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BROADBAND LAMP STANDARD FOR ULTRAVIOLET (UV), VISIBLE, AND INFRARED CALIBRATION TO 6.0 ΜM

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Broadband lamp standard for ultraviolet (UV), visible, and infrared calibration to 6.0 μm

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Abstract

The new broadband spectral radiance standard consists of a specially modified tungsten ribbon-filament lamp with an optical grade, sapphire window. The lamp is calibrated for spectral radiance over the 0.25 to 6.0μm wavelength region. The standard serves as an accurate, convenient alternative to the much more costly high-temperature blackbody standard currently available.

Introduction

The new broadband lamp standard has been set up and is available for calibrating radiometers and spectroradiometers over all or part of the entire 0.25 to 6.0μm wavelength region. The standard serves as an accurate, convenient alternative to the much more costly, high-temperature blackbody systems which are currently available. Calibration of the new standards of spectral radiance are traceable to the National Bureau of Standards.

Although the blackbody was and still is the primary standard used for most infrared calibrations, its use in the UV, visible and near IR spectral region is very limited. With the exception of the blackbody radiators, there were no convenient spectroradiometric standards prior to about 1960 when the National Bureau of Standards set up tungsten-ribbon filament lamp standards of spectral radiance[1]. The lamp choosen for use as a standard in 1960 was the GE 30A/T24/3 (Figure 1). It had a mogul bipost base and a nominal rating of 30 amps at 6 volts. The radiance is emitted from a flat strip filament through a 3cm fused silica window placed parallel to and at a distance of about 9cm from the plane of the filament. The lamps were calibrated for spectral radiance over the 0.25 to 2.6μm wavelength region. The calibration was based on the radiance of a blackbody as defined by the Planck Radiation Law. Although these standards had relatively high uncertainties which ranged from ±8% in the ultraviolet to about ±3% in the visible, they received wide acceptance in scientific research throughout the world.

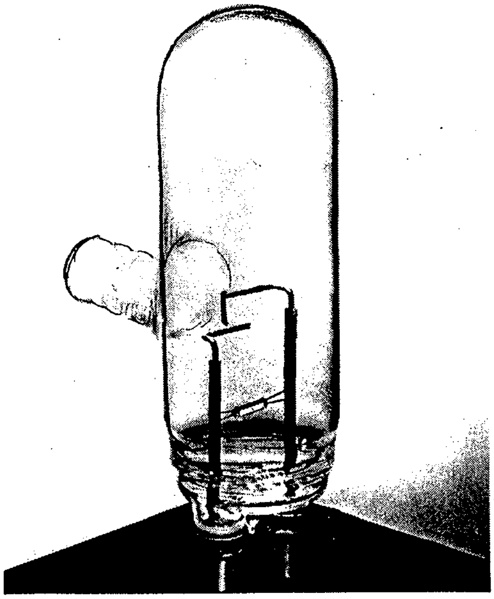


Figure 1. GE 30A/T24/3 Lamp

In 1965[2], NBS reported the capability of determining spectral radiance of tungsten-ribbon filament lamps with an uncertainty of less than ±1%. However, the wavelength range of spectral calibration remained basically the same.

The primary reasons for developing a new broadband spectral radiance standard are as follows:

1) An increasing number of exotic radiometers and spectroradiometers covering extended wavelength regions were being developed. In many cases a lamp standard was required for calibration over the shorter wavelength region (below 2.5μm) and a blackbody was required for calibration over the longer wavelength region (above 2.5μm). Switching standards during the middle of a calibration run is time consuming and also requires the acquisition of two complete calibration systems.

2) Many broadband radiometers sensitive above and below 2.5μm require a single standard source for calibration.

3) The GE 30A/T24/3 type lamps were becoming increasingly difficult to obtain.

A number of commercially available lamps were screened for possible use as a broad-band spectral radiance standard. The main prerequisites were temperature uniformity over a reasonable portion of the filament, stability and availability. The lamp selected for modification for use over an extended wavelength region and for eventual use as a broadband standard of spectral radiance was the GE 18A/T10/2P. This lamp is generally used as a microscope illuminator and has a useable light source of approximately 8mm by 2mm. The pertinent lamp specifications are given below:

Lamp Type	GE 18A/T10/2P
Volts	6
Amps	18
Filament	SR6A
Base	Medium Prefocus
Bulb	T10
L.C.L.	3.6cm
O.A.L.	14.6cm

Previous temperature distribution measurements and life testing[3] on lamps employing the SR6A type filament indicated that the lamp would be suitable for modification and use as a standard. Figures 2 and 3 show the longitudinal and transverse temperature distributions of the filament. Figure 4 shows the color temperature as a function of lamp current and Figure 5 gives the life of the lamp as a function of color temperature.

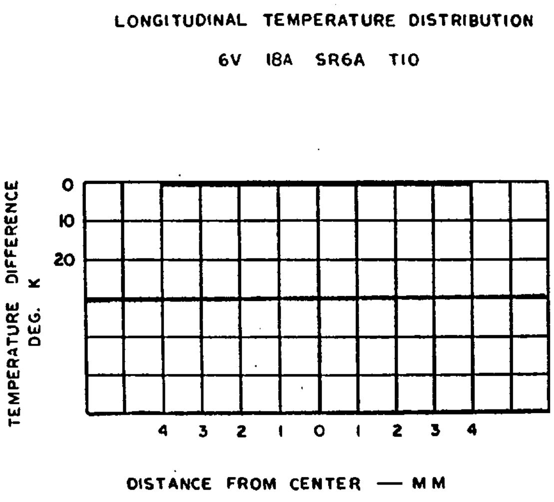


Figure 2

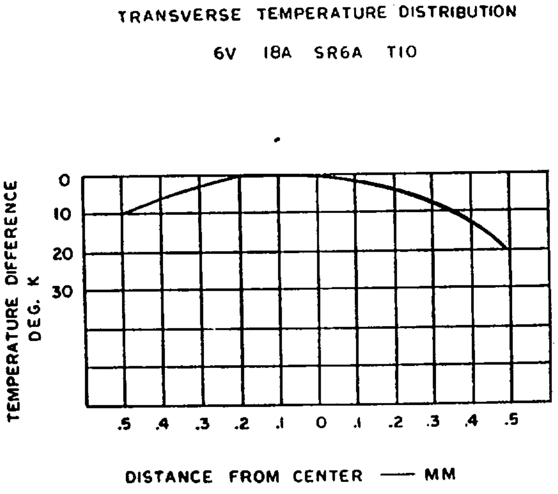
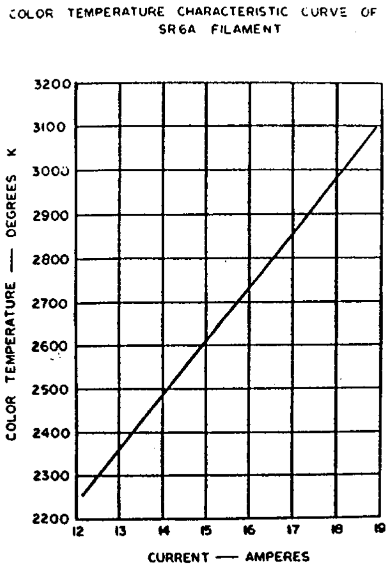


Figure 3

The process involved for modifing the lamp consisted of:



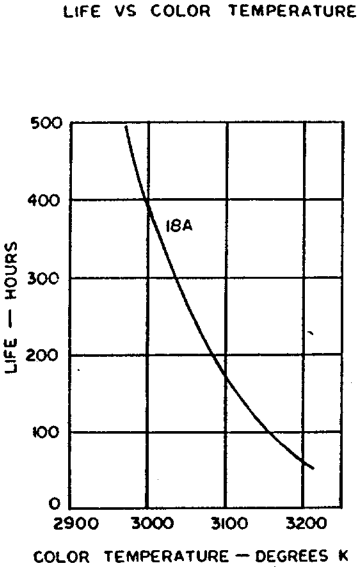


Figure 4

Figure 5

1) A hole was blown into the side of the lamp envelope.

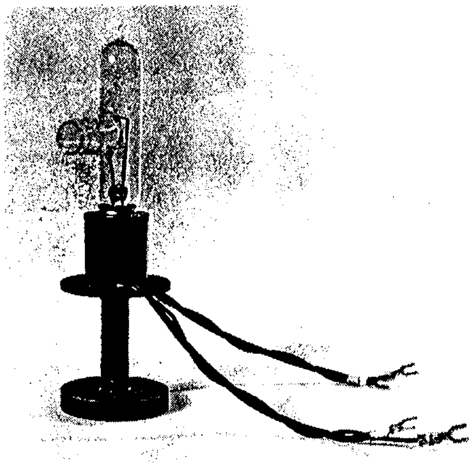
2) A glass tube approximately 3.5cm in length by 2.5cm in diameter was sealed to the side of the envelope directly in front of the filament.

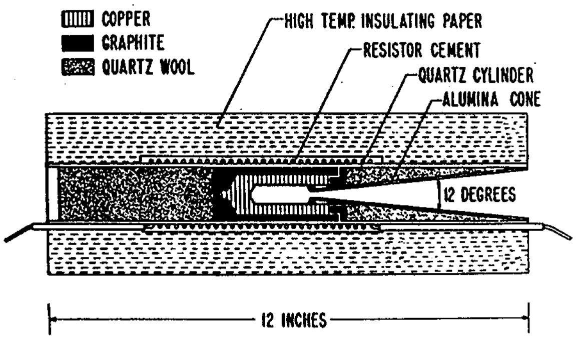
3) An optical grade sapphire disk 2.5cm in diameter and 1mm thick was positioned over the end of the tube and held in place with a metal mold.

4) The glass tube was then heated until the glass began to melt and wet the sapphire window. Cooling of the tube sealed the sapphire window to the end of the glass tube.

5) The lamp envelope is then back-filled with nitrogen at 660 torr and sealed.

Figure 6 shows the modified lamp with a sapphire window. The sapphire window has good transmittance over the entire 250-6000nm wavelength region.





Cross-section of the completed blackbody furnace. The heater windings are shown enlarged for clarity.

Figure 6 Standard of spectral radiance with sapphire window.

Figure 7

Method of calibration

Two sources were employed to calibrate the modified lamps over the entire 0.25 to 6.0μm wavelength regions:

a) An NBS tungsten ribbon-filament lamp standard of spectral radiance was used over the 0.25 to 2.5μm region. The estimated maximum uncertainty in the spectral radiance values supplied with the lamp varies from about 3% at 250nm to 2% at 650nm and longer wavelengths.

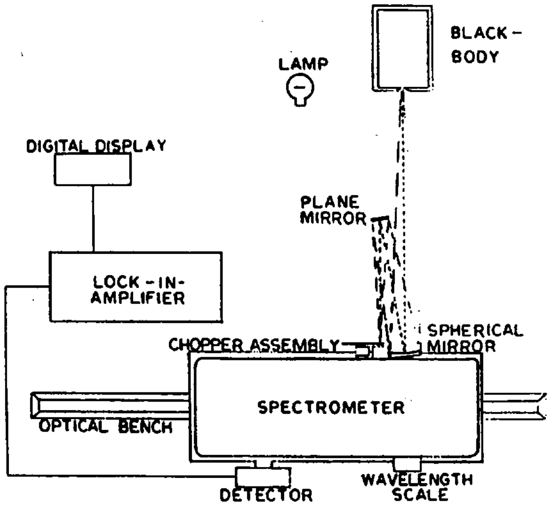
b) A copper freezing-point blackbody[4] was used over the 2.5 to 6.0μm wavelength region. Figure 7 shows a cross-section of the copper-point blackbody and furnace. Construction of the unit is described in great detail in the NBS technical note 483. The spectral radiance of the blackbody, which operated at the freezing point of copper (1083.3 ±0.1°C), was calculated using the Planck equation:

$$L\lambda = C_1/n^2\lambda^5 \, [\exp \; (C_2 \, / n\lambda T) \; -1] \tag{1}$$

where; C_1 is 1.191066×10^{-12} watt cm^2 ster^{-1},
n is the index of refraction of air in centimeters,
λ is the wavelength (in air) in centimeters,
C_2 is 1.4388cm Kelvins
and T is the IPTS-68 blackbody temperature in Kelvins.

The uncertainty in the blackbody radiance during the freeze is less than ±.03%. However, the ability to maintain a freeze during the course of the measurements was extremely difficult. Changes in temperature of 0.5°C were encountered. Accordingly, the uncertainty in the blackbody radiance was on the order of 0.2%.

The principle apparatus used to compare the radiance of the standard sources to the modified lamp is shown in Figure 8. A double monochromator was mounted on an optical bench with the auxiliary optics secured to the monochromator. The measurement procedure consisted of alternately allowing the radiant flux of the standard source and that from the modified test lamp to enter the spectroradiometer after imaging by the same optical system. To insure the highest degree of accuracy in the transfer calibration, the test lamp was compared directly to the standard at each wavelength. This point-by-point method of comparison eliminated any drift or change in the instrumental apparatus over a period of time.



INSTRUMENTAL SET UP FOR CALIBRATING BROADBAND SPECTRAL RADIANCE STANDARDS

Figure 8

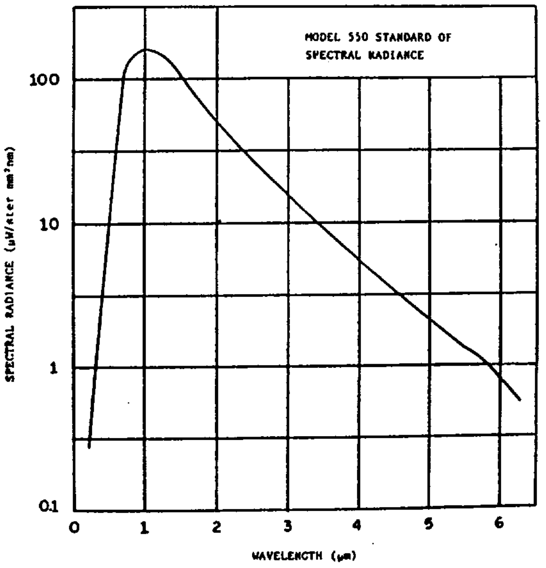


Figure 9

The spectroradiometer utilized a double-grating monochromator. The Czerny-Turner optical design and the use of selected second-order blocking filters reduced the stray light level to less than .001%. Gratings blazed at 300, 500, 2000 and 4000nm were used in combination with PMT, silicon, PbS and thermopile detectors in order to efficiently cover the entire 250-6000nm wavelength region. The wavelength accuracy varied with wavelength as follows:

Wavelength region	Wavelength accuracy
250 to 800nm	± 0.4nm
800 to 1000nm	± 0.6nm
1000 to 3000nm	± 2.5nm
3000 to 4000nm	± 5nm
4000 to 6000nm	± 8nm

Although the monochromator had a number of fixed slits, only the 0.5mm slits were used in the measurements. This produced bandwidths as follows:

Wavelength region	Bandwidth
250 to 1000nm	1nm
1000 to 3000nm	4nm
3000 to 6000nm	8nm

The lamps were operated at a set current of 15.0 amperes dc. The setting of current is especially critical when using the lamp in the ultraviolet. The following table gives the approximate variation in the spectral radiance at a number of wavelengths if there is a 0.1% uncertainty in the setting of the current.

Wavelength (nm)	Uncertainty due to 0.10% current setting error (%)
250	1.2
300	0.9
400	0.6
500	0.4
1000	0.35
1500	0.17
2000	0.14

An Optronic Laboratory Model 16DS Constant Current DC Power Supply was used to operate the sapphire windowed lamp. The estimated uncertainty in the current setting was 0.04%. Accordingly, the radiance uncertainty due to setting of lamp current was less than 0.5% over the entire spectrum.

The uncertainty in the transfer calibration from the NBS standard to the broadband radiance standard is estimated to be less than ±1% over the entire 250 to 2500nm wavelength region. The uncertainty in the transfer calibration from the copper-point blackbody to the broad-band radiance standard is estimated to be less than ±2% over the 2.5 to 6.0μm wavelength region.

Estimates of uncertainty in the final spectral radiance values assigned to a group of broad-band standards as a function of wavelength are given below:

Wavelength range (μm)	Estimated uncertainty (%)
.25 - .28	±5
.28 - .35	±4
.35 - 2.5	±3
2.5 - 3.5	±4
3.5 - 4.5	±5
5.5 - 6	±6

These values are based on a 90% confidence and were obtained by suming the individual errors in quadruture and doubling the result.

Use of the broadband radiance standards

These new standards serve as a convenient means to calibrate various radiometers and spectroradiometers for spectral radiance response. A typical spectral radiance curve is shown in Figure 9.

In operation, the lamp is mounted horizontally and the beam of radiant flux with a horizontal axis passing through the center of the filament is measured. In the original determinations, no portion of the beam measured departed from this axis by more than 2.5 degrees. Hence, if an aperture subtending a larger angle is required in any application of these standards of spectral radiance, it should be ascertained that the irradiance is constant over the whole aperture.

If there is excessive water vapor in the laboratory atmosphere, errors may result at the wavelengths of water vapor absorption bands. In the original calibrations, the comparisons of the lamps with the blackbodies were made at the same distance and in such manner that the effect of water vapor absorption cancelled out.

Values of spectral radiance for these lamps are tabulated as a function of wavelength in microwatts per (steradian-nanometer-square millimeter of filament). Values of spectral radiance for slit widths other than one nanometer, say x nanometers, where x is less than 100, may be found by multiplying the tabulated values by x. With the exception of regions where absorption bands occur, values of spectral radiance for wavelengths other than those given in the table may be obtained through graphical plotting and interpolation.

It is suggested that the auxiliary optics employed with these standards be composed of two units: namely, a plane mirror and a spherical mirror (each aluminized on the front surface). If the spherical mirror is placed at a distance from the lamp filament equal to its radius of curvature, and the plane mirror set about 1/3 to 2/5 this distance from the spherical mirror, facing it and so placed that the angle between incident and reflected beams is 10° or less, a good 1:1 image of the filament itself may be focussed upon the spectrometer 0.5 x 4mm slit. Little distortion of the filament image occurs provided precise optical surfaces are employed and angles between incident and reflected beams are kept to less than 10°. Various optical arrangements may be employed. See, however, Figure 10A for the arrangement employed in the calibration of these lamps. The spherical mirror had a radius of curvature of approximately 71cm.

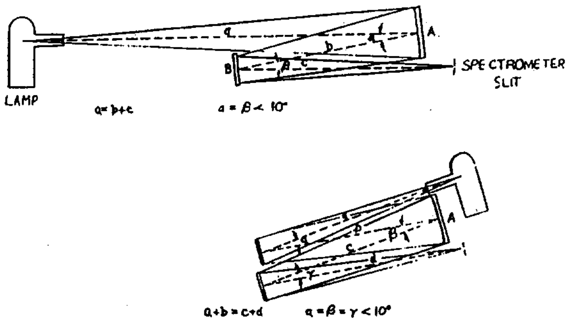


Figure 10 Auxiliary optics when using a lamp standard of spectral radiance in the calibration of a spectroradiometer; and for determining the spectral reflectivity of the aluminized mirrors employed.

The solid-angular aperture of the auxiliary optics should be smaller than the solid-angular aperture of the spectrometer employed so that no loss of radiant energy will result through over-filling the spectrometer optics.

The spectral radiant flux, $\emptyset_\lambda$, in microwatts per nanometer, which enters the spectrometer slit, is computed from the formula:

$$\emptyset_\lambda = R_\lambda \cdot L_\lambda \cdot SA/D^2 \qquad (2)$$

where R_λ is the spectral reflectance of the combination of mirrors used, L_λ is the reported spectral radiance of the standard, S is the area of the spectrometer slit in mm^2, A is the area of the limiting auxiliary optic, and D is the distance of this optic from the slit. For example, in Figure 1, if the spectral reflectance R_λ of mirrors A and B in combination is 0.81, the reported value of L_λ at 600nm is 50.0 microwatts per (steradian-nanometer-mm^2 of source), the slit area S is $2.00mm^2$, the area of the mirror A (the limiting optic) is $25.0cm^2$, and the distance D (b plus c in Figure 10) is 71cm, then:

$$\phi_\lambda = \frac{.81 \times 50.0 \times 2.00 \times 25.0}{(71)^2} = 0.402\ \mu W/nm \qquad (3)$$

No diaphragm or other shielding is required in the use of these standards except for a shield to prevent radiant energy from the lamp from entering the spectrometer directly without first falling on the concave mirror of Figure 10A. An image of the filament should be focussed upon the spectrometer slit, and only the energy by which this image is formed should enter the slit.

In order to calibrate a radiometer with one of these standards of spectral radiance, a knowledge of the spectral reflectance of the mirror surface is required. A good aluminized surface should have a spectral reflectance considerably above 0.87 throughout the spectral region of 0.5 to 2.6μm, increasing slightly with wavelength except possibly for a slight dip near 0.80μm. In practice, the proper reflectance losses can best be determined through the use of a third mirror (a second plane mirror) which may be temporarily incorporated into the optical set-up. See Figure 10B for a possible arrangement of the auxiliary optics to include the third mirror to determine its spectral reflectance.

In measurements wherein two uniform radiance sources (a standard source and a test source) are being compared by the direct substitution method, knowledge of the spectral reflectance of the auxiliary mirrors, the spectral transmittance of the spectrometer and the spectral sensitivity of the detector is not required. The direct substitution method implies use of the same auxiliary optics, slit-widths, detector and areas for both standard and test source at any one wavelength. It is necessary, however, to make sure that the entrance slit of the spectrometer is fully and uniformly filled with radiant flux both from the standard and from the test source; and, if at any one wavelength the detector response for the standard is significantly different from that of the test source, the deviation from linearity of response of the detector must be evaluated and taken into account.

References

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