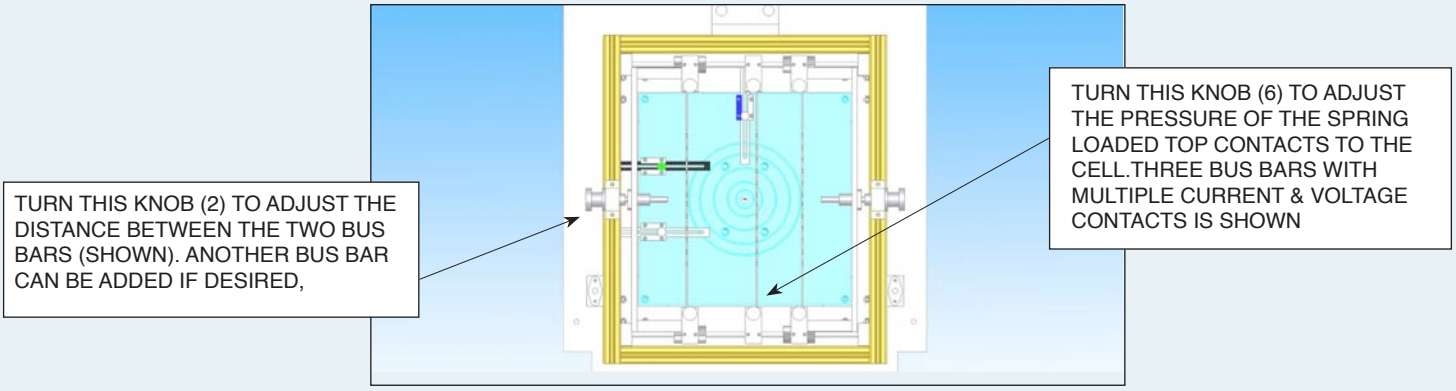


FIGURE 2: TOP VIEW OF CELL PLATE AND AUTOMATED CELL CONTACTING

CELL TESTING FIXTURES
DESCRIPTION & FEATURES

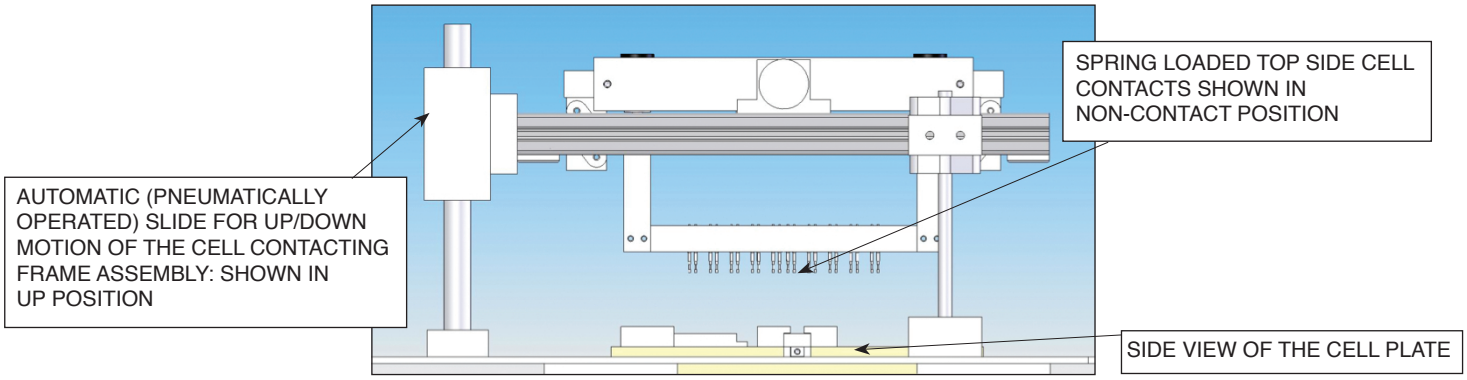


FIGURE 3: SIDE VIEW OF CELL PLATE AND AUTOMATED CELL CONTACTING IN "UP" POSITION

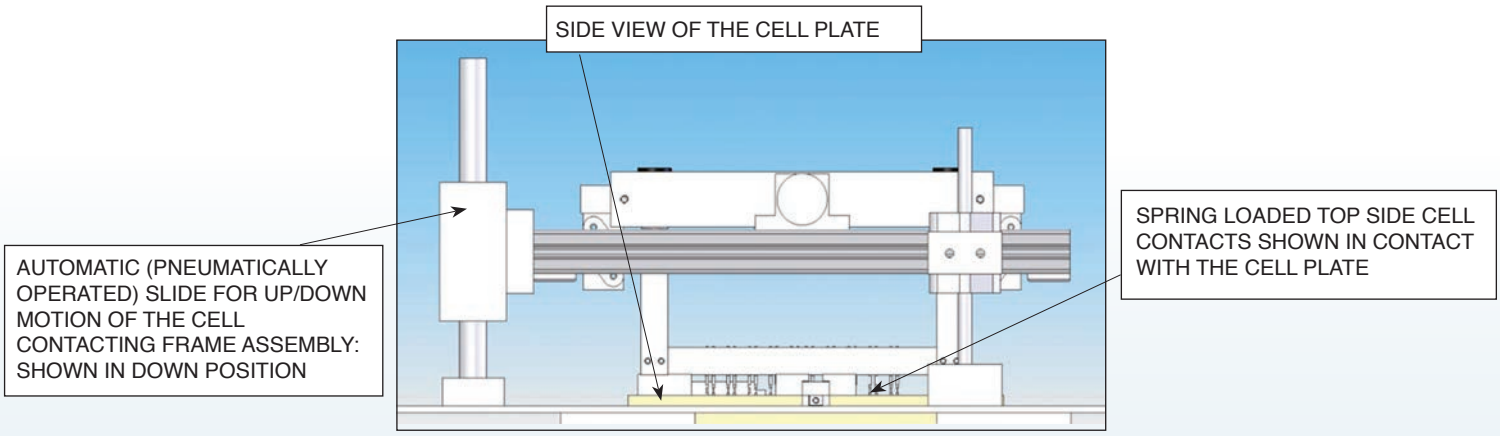


FIGURE 4: SIDE VIEW OF CELL PLATE AND AUTOMATED CELL CONTACTING IN "DOWN" POSITION

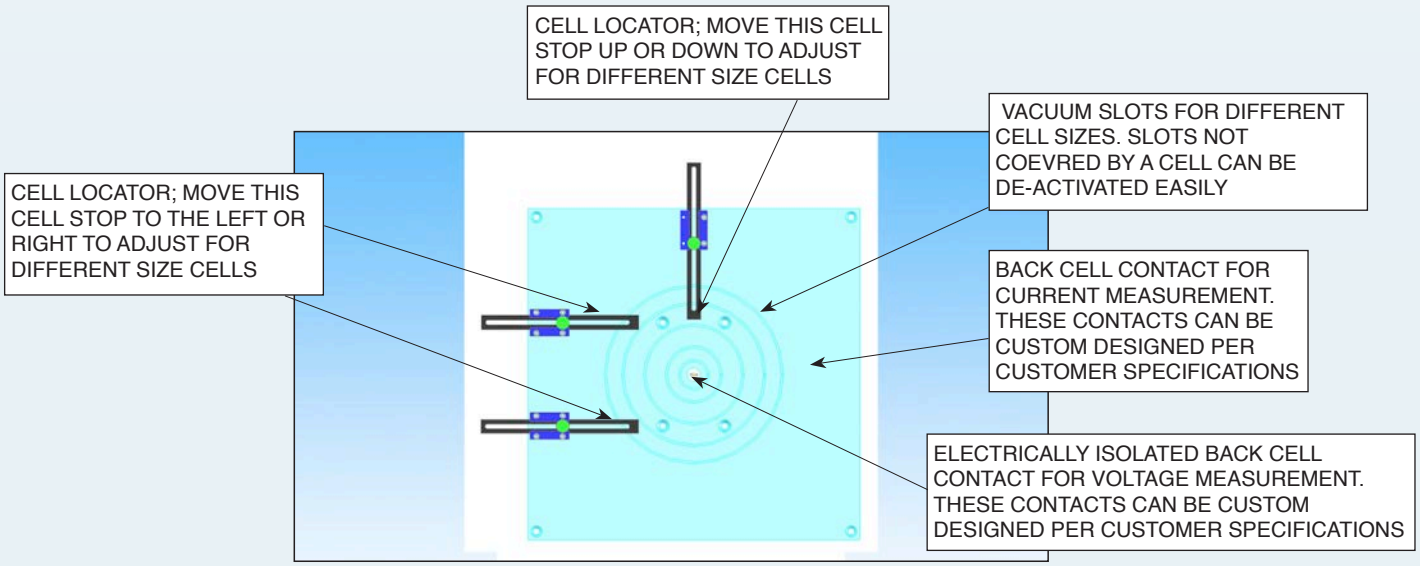


FIGURE 5: TOP VIEW OF CELL PLATE

CELL TESTING FIXTURES
DESCRIPTION & FEATURES

Custom Designed Test Fixtures

Model # 60688

This test fixture is designed for testing small cells, typically cells as small as 10mmx10mm and as large as 50mmx50mm. Both electrical contacts are made to the bottom of the cell. This fixture has the flexibility of being able to select any probe to make contact with the bottom of the cell. The cell is irradiated from the top. The distance between the left and right contacts can also be adjusted to accommodate different distance between cell contacts.

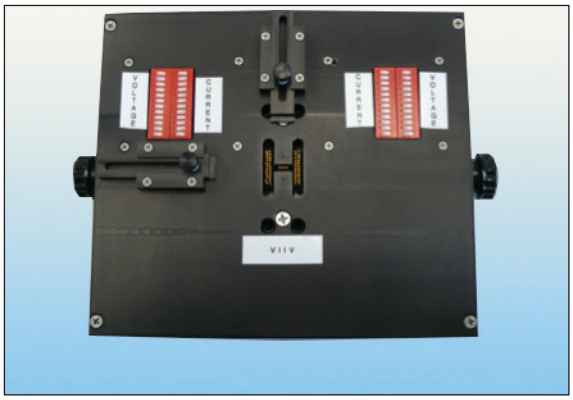


FIGURE 6: MODEL #60688

Model # 60704

This test fixture is designed for testing small cells, typically cells as small as 10mmx10mm and as large as 40mmx40mm. This fixture has full flexibility of cell contacting. User has the flexibility of the following cell contacting scheme. The selection of the cell contacting scheme can be made by connecting different banana sockets at the rear panel. See picture below.

1. **Contact Top & Bottom, both left and right hand side of cell**
2. **Contact Top & Bottom, only left hand side of the cell**
3. **Contact Top & Bottom, only right hand side of the cell**
4. **Contact Top Only**
5. **Contact Bottom Only**

The top contacts are two bus bars; each bus bar has two (2) current and two (2) voltage probes. The bus bars are mounted on a hinged frame so that the frame can be raised for placing the cell on the fixture. After placing the cell on the fixture the frame can be lowered and locked in position to maintain cell contact. The distance between the two bus bars can be adjusted to accommodate different distances between bus bars on the cells. The height of the bus bars can also be adjusted to accommodate different cell thicknesses and adjust cell contact pressure. The distance between the bottom left and right probes can also be adjusted. In addition the height of the bottom probes can also be adjusted to adjust contact pressure.

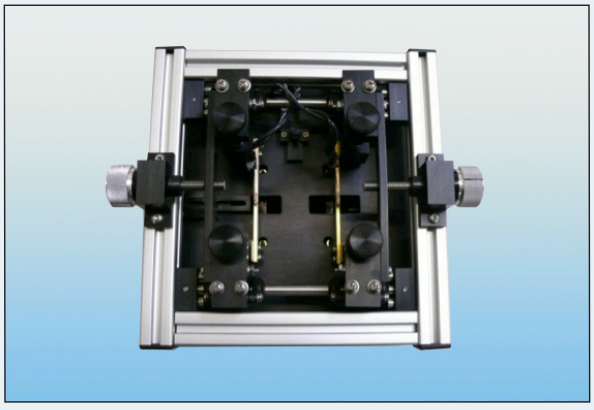


FIGURE 7: TOP VIEW OF THE FIXTURE WITH TOP CONTACTS IN LOWERED POSITION

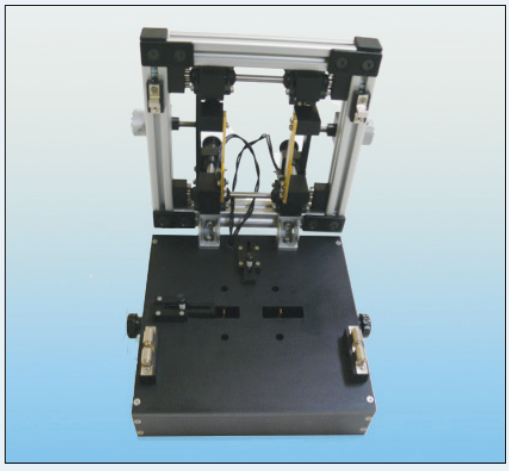


FIGURE 8: FRONT VIEW OF THE FIXTURE WITH TOP CONTACTS RAISED

CELL TESTING FIXTURES DESCRIPTION & FEATURES

Model # 60714

This test fixture is custom designed for testing up to four (4) devices on each cell. The user has the flexibility of testing each device individually or any number of devices together by using switches provided on the front panel. Both electrical contacts are made to the bottom of the cell. The spring loaded probes can be raised or lowered to adjust the cell contact pressure. Once the cells are placed in position on the cell plate, then the upper hinged frame can be lowered to hold the cells down with two spring loaded plungers. The spring loaded plungers can me moved to change the distance between the points where the cell is held down. The cell is irradiated from the top. The distance between the left and right contacts can also be adjusted to accommodate different distance between cell contacts.

FIGURE 9: REAR VIEW OF THE FIXTURE- BANANA JACKS TO SELECT DIFFERENT CELL CONTACTING SCHEME

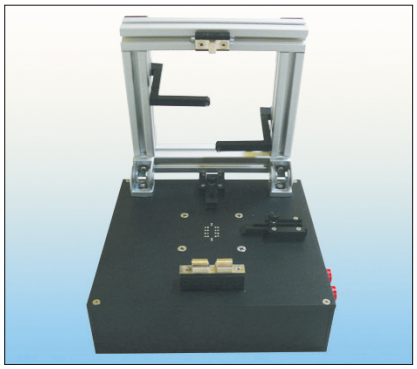


FIGURE 10: SIDE VIEW OF THE FIXTURE WITH CELL CLAMPS RAISED

CC SERIES I-V CURVE DATA ACQUISITION SYSTEM DESCRIPTION & FEATURES

General System Description

The Solar Cell I-V Curve Data Acquisition System characterizes the current-voltage (I-V) characteristics of photovoltaic devices with currents up to 20.0 amperes. It calculates the solar cell parameters, generates printable test reports and saves test data in text files. Curves are measured using classic four probes (Kelvin) technique. The system includes electronics, software, rack-mount computer, chuck and cell testing fixture with irradiance monitoring and optional temperature control. It interfaces with the customers' Solar Simulator or a Solar Simulator can be supplied.

Figure 11: Typical I-V System Console for 1A, 3A & 5A Systems

Figure 12: Typical I-V System Console for 15A & 20A Systems

CC SERIES I-V CURVE DATA ACQUISITION SYSTEM DESCRIPTION & FEATURES

Cell Testing Fixture

The IV Curve Data Acquisition system includes a fixture for holding cell during testing. The fixtures are of appropriate size to hold the cells ranging from the smallest to 300mm x 300mm. Adjustable cell stops are provided in the X & Y Axis to consistently locate cells on the cell plate. There is a provision for vacuum holding the cell during testing. Customer would need to supply an external vacuum source.

Options

Temperature Control

Temperature control of the platen that holds the cell during measurement is available. The standard temperature control range is 0-60OC. Other temperature control ranges are available. Temperature control accuracy is < ±1OC.

Setup and Training

System setup is easy when using the instructions provided in the manual. If desired, PET will provide system setup and training at the customer's facility.

The above specifications provide general information about this product. Actual product can be customized to meet the needs of individual customers.

The IV Systems come with a choice of two different IV Measurement Software: **Standard Software** & **Advance Software.** The choice of Console depends mainly on the maximum current measurement requirement and the software selected.

Standard Software Features

- MS Windows environment and user friendly software.
- Computes solar cell parameters including: ISC, VOC, VMAX, IMAX, PMAX, FF, Efficiency, Rs, Rsh, JSC, RS Density, RSH Density.
- Measures Light & Dark IV Curves.
- Scan data can be saved manually or automatically.
- In automatic file save mode, the user defines a file name series. In this mode, the software creates a summary file of all the major measured parameters for all the cells tested in that series. This helps in analyzing the data for a series of cells tested for trends etc.
- Provides printable test reports and test data in text files for easy exchange between programs
- Solar Simulator shutter control (Solar Simulator sold separately)

EXAMPLES OF STANDARD I-V MEASUREMENT SOFTWARE SCREENS

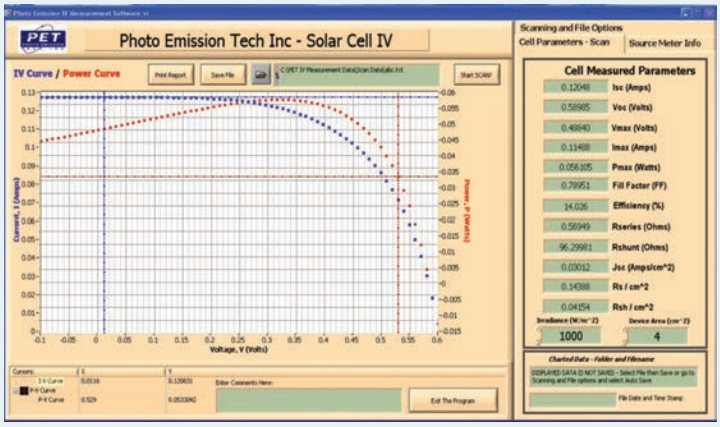


Figure 13: Cell Parameter Scan Screen

EXAMPLES OF STANDARD I-V MEASUREMENT SOFTWARE SCREENS

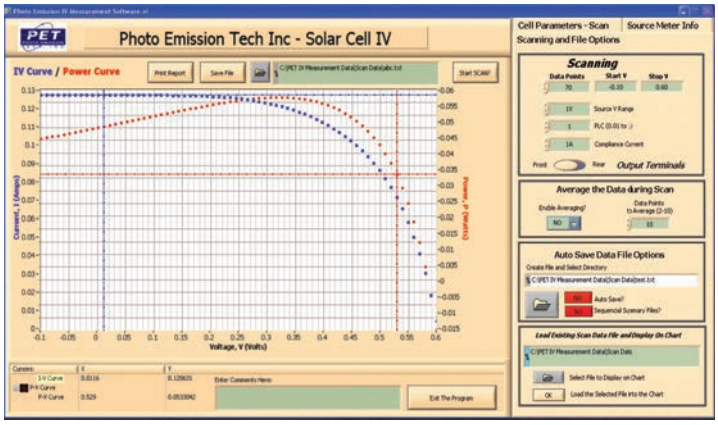


Figure 14: Scanning and File Options Screen

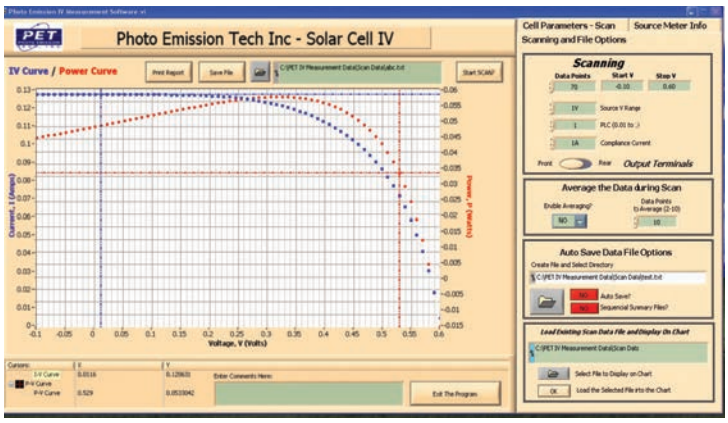


Figure 15: Source Meter Information Screen

TABLE 1
IV SYSTEM TECHNICAL SPECIFICATIONS (WITH STANDARD SOFTWARE)

Model	CC-1	CC-3	CC-5	CC-20
Max. Current Range (A)	±1	±3	±5	±20
Keithley Source Meter Model #	2400/2401	2420	2440	2651
Available Current Ranges	±1A, ±100mA, ±10mA, ±1mA, ±100µA, 10µA, ±1µA	±3A, ±1A, ±100mA, ±10mA, ±1mA, ±100µA, 10µA,	±5A, ±1A, ±100mA, ±10mA, ±1mA, ±100µA, 10µA,	±20A, ±10A, ±5A, ±1A, ±100mA, ±10mA, ±1mA, ±100µA, ±10µA, ±1µA, ±100nA
Max. Voltage Range (V)	±20	±60	±40	±40
Available Voltage Ranges	±20V, ±2V, ±200mV	±60v, ±20V, ±2V, ±200mV	±40V, ±10V, ±2V, ±200mV	±40V, ±20V, ±10V, ±1V, ±100mV
Max. Power (W)	20	60	50	200
Measurement Resolution	16 Bit			
Measurement Accuracy	Better than 0.5%			
Measurement Mode	Fixed or Auto			
Measurement Time (Light)	<500ms for stable light (Up to 4s if filtering for light fluctuations required)			
Measurement Time (Dark)	100-1,000ms			
Maximum Points per Curve	275			
Maximum Data Acquisition	100kHz			
Maximum Cell Throughput	1,200/Hour (With optional Robotics)			
Phase (Power)	Single Phase			
Voltage (Volts)/Frequency (Hz)	115/220VAC: 50-60Hz			
Max. Power Consumption (W)	40 W (Up to 600W With Peltier Cells)			

Advance IV Measurement Software Features

- Easy to use MS Windows environment and user friendly software.
- Software handles measurement of both P type and N type cells without any cell connection changes.
- Advanced noise filtering feature to enable measurement of good quality I-V curves even under fluctuating intensity conditions.
- Light Intensity & Temperature monitoring and control, 0-60OC Standard. Other ranges optional.
- Calculation of cell series resistance according to IEC 60891 standard.
- Procedures for fitting of measured I-V Curve to either equivalent diode models, i.e. SEM-Single Exponential, DEM-Double Exponential and VDEM-Variable Double Exponential with seventeen (17) weight functions.
- Procedures for curve correction to Standard Test Conditions (STC) to IEC60891, Anderson's and Blaessar's or user defined conditions. User has the ability to perform automatic correction of measured I-V curve to STC (Standard Test Conditions), i.e. light intensity and temperature or other conditions specified by the user.
- Computes solar cell parameters including ISC, VOC, FF, IMAX, VMAX, PMAX, Eff , Rs and Rsh and saves them automatically on hard disk drive. In addition cell's temperature and irradiance level is measured and stored for future analysis.
- Thermal Coefficients of ISC, VOC, IM, VM, PM, FF, Eff., RS@VOC & RSH@ISC
- Dark saturation current, RS and RSH determination
- Provides printable test reports and test data in text files for easy exchange between programs.
- Software features include cell sorting in various categories. This cell sorting can be performed in production or in virtual binning modes specified by the user.
- Solar Simulator shutter control (Solar Simulator sold separately) erse →Forward, Forward →Reverse →Forward, Reverse →Forward →Reverse IV Scan Option.
- I-V Scan Delay user sets time delay to start I-V scan after opening shutter. Usefull for testing slow responding devices.

Majority of the features highlighted in yellow are usually not found in competitors' software

EXAMPLES OF ADVANCE I-V MEASUREMENT SOFTWARE SCREENS

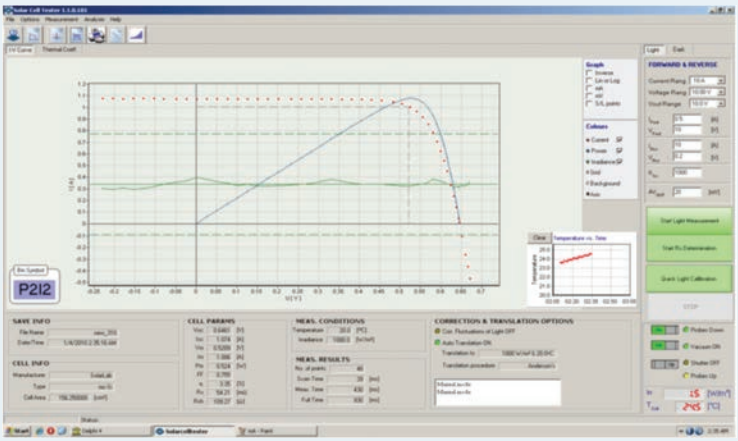


Figure 16 Example of "light" measurement – Advance Software

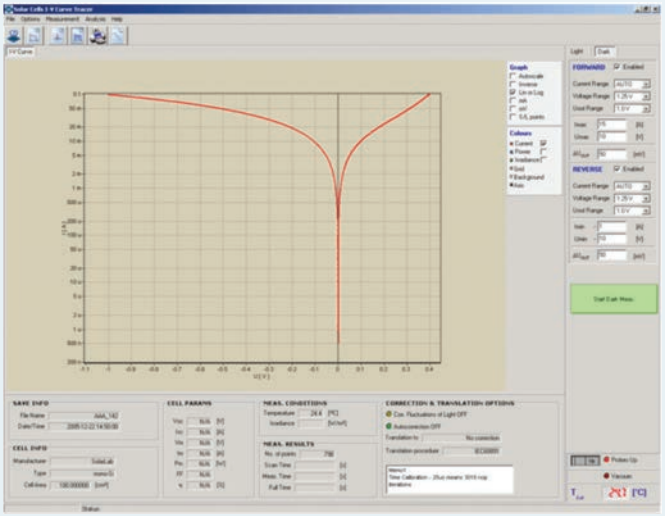


Figure 17 Example of "dark" measurement – Advance Software

EXAMPLES OF ADVANCE I-V MEASUREMENT SOFTWARE SCREENS

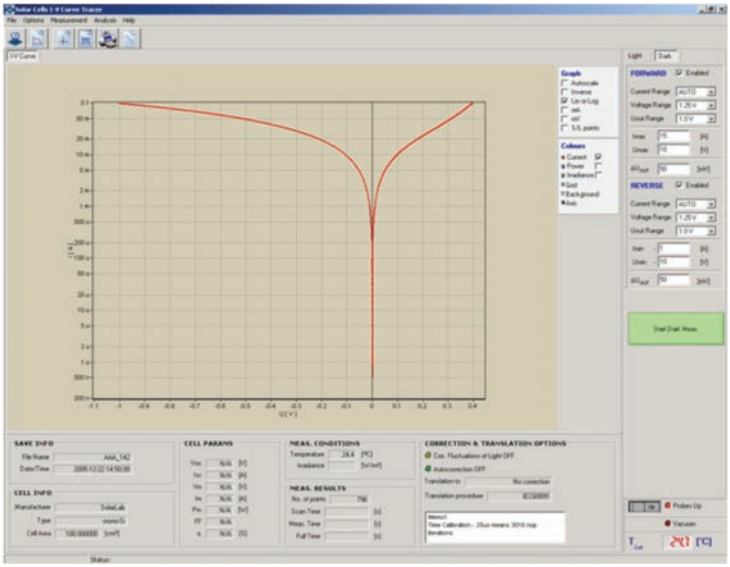


Figure 18 Example of cell's series resistance determination according to IEC 60891 Standard

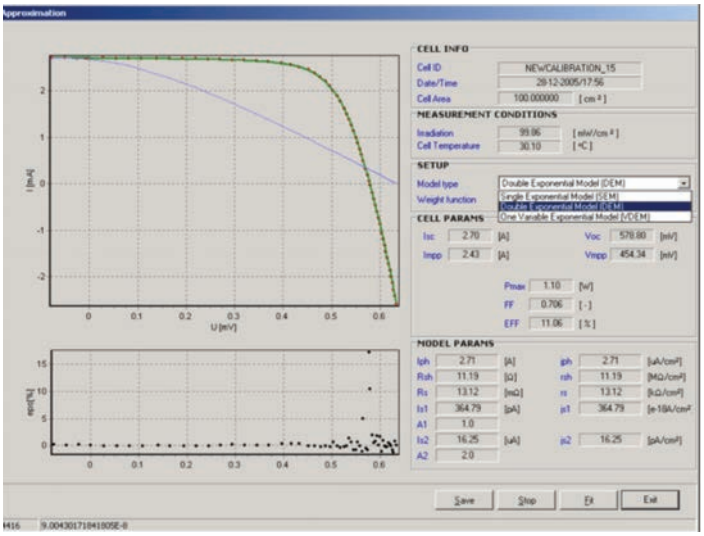


Figure 19 Example of cell's I-V curve fitting to Double Diode equivalent electrical model

The IV Systems come with a choice of two different IV Measurement Software: **Standard Software** & **Advance Software**. The choice of Console depends mainly on the maximum current measurement requirement and the software selected.

FEATURE COMPARISON OF STANDARD & ADVANCE IV MEASUREMENT SOFTWARE		
FEATURE DESCRIPTION	Standard IV MEASUREMENT SOFTWARE	ADVANCE IV MEASUREMENT SOFTWARE
Measure Isc	YES	YES
Measure Voc	YES	YES
Measure FF	YES	YES
Measure Imax	YES	YES
Measure Vmax	YES	YES
Measure Pmax	YES	YES
Measure Efficiency	YES	YES
Measure Rs	YES	YES
Measure Rsh	YES	YES
Measure P & N Type without connection change	YES	YES
Advance Signal Filtering for light fluctuations	YES	YES
Solar Simulator Shutter Control	YES	YES
Measure & Record Cell Temperature	NO	YES
Measure & Record Light Intensity	NO	YES
Calculation of Series Resistance as per IEC 60891	NO	YES
Curve Fitting to Equivalent Diode Models	NO	YES
Weight Functions for Curve Fitting	NO	YES
Curve Correction to STC or User defined Conditions	NO	YES
Derive Thermal Coefficients of Isc, Voc, Im, Vm, Pm, FF, Rs@Voc, Rsh@Isc	NO	YES
Virtual or Actual Cell Sorting (Binning)	NO	YES
Forward → Reverse, Reverse → Forward, Forward → Reverse → Forward, Reverse → Forward → Reverse IV Scan Option	NO	YES
I-V Scan Delay user sets time delay to start I-V scan after opening shutter. Usefull for testing slow responding devices.	NO	YES

TABLE 2
IV SYSTEM TECHNICAL SPECIFICATIONS (WITH ADVANCE SOFTWARE)

Model	CC_1	CC-3	CC_5	CC_15	CC-20
Max. Current Range (A)	±1	±3	±5	±15	±20
Available Current Ranges	±1A, ±100mA, ±10mA, ±1mA,	±3A, ±1A, ±100mA,	±5A, ±1A, ±100mA,	±15A, ±10A, ±1A, ±100mA,	±20A, ±10A, ±1A, ±100mA,
Max. Voltage Range (V)	±20	±60	±40	±10	±10
Available Voltage Ranges	±20V, ±2V, ±200mV	±60v, ±20V, ±2V, ±200mV	±60v, ±20V, ±2V, ±200mV	±10V, ±5V, ±2.5V, ±1.25V,	±10V, ±5V, ±2.5V, ±1.25V,
Max. Power (W)	20	60	50	150	200
Measurement Resolution	16 Bit				
Measurement Accuracy	Better than 0.5%				
Measurement Mode	Fixed or Auto				
Measurement Time (Light)	<500ms for stable light (Up to 4s if filtering for light fluctuations required)				
Measurement Time (Dark)	100-1,000ms				
Maximum Points per Curve	100~1,000 (model specific)				
Maximum Data Acquisition Speed	100kHz			4,096	
Maximum Cell Throughput	1,200/Hour (With optional Robotics)				
Phase (Power)	Single Phase				
Voltage (Volts)/Frequency (Hz)	220VAC (115VAC Optional)/50-60Hz				
Max. Power Consumption (W)	40 W (Up to 600W With Peltier Cells)				
Curve Correction to STC	IEC 80891, JRC or Anderson				
Advance Fitting of I-V Curves	SEM, DEM and VDEM Models (17 Different Weight Functions)				
Thermal Coefficients of Voc and Pm	Standard on All Systems (With Optional Temperature Control)				
Irradiance Monitoring & Correction	Standard on All Systems				

Ordering I-V Measurement System

The I-V Measurement System/Cell Characterization System model numbers should be determined as follows:
CC-S-C- YY- WW

Where: **CC stands for Cell Characterization**

S - Specifies the type of software: S for Standard Software and A for Advanced software

C - Specifies the maximum current measuring capability:
1 – 1A capability
3 – 3A capability
5 – 5A capability
20 – 20A capability

YY - Specifies cell temperature control provision:
TC - Temperature Control Provision (5-70 C)
NT - No Temperature Control Provision

WW- Specifies cell contacting provision:
MA- Manual Contacting Provision
AT- Automatic Contacting Provision

For example: Model # CC-A-5-TC-MA is an I-V Measurement system with Advanced Software and 5A current capability, with Cell Temperature Control option and Manual Cell Contacting.

ACCESSORIES

Reference Cells:

The Reference Cells incorporate a 2 x 2 cm either mono-crystalline or poly-crystalline cell.The main features are:

- Lightweight black anodized aluminum body
- Holes for ease of mounting
- Designed for use with any Solar Simulator
- Cell protected by quartz window
- Special window material can be incorporated
- Available in poly- or mono-crystalline
- Other type of cells can be incorporated

Two different models are available. Standard Reference Cell and Shunted Reference Cell

Solar cell short circuit current (ISC) is directly proportional to the intensity of the light incident on the solar cell. Because of this property of the solar cell, it can be used to set the intensity of the solar simulator as well as calibrate any photo detector used with the IV measurement system to measure the light intensity during IV measurement. This Reference Cell consists of a 20mm x 20mm mono-crystalline silicon Photovoltaic Cell encased in a metal enclosure with a protective quartz widow and a temperature sensor. The standard temperature sensor is a 100Ω platinum Resistance Temperature Detector (RTD). Alternative temperature sensor can be installed upon request.

The calibration report for this type of reference cell provides the test data for the parameters: ISC, JSC, VOC, IMAX, VMAX, PMAX, and FF. In addition the spectral response of the solar cell is also measured and provided. A correction factor for the spectral mismatch is applied to the calibration ISC value. This cell has 4-wire connection for cell measurement and 4-wire connection for temperature measurement for more accurate measurements.

Standard Reference Cell

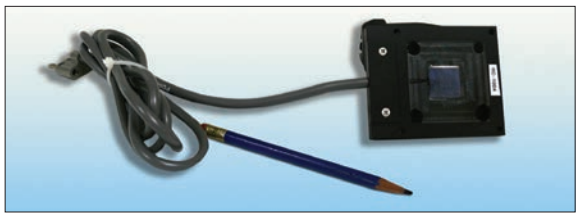
The shunted reference cell (a resistor installed across the two electrodes of the cell) can be used to set the intensity level of the Solar Simulator directly on the Solar Simulator. It cannot be used to set the intensity of the Solar Simulator using the short circuit current measurement through an IV measurement system. This type of reference should be used to set the intensity of the solar simulator for tests other than solar cell testing.

For this type of reference cell the cell output in mV is specified for one sun intensity. Typical value for (mono-crystalline silicon) this type cell is ~50-60mV. In order to calibrate the solar simulator, the cell is placed under the solar simulator light. The output of the reference cell is attached to a digital voltmeter. The intensity of the solar simulator is adjusted until the DVM reads a value that is the calibrated value of the reference cell. Once the reference cell output reads the same as the calibrated value then the solar simulator intensity is set to one sun.

Intensity Meter

When used with Reference Solar Cell, the intensity of the solar simulator can be measured and calibrated. In addition the Meter can be used to measure and display the temperature of the Reference Cell. The Meter reads the calibrated solar simulator irradiance. It can be easily integrated with PET I-V Testing system.

For more details, see data sheet for the Intensity Meter on our website.



Shunted Reference Cell

Irradiance Non-Uniformity Testing:

The uniformity testing/mapping system is a very convenient and easy way to check the uniformity of the Solar Simulator Light Beam. Manual and semi-automated versions are available. The system includes all the necessary equipment to check the uniformity. This includes a 6x6 matrix Test Grid for customer specified area. The grid is designed to test 36 points (6 x 6) over the area of illumination as per ASTM Standard E927-04. A 8x8 matrix Test Grid as required by IEC 60904-9 for measuring non-uniformity of the irradiance can also be provided. The cell in the Test Cell Fixture is calibrated to a traceable standard for 1 sun. Hence this cell can be used not only to check uniformity but also adjust the intensity of the Solar Simulator to 1 sun intensity. The Test Cell Fixture has a silicon cell; however, other type of cells (supplied by customer) can be incorporated in to the Test Cell Fixture to better match the spectral response of customers' cells. However, special grids can be supplied or made by the customer to test more or less points in the area of illumination.

Temporal Stability Testing:

The temporal stability testing system is a very convenient and easy way to check the stability of the Solar Simulator Light Beam. The system includes all the necessary equipment to check the stability. The cell in the Test Cell Fixture is calibrated to a traceable standard for 1 sun. Hence this cell can be used not only to check temporal stability but also the uniformity of the light and calibrate the intensity of the Solar Simulator to 1 sun intensity. The Test Cell Fixture has a silicon cell; however, other type of cells (supplied by customer) can be incorporated in to the Test Cell Fixture to better match the spectral response of customers' cells.

Extended Warranty

Our products carry standard two-year warranty. An additional one year extended warranty is available at additional cost at the time of equipment purchase. Please contact the factory. In addition, annual maintenance contracts are also available.

:REPRESENTED BY

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