Calibration of spectral responsivity of IR detectors in the range from 0.6 μm to 24 μm

Vyacheslav B. Podobedov*, George P. Eppeldauer, Leonard M. Hanssen, Thomas C. Larason, National Institute of Standards and Technology, Gaithersburg, MD, USA 20899

ABSTRACT

We report the upgraded performance of the National Institute of Standards and Technology (NIST) facility for spectral responsivity calibrations of infrared (IR) detectors in both radiant power and irradiance measurement modes. The extension of the wavelength range of the previous scale, below 0.8 μm and above 19 μm in radiant power mode as well as above 5.3 μm in irradiance mode, became available as a result of multiple improvements. The calibration facility was optimized for low-level radiant flux. A significantly reduced noise-equivalent-power and a relatively constant spectral response were achieved recently on newly developed pyroelectric detectors. Also, an efficient optical geometry was developed for calibration of the spectral irradiance responsivity without using an integrating sphere. Simultaneously, the upgrade and maintenance of the NIST transfer standards, with an extended spectral range, were supported by spectral reflectance measurements of a transfer standard pyroelectric detector using a custom integrating sphere and a Fourier transform spectrometer. The sphere reflectance measurements performed in a relative mode were compared to a bare gold-coated mirror reference, separately calibrated at the Fourier transform Infrared Spectrophotometry facility to 18 μm. Currently, the reflectance data for the pyroelectric standard, available in the range up to 30 μm, are supporting the absolute power responsivity scale by the propagation of the reflectance curve to the absolute tie-spectrum in the overlapping range. Typical examples of working standard pyroelectric-, Si-, MCT-, InSb- and InGaAs- detectors are presented and their optimal use for scale dissemination is analyzed.

Keywords: IR spectral responsivity, detector, radiant power, irradiance, calibration, radiometry

1. INTRODUCTION

IR detectors (sensors) are widely used in the radiometric applications related to environmental and industrial monitoring, chemical/spectral analysis, medical diagnostics, satellite remote sensing, missile guidance, homeland security and many others. The variety of IR detectors is represented by both relatively simple and inexpensive detectors as well as very complex and expensive devices integrated into liquid nitrogen or He cryogenic systems. Spectral responsivity and noise equivalent power (NEP) are the basic characteristics of IR detectors designated for measurement of the parameters of optical radiation. The calibration of spectral responsivity and NEP helps to provide information for the selection of correct and cost-effective choice of detectors. The Infrared Spectral Calibration Facility (IRSCF) was developed at NIST over the past 10 years with major funding from U.S. government agencies and in collaboration with leading detector manufacturers. Calibrated detectors serve to improve the quality of customer detectors as well as the quality control of their manufacture. We evaluate different broad- and narrow-band customer detectors for transfer of radiant power and/or irradiance responsivity scales to other instruments. The tests include spectral power and/or spectral irradiance responsivity and NEP measurements. The responsivity is calibrated in units of V/W or V W⁻¹ cm⁻² in an alternating current measurement mode at a chopping frequency of 10.5 Hz. Currently, calibration of detector responsivity is available over a wavelength range from 0.6 μm to 24 μm with simultaneous measurement of NEP and the spatial non-uniformity of response. Calibration of the detector spectral responsivity may be performed in two basic modes. In radiant power mode, the detector spatial uniformity in ideal case should be perfect and the total power in the incident radiation is measured by underfilling the detector. The irradiance responsivity calibration mode is used for detectors with a high non-uniformity of spatial response, but this mode has limited application due to the greater loss of signal as compared to the radiant power mode.

In this paper, we describe the upgraded IRSCF and several improvements along with evaluation of advanced IR detectors that help to extend the range for calibration of spectral responsivity. We present an analysis of uncertainty components.

*vyacheslav.podobedov@nist.gov; phone 1 301 975-4253; fax 1 301 869-5700
for the calibration process within the extended spectral range. The paper includes results related to maintenance of the NIST responsivity scale and transfer standards.

2. RESPONSIVITY SCALE

The implementation of a spectrally tunable radiation source into the calibration facility has made it possible to transfer the radiant power scale from absolute cryogenic radiometers to transfer radiometers operating over a wide spectral range. The method described in Ref. 6 comprises a responsivity measurement of a transfer radiometer at a few fixed wavelengths (tie points) at which the measured input (power or irradiance) is calibrated using an absolute cryogenic radiometer. In the next step, the tie points calibration is propagated across the spectral range covered by the transfer radiometer using its known relative spectral responsivity curve. The latter is obtained independently; in our case, from the spectral reflectance of the pyroelectric detector of the transfer radiometer.

To extend the responsivity scale to wavelengths above 19 µm, spectral reflectance measurements of the pyroelectric detector were performed using a custom integrating sphere for detection and a Bruker Vertex 80v Fourier Transform spectrometer as the spectral source. The integrating sphere used is a copy of the Infrared Reference Integrating Sphere used in NIST's Fourier Transform Infrared Spectrophotometry (FTIS) facility for standard calibration measurements of transmittance and reflectance. The gold-coated diffuse interior surface of the sphere has a superior diffuse character at long wavelengths > 10 µm. Measurements were performed using a liquid-Helium-cooled Si:B detector, which has responsivity from 5 µm to 30 µm. The detector's near-normal spectral absorptance is obtained by subtraction from 1 of the near-normal (8 deg.) hemispherical spectral reflectance measurements. The sphere reflectance measurements were made in a relative mode, with a bare gold-coated mirror reference, separately calibrated at the FTIS facility to 18 µm. A black-paint coated 5 mm aperture was placed over the sphere sample port, and the detector element was centered on the aperture with a minimal gap of 0.5 mm between them. A good quality bare gold mirror will have essentially (within 0.001) constant reflectance over the range of 15 µm to 30 µm. The relative reflectance of the detector is multiplied by the gold mirror reflectance values to obtain the detector reflectance values. Two additional characterization measurements were performed: 1) an "empty port" measurement to characterize the degree of scattered light overfilling the sphere sample port, and 2) a comparison measurement of a diffuse gold reference and the gold mirror reference to provide a correction for the diffuse character of the detector coating and its interaction with the sphere.

In Fig. 1, two data sets for the transfer radiometer are presented, the absorptance measured in the range from 6 µm to 30 µm and a previously calibrated spectral responsivity of this radiometer in the range of 6 µm to 19 µm. The best fit of both data sets was performed by a least square minimization of the sum $\Sigma(R_i - A_i \cdot K)$, where $R$ and $A$ are the responsivity

![Figure 1. Extension of the radiometric scale into the long-wavelength range using absorptance data (solid circles) and direct responsivity measurements.](http://proceedings.spiedigitallibrary.org/)
and a detector absorptance, \( K \) is a scaling coefficient and the index \( i \) denotes individual data points in the spectrally overlapping region (6 \( \mu \)m to 19 \( \mu \)m). Thus, using the optimum coefficient \( K \) and the measured absorptance data \( A_i \), one can define the spectral responsivity of the transfer radiometer in the rest of the spectral range above 19 \( \mu \)m as \( R_i = A_iK \).

Multiple upgrades of the NIST IR calibration facility have made it possible to calibrate the spectral responsivity of detectors in the range of 0.6 \( \mu \)m to 24 \( \mu \)m in radiant power mode, and from 0.6 \( \mu \)m to 12.5 \( \mu \)m in irradiance mode. The available radiometric scale is supported by a set of the primary transfer radiometers (standards) currently used for both detector calibration and verification of the radiometric scale as demonstrated in Fig. 2. The top standard is a cryogenic radiometer calibrated at few laser wavelengths\(^8\). The radiant power scale from this standard is transferred to the sphere input extended-InGaAs radiometer, two InSb radiometers and two temperature stabilized pyroelectric radiometers. The continuous responsivity scale over the range 0.6 \( \mu \)m to 24 \( \mu \)m for the radiance power mode is realized by using the reflectance data of the pyroelectric detectors\(^9\) and a mutual scale correlation for all five radiometers in the spectrally overlapped regions\(^10,11\). The latter procedure is also used for the periodical checkup of different standards assuming that their ageing effects would unlikely be the identical. Based on the observed agreement of measured responsivities, the spectral responsivity scale is maintained with an uncertainty of about 1\%. The responsivity scale for the irradiance responsivity mode originates from the extended-InGaAs radiometer calibrated in the radiant power mode. This radiometer has a precise area aperture at the sphere input. Thus the irradiance responsivity \( R_{IRR} \) may be found as \( R_{IRR} = R_{POW}S \), where \( S \) is a known aperture area. The uncertainty of the scale in the irradiance mode is also about 1 \% over the range of 0.6 \( \mu \)m to 5.2 \( \mu \)m. The extension of the scale to 12.5 \( \mu \)m by means of a large area MCT detector is currently in progress and the current uncertainty of its responsivity scale is about 3 \% (see Section 4.1).

### 3. IR SPECTRAL CALIBRATION FACILITY

#### 3.1. Spectrally tunable radiation source

Generally, the facility designated for calibration of detector responsivity has two basic components: a source of radiation at the wavelength of interest and a standard detector with a known responsivity utilized as a reference for the detector to be calibrated. While a single wavelength source may be of particular interest, calibration over a wide spectral range provides valuable information for broadband applications of the detector. The NIST IRSCF presented in Fig. 3 utilizes a broad band radiation source (1100 °C blackbody) and a monochromator based system acting as a spectrally tunable bandpass filter. An f/4 monochromator operating with six diffraction gratings and a set of the order sorting filters, splits the entire operating range from 0.6 \( \mu \)m to 24 \( \mu \)m into a few smaller ranges to maximize the throughput of the IR radiation from the source. Fast access to the desired spectral sub-range is provided by a 4-grating turret in the monochromator. The optical system for delivery of the source radiation to the monochromator and detectors consists of a set of gold-coated mirrors schematically shown in Fig. 3. A compact and convenient configuration for the power responsivity mode consists of a 152 mm diameter f/2 spherical mirror at the input, and two 90° off axis parabolic mirrors at the output of the monochromator.
In radiant power mode, the detector input beam is formed by two off-axis parabolic mirrors following the monochromator exit aperture. The two mirrors have different focal lengths in order to reduce the image size of the beam at the detector. The resulting beam diameter (full width half maximum) is about 2.4 mm and its profile is close to a Gaussian shape. The resulting geometry of the beam defines the diameter of the detector acceptable for calibration. The total power $P$ applied to a detector may be defined by the integration over the detector area $S$ as $P = \int_S P(S) dS = \pi \int_R P(R) R^2 dR$, where $P(S)$ is a radial power distribution in the beam and $R$ is radius of the detector. In Fig. 4, the fraction of the beam incident on the detector, as a function of the detector diameter, is presented. From Fig. 4 it follows that diameter of the detector to be calibrated should be at least 4 mm to avoid a significant contribution into the uncertainty budget. For the same reason, the lack of centering of the detector relative to the incident beam may cause a signal loss and related errors in
responsivity calibration. To reduce the errors, each detector undergoes a few steps of fine adjustments using feedback provided by scan data in the X- Y- and Z-directions. An example of an acceptable detector position is displayed in Fig. 5. In this case, the signal drop is less than 0.25 % of the maximum if ΔX or ΔY do not exceed ± 0.5 mm. The effect of Z-axis positioning on the responsivity measurements is much smaller, and can be minimized in the radiant power mode without fine adjustment. All positioning errors are included in the calculation of the uncertainty budget for responsivity calibrations. While additional reduction of the beam diameter is possible through reduction of the monochromator aperture, the resulting loss of beam power would lead unacceptable noise levels. For the irradiance mode (Section 4.1), the off-axis parabolic mirrors are removed and the radiation from the monochromator output either directly irradiates the detector or is directed to a 100 mm diameter gold coated sphere, which subsequently illuminates the detector area.

The test detectors and a standard detector are placed on an XYZ translation stage, which provides precise detector positioning to within a few micrometers relative to the beam. The outputs from both the test detector and the standard detector are measured as a function of wavelength and recorded in a data file. The signal related uncertainty is derived from the standard deviation of a preset number of single measurements performed by the lock-in amplifier. Most of the measurements are performed in AC mode at a modulation frequency of 10.5 Hz. To reduce the effect of absorption by water vapor, the significant part of the calibration facility is purged by dry air. The complete functionality of the IRSCF including a wavelength drive, an order sorting filter wheel, a translation stage, and data collection electronics, is controlled by computer program.

3.2. Wavelength scale

The calibration of a detector’s spectral responsivity is based on a comparison of the outputs from a test unit, \( U_t(\lambda) \), and a standard, \( U_s(\lambda) \), as
\[
R(\lambda) = \frac{R_t(\lambda)U_t(\lambda)}{U_s(\lambda)}
\]
where \( R_t \) and \( R_s \) are the responsivities of the test unit and standard, respectively.12 Thus the periodic maintenance of the calibration facility includes both a checkup/calibration of the monochromator wavelength scale and the responsivity scale. This is done with several standard detectors, as described below. The spectral responsivity \( R_t(\lambda) \) of the test unit is derived from the responsivity \( R_s(\lambda) \) of the standard unit by comparison of the output from both units presumably obtained under the same conditions. The latter however includes a few parameters, which may change over time in the calibration process. In particular, the wavelength scale defined by the monochromator is a critical parameter that has to be maintained properly to minimize the related uncertainty in a spectral responsivity calibration. As shown in Ref. 4, the associated error in the definition of the detector responsivity

\[
\Delta R/R_t = [(\Delta U_t/U_t)^2 + (\Delta U_s/U_s)^2]^{0.5} = [(\partial U_t/\partial \lambda \Delta \lambda/U_t)^2 + (\partial U_s/\partial \lambda \Delta \lambda/U_s)^2]^{0.5},
\]

may be determined from the output variation of both units as where \( U_t, U_s, \Delta U_t, \) and \( \Delta U_s \) are the unit outputs and their expected changes due to a possible wavelength deviation \( \Delta \lambda \), respectively. As seen from Eq. 1, the relative error \( \Delta R/R \) depends on the spectral flatness of the output \( \partial U_t/\partial \lambda \) and the value of both \( \Delta \lambda \) and \( U \). Accordingly, higher values of the
The output $U$ depends on many factors and may significantly vary over the spectral range. Of these three parameters, the wavelength deviation, $\Delta\lambda$, is dependent on the calibration of the monochromator wavelength scale and its reproducibility. The latter has a random nature and is usually included in the error for the targeted wavelength. Multiple records of the radiation spectrum at a known wavelength $\lambda_0$, enable us to experimentally define the value of $\Delta\lambda$ representing the wavelength reproducibility as a standard deviation of the wavelengths measured.

Calibration of the monochromator operating in the IR range is performed by means of a He-Ne laser at the monochromator input, with its order sorting filter removed. In the range below 1 μm, a set of Hg-, Ne- and Kr plasma lines are utilized. The radiation pattern of the diffraction grating contains multiple diffraction peaks corresponding to different diffraction orders. In the case of a He-Ne laser, the output of the detector will appear as a periodic structure with a period of 0.6328 μm. The radiation of the He-Ne laser creates reference peaks for very high orders of the diffraction grating. The position of the diffraction grating corresponding to these peaks will be the same for broadband source radiation at $\lambda_n = n \cdot 0.6328$ μm, where $n$ is a grating diffraction order. The value of $n$ and, therefore, the $\lambda_n$, may be found using any alternative spectral reference, for example, a bandpass filter. Calibration of the wavelength scale comprises the definition of the relation between $\lambda_n(n)$ and the decoder reading, $D(\lambda_n)$. Then the complete calibration curve $D(\lambda)$ for a particular grating is obtained from a multipoint fitting, usually made with a 2nd-order polynomial. The resulting dependences, $D(\lambda)$ are implemented into the program that controls the monochromator wavelength according to its decoder position as shown in Fig. 6. The analysis of Eq. 1 leads to the estimates of the wavelength related errors for spectral responsivity presented in the Table 1. The analysis was performed based on the measured output characteristics of a pyroelectric detector having a nearly flat responsivity curve over the wide spectral range. Partial derivatives, $\partial U/\partial \lambda$, and $\partial U/\partial \lambda$, were taken from the slope of the measured output spectral distributions. The derivative values vary across

![Figure 6. Calibration curves for the decoder position against the known wavelength for six gratings.](http://proceedings.spiedigitallibrary.org/)

Table 1. The wavelength related uncertainty of spectral responsivity

<table>
<thead>
<tr>
<th>Grating</th>
<th>Range, μm</th>
<th>$\Delta R/R$ wavelength related error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6 – 0.8</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>0.8 – 1.4</td>
<td>0.07</td>
</tr>
<tr>
<td>3</td>
<td>1.4 – 3.5</td>
<td>0.085</td>
</tr>
<tr>
<td>4</td>
<td>3.5 – 6.5</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>6.5 – 11</td>
<td>0.05</td>
</tr>
<tr>
<td>6</td>
<td>11 – 24</td>
<td>0.08</td>
</tr>
</tbody>
</table>
the entire spectral range since they depend on both the source and the grating spectral efficiency. Thus the maximum values for each of the six spectral sub-ranges were selected for the estimates to account for the worst-case scenario. Practically, the errors in the wavelength scale may have different effects for different detectors depending on their spectral functions $U_t(\lambda)$. In particular, the lower effect will be observed for detectors with the $U_t(\lambda)$ function similar to that of the standard detector. In Section 4.3, it will be shown that using the described procedure of the wavelength scale calibration, the resulting uncertainties are only a minor contribution to the total uncertainty of the responsivity calibration.

4. RECENT ADVANCES IN OUR CALIBRATION METHODS

4.1. Sphereless geometry for calibration in the irradiance responsivity mode

Integrating sphere based sources are widely used for operations with IR detectors when a high spatial uniformity of detected radiation is required\(^{13}\). The radiation uniformity in this case is obtained due to the multiple reflections inside the sphere resulting, however, in a significant loss of radiation at the output. For calibration of irradiance responsivity of IR detectors, the low output may become a principal factor limiting the choice of detector, spectral range and calibration accuracy. For non-laser tunable sources, this problem becomes significant for wavelengths above 5 µm where most IR detectors do not have a sufficiently low NEP needed for accurate irradiance measurements. In order to extend the spectral scale of our irradiance responsivity calibration, we have evaluated using the extended beam coming from the monochromator output aperture as a source. The basic goals are to get a higher level of irradiance when compared to using a sphere based source, and to provide a field with sufficiently spatially uniform irradiance acceptable for calibration.

Fig. 7 shows two optical geometries used for irradiance responsivity measurements. In the upper portion, where an integrating sphere is used, the output of monochromator is directed to the input port and radiation from the output port configures the irradiance field applied to a detector in position 1. The lower portion alternative has the irradiance field created directly by the monochromator beam (detector position 2). Signal measurements performed at 4.5 µm at a constant distance $L$ between source and detector show an irradiance at the detector about 300 times higher for the direct case, than when using a gold-coated 100 mm sphere. A signal increase by a factor of 840 was measured at 0.85 µm, using a sphere with a very high reflectance polytetrafluoroethylene coating. This result is to be expected because of reflection losses inside the sphere and the nearly hemispherical output angle $\phi_s$, as compared to the output angle $\phi_m$ defined by the monochromator f-number.

Since the spatial uniformity of the irradiance field is a basic requirement for an adequate responsivity calibration, it was experimentally verified at a few fixed wavelengths in two orthogonal directions (i.e. along X and Y axes) through the approximate center of the detector. In Fig. 8, an example measurement result is shown, for a distance of 250 mm from...
the source. The plots show the non-uniformity, which contributes to the uncertainty budget. For detectors with dimensions of a few mm, no significant change of the signal will be observed, provided both the test and reference detectors are set to the same spot. Precise positioning of detectors is achieved in the setup as described in Section 3.1 on radiant power mode measurements. A direct comparison of irradiance responsivity measured in both geometries is shown in Fig. 9. For the purpose of this comparison, the output radiation from the monochromator was reduced to a level where noise-related features are clearly seen in the measurements using the sphere. Using the same output of the monochromator for the extended beam geometry, a significantly less noisy spectrum was obtained.

![Image](http://proceedings.spiedigitallibrary.org/)

**Figure 8.** Non-uniformity of the irradiance field within X = +/- 5 mm (square markers) and Y = +/- 5 mm from the center as measured with a 5 mm-detector. Left panel presents the extended beam, right panel presents the gold-coated sphere.

It should be noted that one expected disadvantage of a sphereless geometry is the polarization of the output beam, as compared to the sphere geometry. This factor can be taken into account in the uncertainty budget.

### 4.2. Advanced detectors and applications

The advantage of a sphereless geometry was used for the extension to 12.5 μm of the scale available for calibration of the spectral irradiance responsivity. Previously, the range up to 5.5 μm was covered by InSb detectors having a relatively large detector area and a very good NEP. There are not many detectors with similar characteristics in the range above 5.5 μm. The calibrated spectral irradiance responsivity of a photoconductive (PC) mercury cadmium telluride (MCT) detector is described below. The 4 mm x 4 mm detector has an NEP of $1.0 \times 10^{-9}$ W cm$^{-2}$ Hz$^{-0.5}$ at 8.7 μm and a modulation...
frequency \( F_{\text{mod}} = 10.5 \text{ Hz} \). The MCT detectors are known to have a large spatial non-uniformity of response. However, this kind of non-uniformity is not critical for calibration of irradiance responsivity. The extension of the irradiance calibration scale above 5.5 \( \mu m \) where the reference standard was not available, was based on the three data sets for MCT detector: power responsivity in the range 3 \( \mu m \) to 12.5 \( \mu m \), irradiance responsivity in the range 3 \( \mu m \) to 5.5 \( \mu m \) and a spectral ratio of outputs in both radiant power and irradiance modes. The latter is necessary to check a possible spectral non-uniformity that may limit the application of the sphereless method. The corresponding normalized ratio presented in Fig. 10a indicates less than a 1.5 \% difference, therefore the spectral shape of the irradiance responsivity will be similar to that of the known power responsivity within the expected uncertainty budget. Thus, once the irradiance responsivity of the MCT detector is directly calibrated in the range up to 5.5 \( \mu m \), the remaining piece of the range may be characterized by a shape or radiant power responsivity prorated to the known irradiance responsivity value below 5.5 \( \mu m \). This is demonstrated in Fig. 10b where the best match of two data sets was provided in the overlapped range below 5.5 \( \mu m \). While the estimated uncertainty of this type of calibration is about 3 \% \((k = 2)\), an independent verification of the radiometric scale may be needed: i.e. a direct comparison to reference standards, when available for this wavelength range.

Pyroelectric detectors sensitive to temperature change are widely used for the detection of electromagnetic radiation\(^{14}\). In contrast to their relatively low spectral responsivity and high NEP, the spectral range is extremely large, ranging from the UV to the IR\(^{15}\). A few hybrid temperature-stabilized pyroelectric detectors\(^{16}\) serve as one type of primary calibration standard at the IRSCF. Most of the pyroelectric detectors tested until recently have had an NEP on the order of a few nW. After numerous iterative improvements, the most recent of these devices have exhibited a signal-to-noise...
performance about 200 times better than previously obtainable. Certain improvements in the pre-amplifier’s input electronic circuit, including an increase of the load resistor from 10 GOhm to 100 GOhm and optimization of the band pass (upper roll-off frequency), made it possible to significantly reduce the NEP of the pyroelectric detector.

In Fig. 11, a comparison of NEP of two pyroelectric detectors with the same 5 mm diameter of the detector is presented. A significant reduction of the NEP for new detectors was observed at several different equivalent noise bandwidths (ENBW) of the lock-in amplifier. The noise measurements were performed using a calibrated lock-in amplifier with a low-pass filter, set to 24 dB/octave and time constant between 100 ms and 3 s. Under these conditions, a time constant of 100 ms corresponds to an ENBW of 0.78 Hz. From the data presented in Fig. 11 the NEP of the advanced pyroelectric detector was found to be equal to $3.5 \times 10^{-10} \text{ W Hz}^{-0.5}$.

### 4.3. Calibration uncertainty

The new facility allows for responsivity calibrations in both radiant power mode (0.6 µm to 24 µm) and irradiance mode (0.6 µm to 12.5 µm) with uncertainties of 2 % to 3 % ($k = 2$). The basic components of the uncertainty budget are shown in Tables 2 and 3. It should be noted that the most significant contribution is from the scale transfer as displayed in Fig. 2. In the long-wavelength range or at the edges of the spectral sub-ranges the available signal to noise ratio becomes noticeable as well. On the other hand, usually the observed deviation of the experimentally measured data from the responsivity fitting function is lower than the combined uncertainty presented in Tables 2 and 3. It is anticipated, therefore, that upon reduction of these two components, an uncertainty better than 1 % ($k = 2$) may be achieved in the future for the entire spectral range. The estimate of the uncertainty component related to the ageing effect of the reference detector is problematic since it may occur slowly over a long period. Using group policy for the detector standard(s) and periodic comparison of different standard detectors in the spectrally overlapping regions is helpful to identify this effect, assuming that ageing effects for different detectors would unlikely be the same.

### 5. CONCLUSIONS

The spectral coverage of the NIST IR Spectral (Detector) Calibration Facility designed for calibration of the spectral responsivity of detectors in both radiant power and irradiance measurement modes has been extended. The responsivity is calibrated in units of V/W or $\text{V W}^{-1} \text{cm}^2$ in AC measurement mode at a chopping frequency of 10.5 Hz. The present ranges of 0.6 µm to 24 µm and from 0.6 µm to 12.5 µm are available for radiant power and irradiance modes,
respectively. The extension of the wavelength range was enabled by new reflectance data for the reference pyroelectric detector and an upgrade of both the monochromator and radiation source. For irradiance responsivity mode, a sphereless optical geometry providing a relatively high irradiance in the detector plane, was developed and evaluated. Detectors to be tested should have a minimum detector diameter of 5 mm and acceptance angle of 20 degrees and include a preamplifier used with the detector. Typical calibration uncertainties vary over the spectral range, but generally do not exceed 2.3 % and 3.0 % \( (k = 2) \) in the radiant power and irradiance modes, respectively. The facility also provides measurements of NEP (or noise equivalent irradiance), as well as precise scanning of the detector’s active area for spatial non-uniformity of response. The radiometric scale is supported by several reference detectors (standards) including low NEP pyroelectric, InSb, sphere-input-extended InGaAs, and PV-MCT detectors.

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