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Standard Test Method for Spectral Responsivity Measurements of Photovoltaic Devices[1]

This standard is issued under the fixed designation E1021; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

~~1.1This test method is to be used to determine either the absolute or relative spectral responsivity response of a single-junction photovoltaic device. This test method requires the use of a bias light.~~

~~1.2~~

1.1 This test method is to be used to determine either the absolute or relative spectral responsivity response of a single-junction photovoltaic device.

1.2 Because quantum efficiency is directly related to spectral responsivity, this test method may be used to determine the quantum efficiency of a single-junction photovoltaic device (see 10.10).

1.3 This test method requires the use of a bias light.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E772 Terminology of Solar Energy Conversion

E927 Specification for Solar Simulation for Photovoltaic Testing

E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight

E973 Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum ~~E1328Terminology Relating to Photovoltaic Solar Energy Conversion~~

E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells

E2236 Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction Photovoltaic Cells and Modules

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37 Tilted Surface

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E772~~and in Terminology E1328~~.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *chopper*, *n*—a rotating blade or other device used to modulate a light source.

3.2.2 *device under test (DUT)*, *n*—a photovoltaic device that is subjected to a spectral responsivity measurement.

[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.3 *irradiance mode calibration*, *n*—a calibration method in which the reference photodetector measures the irradiance produced by the monochromatic beam.

3.2.4 *monitor photodetector*, *n*—a photodetector incorporated into the optical system to monitor the amount of light reaching the device under test, enabling adjustments to be made to accommodate varying light intensity.

3.2.5 *monochromatic beam*, *n*—chopped light from a monochromatic source reaching the reference photodetector or device under test.

3.2.6 *monochromator*, *n*—an optical device that allows a selected wavelength of light to pass while blocking other wavelengths.

3.2.7 *power mode calibration*, *n*—a calibration method in which the reference photodetector measures the power in the monochromatic beam.

3.2.8 ~~*quantum efficiency*, *n*—number of collected electrons per incident photon at a specific wavelength in percent units.~~

~~3.2.9~~*reference photodetector*, *n*—a photodetector used to quantify the amount of light in monochromatic beam.

~~3.2.10~~

3.2.9 *spectral bandwidth*, *n*—the range of wavelengths in a monochromatic light source, determined as the difference between its half-maximum-intensity wavelengths.

3.3 *Symbols:*

3.3.1 The following symbols and units are used in this test method.

A—illuminated device area, m^2,

c—speed of light in vacuum, 299792458 $m \cdot s^{-1}$,

CV_{Mi}—monitor photodetector calibration value for irradiance mode, ~~A·m~~$A \cdot m^2$ ~~·W~~W^{-1},

CV_{Mp}—monitor photodetector calibration value for power mode, ~~A·W~~$A \cdot W^{-1}$

ε—small wavelength interval, nm or μm,

E_o— reference total irradiance, $W \cdot m^{-2}$,

E_o (λ)—reference spectral irradiance, $W \cdot m^{-2} \cdot nm^{-1}$ or $W \cdot m^{-2} \cdot \mu m^{-1}$,

E_M—monochromatic source irradiance, $W \cdot m^{-2}$,

Err—fractional error in measurement, dimensionless,

h~~—Planck's constant, J·s,~~ —Planck's constant, $6.62606957 \times 10^{-34}$ J·s,

I—current, A,

I_{mc}—monitor photodetector current during calibration, A,

I_{mt}—monitor photodetector current during test, A,

I_{sc}—solar cell short-circuit current, A,

I_o—I_{sc} under E_o(λ), A,

J_{sc}—solar cell short-circuit current density, $A \cdot m^{-2}$,

K_i—relative-to-absolute spectral responsivity conversion constant for irradiance mode, $A \cdot m^2 \cdot W^{-1}$,

K_p—relative-to-absolute spectral responsivity conversion constant for power mode, $A \cdot W^{-1}$,

λ—wavelength, nm or μm,

λ_o—a specific wavelength, nm or μm,

M—spectral mismatch parameter,

P—monochromatic beam power reaching the photodetector, W,

ϕ—power of the monochromatic beam or irradiance of the monochromatic beam, W or $W \cdot m^{-2}$,

q~~—elementary charge, C,~~ —elementary charge, $1.602176565 \times 10^{-19}$ C,

Q~~—external quantum efficiency,~~ —external quantum efficiency dimensionless or percent,

R_{ia}—absolute spectral responsivity for irradiance mode, $A \cdot m^2 \cdot W^{-1}$,

R_{pa}—absolute spectral responsivity for power mode, $A \cdot W^{-1}$,

R_{ir}—relative spectral responsivity for irradiance mode, dimensionless,

R_{pr}—relative spectral responsivity for power mode, dimensionless,

SR—spectral responsivity, $A \cdot W^{-1}$ or $A \cdot m^2 \cdot W^{-1}$.

3.3.2 Symbolic quantities that are functions of wavelength appear as *X* (λ).

4. Summary of Test ~~Methods~~Method

4.1 The spectral responsivity of a photovoltaic device, defined as the output current per input irradiance or radiant power at a given wavelength, and normally reported over the wavelength range to which the device responds, is determined by the following procedure:

4.1.1 A monochromatic, chopped beam of light is directed at normal incidence onto the cell. Simultaneously, a continuous white light beam (bias light) is used to illuminate the DUT at irradiance levels between one third and one half of normal end use operating conditions intended for the device. See Fig. 1.

4.1.2 The magnitude of the ac (chopped) component of the current at the intended voltage is monitored as the wavelength of the incident light is varied over the spectral response range of the device.

4.2 Measurement of the absolute spectral responsivity of a device requires knowledge of the absolute beam power or irradiance produced by the monochromatic beam. The total power or irradiance of the monochromatic beam incident on the device is

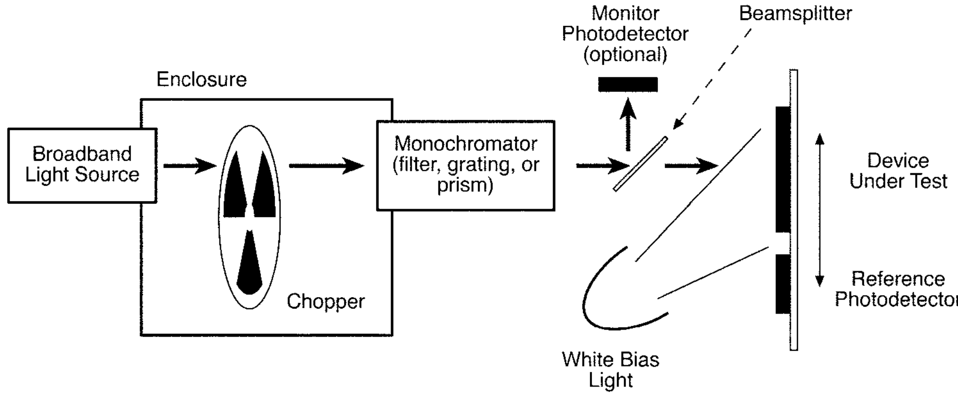

FIG. 1 Example of Spatial Placement of Optical Components for Spectral Responsivity Measurement

determined by the reference photodetector (see 6.1). The absolute spectral responsivity of the device can then be computed using the measured device photocurrent and the power or irradiance of the monochromatic beam.

4.3 The choice of power versus irradiance mode may depend on the spatial non-uniformity of the test device. Overall spectral response of a test device with substantial spatial non-uniformity of response should be performed in irradiance mode.

4.4 The test procedure can be adapted to provide absolute or relative spectral responsivity measurements, depending on the calibration device used, its calibration mode and the relative sizes of the calibration device, the monochromatic beam size, and the device being measured.

5. Significance and Use

5.1 The spectral responsivity of a photovoltaic device is necessary for computing spectral mismatch parameter (see Test Method E973). Spectral mismatch is used in Test Method E948 to measure the performance of photovoltaic cells in simulated sunlight, in Test Methods E1036 to measure the performance of photovoltaic modules and arrays, in Test Method E1125 to calibrate photovoltaic primary reference cells using a tabular spectrum, and in Test Method E1362 to calibrate photovoltaic secondary reference cells. The spectral mismatch parameter can be computed using absolute or relative spectral responsivity data.

5.2 This test method measures the differential spectral responsivity of a photovoltaic device. The procedure requires the use of white-light bias to enable the user to evaluate the dependence of the differential spectral responsivity on the intensity of light reaching the device. When such dependence exists, the overall spectral responsivity should be equivalent to the differential spectral responsivity at a light bias level somewhere between zero and the intended operating conditions of the device.

5.3 The spectral responsivity of a photovoltaic device is useful for understanding device performance and material characteristics.

5.4 The procedure described herein is appropriate for use in either research and development applications or in product quality control by manufacturers.

5.5 The reference photodetector's calibration must be traceable to SI units through a National Institute of Standards and Technology (NIST) spectral responsivity scale or other relevant radiometric scale.[3,4] The calibration mode of the photodetector (irradiance or power) will affect the procedures used and the kinds of measurements that can be performed.

5.6 This test method does not address issues of sample stability.

~~5.7Using results obtained by this test method and additional measurements, one can compute the internal quantum efficiency of a device.~~

5.7 Using results obtained by this test method and additional measurements including reflectance versus wavelength, one can compute the internal quantum efficiency of a device. These measurements are beyond the scope of this test method.

5.8 This test method is intended for use with a single-junction photovoltaic cell. It can also be used to measure the spectral responsivity of a single junction within a series-connected, multiple-junction photovoltaic device if electrical contact can be made to the individual junction(s) of interest.

5.9 With additional procedures (see Test Methods E2236), one can determine the spectral responsivity of individual junctions within series-connected, multiple-junction, photovoltaic devices when electrical contact can only be made to the entire device's two terminals.

5.10 Using forward biasing techniques[5], it is possible to extend the procedure in this test method to measure the spectral responsivity of individual series-connected cells within photovoltaic modules. These techniques are beyond the scope of this test method.

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[3] Larason, T. C., Bruce, S. S., and Parr, A. C., NIST Special Publication 250-41 Spectroradiometric Detector Measurements, Washington, DC, U.S. Government Printing Office, 1998. Also available at http://ois.nist.gov/sdm/

[4] Eppeldauer, G., Racz, M., and Larason, T., "Optical characterization of diffuser-input standard irradiance meters," SPIE Vol 3573, 1998, pp. 220-224.

[5] Emery, K. A., "Measurement and Characterization of Solar Cells and Modules," Handbook of Photovoltaic Science and Engineering, Chapter 16, pp. 701-747, Luque, A., and Hegedus, S., Eds., John Wiley & Sons, W. Sussex, U.K., ISBN 0-471-49196-9.

6. Apparatus

6.1 *Reference Photodetector*:

6.1.1 The following detectors are acceptable for use in the calibration of the monochromatic light source:

6.1.1.1 Pyroelectric radiometer, and

6.1.1.2 Cryogenic radiometer, and

6.1.1.3 Spectrally calibrated photodiode, photodiode irradiance detector, or solar cell, calibrated in power or irradiance mode.

NOTE 1—A spectrally calibrated photodiode should have calibration data that includes the entire spectral response range of the device to be tested. If a part of the range is omitted, it will limit the spectral range of the results of this test, causing an error in computing the spectral mismatch parameter.

NOTE 2—A photodetector calibrated in power mode must have spatially uniform spectral responsivity over its photosensitive region. A photodetector calibrated in irradiance mode may have spatially non-uniform spectral responsivity characteristics, and must only be used with a uniform monochromatic beam larger than its surface area. See also Table 1.

6.1.2 The reference photodetector must have a known linear current versus incident light intensity ratio over the range of intensities and wavelengths of the monochromatic light source.

6.1.3 The reference photodetector's calibration must be traceable to SI units through a National Institute of Standards and Technology (NIST) spectral responsivity scale or other relevant radiometric scale.[3,4]

6.1.4 The uniformity of responsivity over the surface of the reference photodetector must be characterized if it will not be entirely illuminated by the monochromatic light beam. A photodetector with spatially uniform sensitivity is suitable for use in power mode. Non-uniform detectors are suitable for use in irradiance mode with uniform light beams only. For best results, use a photodetector with the best spatial response uniformity available.

6.1.5 The reference photodetector's angular sensitivity must be compatible with the beam divergence angle of the monochromatic light source in 6.3.

6.1.6 The reference photodetector's frequency response must be known or invariant in the range of chopping frequencies to be used in the test.

6.1.7 If the reference photodetector has an aperture smaller than its photosensitive area, then irradiance and power mode calibrations can be converted to each other. If calibrated in irradiance mode, the aperture must have limited the monochromatic beam to the photosensitive region during the photodetector's calibration. If calibrated in power mode, the aperture must limit the monochromatic beam to the photosensitive region during use in irradiance mode.

6.1.8 The change in responsivity of the reference detector with wavelength over the bandwidth of the monochromatic light must be less than 1%. Avoid using a semiconductor based reference photodetector near its energy gap.

6.2 *Monitor Photodetector and Associated Optics (optional)*:

6.2.1 The monitor photodetector can be a pyroelectric radiometer, a photodiode, or a solar cell.

6.2.2 Additional optical elements are needed to sample the light in the monochromatic beam and provide it to the monitor photodetector.

6.3 *Monochromatic Light Source*:

6.3.1 A variety of different laboratory apparatus are available for the generation of monochromatic light.[5] Grating monochromators coupled with tungsten or other light sources are most commonly used. Discrete and tunable continuous-wave lasers offer another source of monochromatic light. The wide range of wavelengths available coupled with the high optical quality of ~~laser beams~~ lasers renders them attractive. Light emitting diodes (LEDs) can also provide stable, monochromatic light over a range of discrete wavelengths in the visible and near-infrared regions. Another source is the use of narrow-bandpass optical filters

TABLE 1

Reference Detector Design Mode	Rference Detector Calibration Mode	Beam Size Relative to Reference Detector	Beam Uniformity over Reference Detector Surface	Beam Size Relative to DUT	Beam Uniformity over DUT Surface	Type of Measurement that can be Performed	Case
Irradiance	Irradiance	Larger	Uniform	Larger	Uniform	Absolute	A1
Irradiance	Irradiance	Larger	Uniform	Smaller	Nonuniform	Relative	A2
Irradiance	Irradiance	Larger	Uniform	Smaller	Defined, Uniform	Absolute	A3
Power	Power	Smaller	Nonuniform	Smaller	Nonuniform	Absolute	B
Power	Irradiance	Larger	Uniform	Larger	Uniform	Absolute	C1
Power	Irradiance	Larger	Uniform	Smaller	Nonuniform	Relative	C2
Power	Irradiance	Smaller	Uniform	Smaller	Defined, uniform	Absolute	C3
Power	Irradiance		Nonunifrom	Smaller	Nonuniform	Absolute	D
Irradiance	Power	(reference photodetector calibration not valid)					
Irradiance	Irradiance	Smaller	(reference photodetector calibration cannot be used)				

NOTE 1—The kinds of measurements that can be performed depend on the calibration mode of the reference photodetector and the relationship between the size of the reference photodetector, DUT, and monochromatic beam. "Smaller" means the entire beam reaches the photosensitive surface of the reference detector or DUT. "Larger" means the entire detector or device is illuminated. "Uniform" means the part of the beam that intercepts the reference detector or DUT is uniform. "Defined" means the beam power is known because the irradiance is uniform over the area of an aperture placed between the source and the DUT. Where "absolute" measurement capability is indicated, it is implied that "relative" measurements can also be performed.

in conjunction with a broad-spectrum light source such as tungsten. The wavelength range, spectral bandwidth, and wavelength increment must be consistent with the expected responsivity characteristics of the device to be tested.

6.3.2 The monochromatic light source shall be capable of providing wavelengths that extend beyond the response range of the device to be tested. When the measurement is intended to be used to compute the spectral mismatch parameter for a terrestrial spectrum, the monochromatic source wavelengths do not need to go below 300 nm.

6.3.3 The following characteristics for the monochromatic source are recommended. The test report must provide explanation for any deviation from these recommendations.

6.3.3.1 A minimum of 12 wavelengths within the spectral response range of the device to be measured is recommended.

6.3.3.2 All increments between wavelengths should be less than 50 nm. Additional wavelengths may be required in wavelength regions where the spectral responsivity changes substantially (more than 10 percent change between measured wavelengths) with small changes in wavelength, such as at the band gap in a direct band gap semiconductor.

6.3.3.3 The spectral bandwidth of the monochromatic light source should not exceed 20 nm for any wavelength used in the test.[6]

6.3.4 The presence of small amounts of light in the monochromatic beam at wavelengths other than the intended wavelength can cause substantial errors in the measurement. The magnitude of expected error can be determined from the following equation:

$$Err \cdot SR_{\lambda o} \cdot \O_{\lambda o} \cdot 2\varepsilon > \int_{0}^{\lambda_o - \varepsilon} SR(\lambda) \cdot \O(\lambda) \cdot d\lambda + \int_{\lambda_{o+\varepsilon}}^{\infty} SR(\lambda) \cdot \O(\lambda) \cdot d\lambda \qquad (1)$$

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where ε is 1.5 times the spectral bandwidth in 6.3.3.3, λ_o is the wavelength of concern, *SR* is the spectral response of the test device, and ϕ is the power or irradiance of the monochromatic beam. The apparatus must be designed and tested to ensure that this requirement is met for a particular error level (0.005 is recommended). If a higher error level is used in the test, it must be noted in the test report. The error can be estimated by measuring a test device known to respond at a wavelength of concern with a filter that blocks that wavelength in front of the test device. In a grating monochromator system, this may require the use of order-sorting filters or a prism monochromator to attenuate stray light and higher-order wavelengths of the diffracted light. Stray light is a particular problem when making measurements in the ultraviolet region using tungsten sources or using a pyroelectric reference detector with bandpass filters.

6.3.5 Care must be taken to minimize scattered chopped light reaching the DUT. A non-reflective cavity enclosing the monochromatic light chopper (see 6.4), and the adjacent entrance or exit optics of the monochromatic light source can help minimize the modulation of stray light by the chopper. Monochromator entrance and exit slits should be non-reflective. Materials that appear black to the eye may actually reflect substantial amounts of infrared light. To evaluate the presence of stray light due to bias light modulated by the chopper, one can measure the signal produced by a DUT with bias light present but the lamp in the monochromatic source turned off (not shuttered).

6.3.6 The monochromatic light source shall be capable of providing a temporal stability of ±1 % during the calibration and measurement period unless a monitor photodetector is used, in which case ±10 % is acceptable. The temporal stability need only be maintained during the time needed for a complete cycle of measuring the signal from the DUT and measuring the signal from the reference photodetector and exchanging the positions of these two units (if applicable).

6.3.7 If the monochromatic beam spatial uniformity deviates more than ±2 % over the part of the beam intercepted by the device being tested, then the source is considered "nonuniform," and the kinds of tests that can be performed are limited, according to Table 1.

6.3.8 It is recommended that the monochromatic light source be able to illuminate the entire area of the device to be tested. If it is not, at least two measurements of the spectral responsivity in different regions of the device are required (see 9.1.13 and 9.1.13.1).

6.3.9 The monochromatic source must illuminate the entire reference photodetector and be uniform over the detector's photosensitive area if the photodetector has an irradiance-mode design.

6.3.10 An optical shutter may be used to interrupt the monochromatic beam to reduce delays involved with source and supply warm-up times during the test procedure (see 9.1.2 and 9.1.4). Such a shutter should be installed between the chopper and the test fixture to prevent chopped bias light from being interpreted as true signal.

6.3.11 The center wavelength of a bandpass filter should be measured preferably with a spectroradiometer in the test plane as opposed to measuring the filter transmittance.[6] If a monochromator is used, its wavelength calibration should be periodically checked.

6.4 *Monochromatic Light Chopper*—A rotating blade or other device used to modulate the monochromatic light source.

6.4.1 The chopper blades should be designed to minimize modulated stray light.

6.4.2 To minimize the modulation of room light or bias light, the chopper should be configured to be close to the monochromatic light source, or integrated within the monochromatic light source. If the chopper and filters are mounted at the exit of the monochromator, the filters should be between the chopper and the test device.

6.5 *Bias Light Source*—A stable, dc light source used to illuminate the device during the measurement.

[6] Field, H., "Solar cell spectral response measurement errors related to spectral band width and chopped light waveform," *Proc. 26th IEEE Photovoltaic Specialists Conf.*, Anaheim, CA, 1997, pp. 471-474.

6.5.1 The bias light should meet the criteria for a Class C solar simulator as described in Specification E927.

6.5.2 The light should be of sufficient intensity to ensure the DUT is operating in its linear response region. If the DUT is not linear, the bias light source should provide bias light over the intensity range of interest.

6.5.3 The bias source should contain no significant harmonics of the chopper frequency used with the monochromatic source. This can be achieved by using a well regulated, dc power supply for the bias light. Mechanical vibrations, either from the chopper or other sources, shall not be allowed to modulate the bias light.

6.6 *Modulated Current Measurement Instruments*—A system to quantify the alternating current produced by the DUT, the monitor photodetector (if used) and (if appropriate) the reference photodetector.

6.6.1 A current-to-voltage converter, followed by a lock-in amplifier or true-root-mean-square (RMS) voltmeter can be used to detect the low-level, modulated current from the photovoltaic device. An analog-to-digital converter with digital filtering can also be used.

6.6.2 True-RMS voltmeters respond to both the ac and the dc components of the short-circuit current which then must be separated to determine the ac component. An acceptable method uses the square-root of the difference between the square of the signal and the background (or noise) signal.

6.6.3 Choice of current-to-voltage converter and other signal conditioning instruments must include consideration of the DUT operating voltage, and that both a low-level ac, as well as a high-level dc signal may be present.

6.6.4 The frequency response of the instrumentation must be known or invariant in the range of frequencies to be used by the chopper.

6.7 *Test Fixture*—A means to mount the device to be tested in a position to allow illumination by both the monochromatic and bias light sources.

6.7.1 The test fixture shall also allow the reference photodetector (see 6.1) to be illuminated by the monochromatic and the bias light sources (if the reference photodetector was calibrated with bias light) in the same plane as the photovoltaic device. Exception: if the monochromatic beam is smaller than the reference photodetector's sensitive surface, then the reference photodetector does not need to be in the same plane as the DUT.

6.7.2 The test fixture shall allow for temperature regulation of the DUT's junction to 25 ± 5°C or other temperatures of interest.

7. Preparation of Apparatus

7.1 Configure the apparatus according to Fig. 1.

7.2 Select a ~~chopper~~chopping frequency that is compatible with the frequency response of the reference photodetector, test device, and modulated current measurement instrumentation. The frequency should not be an integer multiple of the ac line frequency. If a pyroelectric radiometer is used, the chopper frequency must be compatible with its instrumentation and calibration. If the reference photodetector requires unmodulated light, such as the case of a pyroelectric radiometer with internal chopper, turn the chopper off and ensure that it does not block the beam.

7.3 Configure equipment gains and ranges to optimize measurement accuracy while avoiding saturation by dc signals caused by the bias light.

7.4 Set time constants or integration periods on modulated current measurement instrumentation so that readings represent multiple periods of the chopper frequency. If the integration period is less than a chopper period, substantial errors will occur.

7.5 If multiple readings are made at each wavelength interval, it is recommended that the reading interval be set so that modulated current measurement instrumentation readings are independent of each other.

8. Hazards

8.1 *Precaution*—In addition to other precautions, appropriate steps must be taken to protect against the following hazards:

8.1.1 *Eye*—Light sources used, particularly if a laser is employed as the monochromatic light source (intensity) or if an arc lamp is used (ultraviolet, intensity).

8.1.2 *Electrical*—High voltages present when lasers or arc lamps are used.

8.1.3 *Bodily Injury*—The possibility of bulb explosion, if arc lamps are used. Light choppers when rotating at high speeds.

9. Procedure~~s~~

9.1 The signals from the reference photodetector and DUT must be measured at all wavelengths. The order of measurement depends on the apparatus used. If there is no provision to mount the reference photodiode and the DUT at the same time, it is expedient to measure the reference photodiode at all wavelengths and then measure the DUT. The procedure is presented with this presumption, but it is also acceptable to measure both signals at a particular wavelength, change wavelengths, and measure them again. The sequence can vary from that presented here.

9.1.1 Mount the reference photodetector in the test fixture. Adjust temperature control equipment as appropriate.

9.1.2 Turn on or unblock the monochromatic light source.

9.1.3 Measure the source irradiance as a function of wavelength at a minimum of 12 wavelengths throughout the spectral response range of the device to be tested, using the reference photodetector output. The wavelengths used for the source irradiance and the DUT response measurements (see 9.1.11) must be identical.

9.1.3.1 If a monitor photodetector is employed, also measure the signal produced by the monitor photodetector while measuring the reference photodetector signal.