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AN INTRODUCTION TO SOLAR SIMULATORS

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Basics of Solar Radiation

In order to understand the importance of a good quality Solar Simulator, it is important to review the major factors that affect the amount of solar radiation reaching the earth's surface.

1. Earth's distance from the sun

One of the major factors is Earth's distance from the Sun. This varies throughout the year. As a result, the incident solar radiation reaching the earth's surface at any given point and time varies with the time of the year. This is because of earth's position relative to the sun varies throughout the year. The irradiance that reaches the earth's outer atmosphere, when the sun and earth spaced at 1AU (the mean earth-sun distance), is called the solar constant. The accepted value for the solar constant is currently 1,366 W/m^2. The solar constant is the total integrated irradiance over the entire spectrum. A major portion, 96.3% of the total irradiance, is within the 200 to 2,500nm spectrum.

2. Earth's atmosphere

The sun light has to pass through the earth's atmosphere (Air Mass) to reach the surface of the earth. The angle at which the sun approaches a given point on the surface of the earth (zenith angle) varies from the morning until the evening.
For example, at noon time Sun is directly overhead, hence the distance the light has to travel through atmosphere (Air Mass) to reach the earth's surface is the shortest during the day. At any other time, the distance the light has to travel through atmosphere (Air Mass) to reach the earth's surface is always longer than at noon, being the longest in the morning and evening.

3. Earth's Topography

The distance of the sun to a given point on the surface of the earth also depends on the altitude of that point. For example, with the sun overhead, the irradiance in Denver (mile high city) will be higher than the irradiance at sea level. With the sun overhead, the radiation that reaches the ground passes straight through all the air mass overhead. This level of radiation is referred to as Air Mass 1 Direct (AM1D) spectrum. For standardization purposes sea level is used as a reference site. The global radiation with the sun overhead is referred to as Air Mass 1 Global (AM1G) spectrum. The radiation in space, outside the earth atmosphere, is referred to as Air Mass 0 (AM0) spectrum. Actual path length can correspond to air masses of les than 1 (high altitude sites), to very high air masses just before sunset. Since the atmospheric path changes throughout the day, the global average radiation is referred to as Air Mass 1.5 Global (AM1.5G) spectrum.

The Need for Standards

In order to be able to compare performance of products, it is necessary to define a standard set of test conditions using solar simulators. Some of the highlights of these standards are as follows:

- Spectrum of solar radiation in space is Air Mass 0. Spectrum of global solar radiation reaching the earth's surface with the sun directly overhead is Air Mass 1G.
- Spectrum of solar radiation reaching the earth's surface when the sun's vector is 48.2 degrees form the vertical is Air Mass 1.5.
- Spectrum of solar radiation reaching the earth's surface when the sun's vector is 60.1 degrees form the vertical is Air Mass 2.0.

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- In addition to defining Air Mass Standards, there are standards for the class of system. The class of a Solar Simulator refers to how well the characteristics of the simulated radiation match characteristics of the solar radiation.

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 904-9 – 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 American standard.

- **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 sun light;

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

ASTM E927 STANDARD

Table 1 Classification of Simulator Performance

Characteristic	Simulator Class		
	A	B	C
Non-Uniformity of Total Irradiance	≤2%	≤5%	≤10%
Temporal Instability of Irradiance	≤2%	≤5%	≤10%
Spectral Match to Table 2- All Intervals	≤±25% or 0.75 – 1.25	≤±40% or 0.60 – 1.4	≤-60/+100% or 0.4 – 2.0

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Table 2 Spectral Distribution of Irradiance Performance Requirements			
Percent of Total Irradiance			
Wavelength Interval, nm	Percent of AM1.5 Curve (normalized for 400-1,100 nm)		Percent of AM0 Curve (normalized for 300-1,400 nm)
	Direct	Global	
300-400	N/A	N/A	8.9
400-500	15.6	18.5	18.2
500-600	19.9	20.1	18.1
600-700	17.4	18.3	15.5
700-800	15.9	14.8	12.4
800-900	13.3	12.2	9.8
900-1,100	17.9	16.1	8.1
1,100-1,400	N/A	N/A	9.0

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 total irradiance must be **≤2%**, the temporal instability of total irradiance must be **≤2%** and the spectral match in each wavelength interval must be **≤±25%**.

Even though the individual wavelength bands have a seemingly large tolerance, the overall intensity still has to match the specified one sun intensity. One of the reasons these tolerances are large is because the state of art technology for lamps is not advanced enough to make a lamp better than Xenon lamp, which has the closest spectral match to the sun light. Another thing to keep in mind is that even though the standard allows wide tolerance, most good quality solar simulators have much better spectral match in each waveband than that allowed by the standard.

ASTM is in the process of implementing a revised standard which will 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 non-uniformity class of the system, second letter in the class designation refers to the temporal instability class of the system and the third letter in the class designation refers to the spectral match class of the system. The new standard still allows a single letter designation. For example, a Class A signifies that the solar simulator meets all three requirements of class A.

Solar Simulators Customization

In addition to using the Solar Simulator for testing the efficiency of solar cells, it can be used to life test various materials. 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 100mW/cm^2 or 1,000W/m^2. If the intensity is increased to 200mW/cm^2 or 2,000W/m^2, then the solar simulator would be classified as “two suns”.