System for measuring the angular response of radiometers

Luiz Ângelo Berni, Waldeir Amaral Vilela, Antonio Fernando Beloto, Felipe Oliveira de Sena

Instituto Nacional de Pesquisas Espaciais (INPE), Laboratório Associado de Sensores e Materiais (LAS). Av. dos Astronautas, 1758 – São Jose dos Campos/SP, 12227-010

ABSTRACT

To measure the angular response of radiometers developed in the laboratory, an automated system was assembled and characterized. The main light source is a QTH lamp of 1000W and for UV radiometers a Hg(Xe) lamp of 500W. The light beam has a useful diameter of 40 mm, a half divergence of 10mrad and the spatial uniformity is better than 97%. Errors up to 5% at large angles were estimated for misalignments of 1° in the positioning of the radiometers . In this work details of the system and results of measurements obtained with radiometers developed in the laboratory and with commercial ones are presented.

Keywords: radiometer, angular response, irradiance.

1. INTRODUCTION

For irradiance measurement one can choose between two types of instruments, high spectral resolution instruments or low spectral resolution instruments. The high resolution instruments are more expensive, bulky, require periodic calibrations and typically are computer controlled and therefore require more effort when used in field. Low resolution instruments are small, relatively inexpensive, easy to use and do not provide information regarding the wavelength of the radiation to be measured. Typically, these measures are used for instruments that have hemispherical field of view and for this reason the angular response should decrease according to the angle of radiation incidence. It is well known that sensors used for these measurements do not show a perfect cosine law response and that this response becomes worse with the increase of the incidence angle, mainly due to the specular reflection for large angles. To measure the angular response of radiometers developed in the laboratory, an automated system was assembled and characterized [1].

1.1 Optical system setup

To measure the cosine response of radiometers it was mounted in the laboratory an optical bench as shown in Figure 1. The main light source is a QTH lamp of 1000W (Newport 6315)   powered by a radiometric power supply (Newport 69935). When measuring UV radiometers the light source can be changed by a Hg(Xe) discharge lamp of 500W (Newport 66142 and 69920). The light beam travels along a path of 3 m with five apertures of 40mm to collimate the beam and to block the stray light. At the end of the path there is a sixth aperture with adjustable diameter between 1 and 40mm. To guide the light beam from the first arm to the second one in the collimation path are used first surface flat mirrors of protected aluminum. In the beginning of the second arm it is possible to attach a filter to select a specific wavelength instead of the broadband lamp spectrum for measuring the angular dependence of the response with wavelength. Interference filters between 250 nm and 1100 nm with an average band path (FWHM) of 4 nm are possible to be used [2].

The radiometers under testing are assembled on a table connected through gears and bearings with a step motor of 18 Kgf.cm and a driver controls the motor which allows the rotation step angle to be chosen between 0.045^o and 0.9^o. A dedicated program in C^{++} especially developed for this purpose is used to control the driver and to do the acquisition of signals using a $6_{1/2}$ digit multimeter of 0.0035% precision (Agilent 34401A). Figure 1(right) shows a picture of the radiometer support. If necessary, the system allows the installation of a chopper and lock-in amplifier to detect low signals.
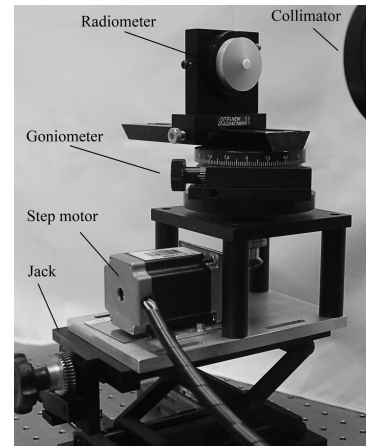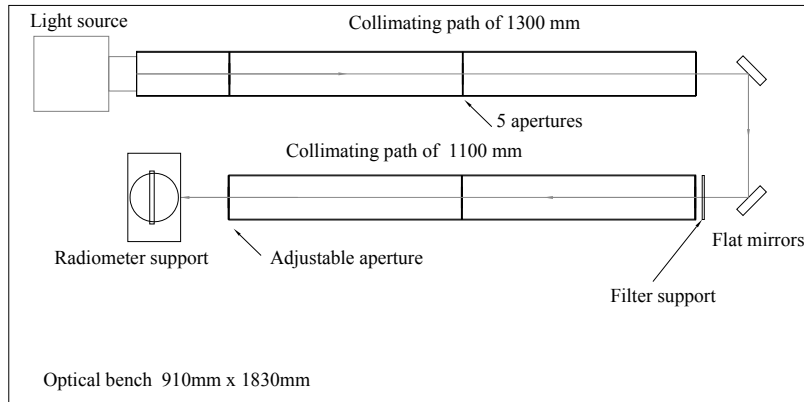
Figure 1: Drawing of the system set up (left) and details of the radiometer support, goniometer and step motor (right). The picture shows a homemade radiometer under test

2. RESULTS

2.1 System characterization

The divergence and the spatial profile of the main light beam source were measured at the same place where radiometers are tested. The half angle divergence measured was 10 mrad and the beam profile is showed in the Figure 2 (left). The beam profile in figure 2 represents the average of measurements done in the vertical and horizontal planes through the center of the beam. The spatial uniformity of the beam was measured through sixteen points over its cross section, and the result is estimated to be better than 97%. The spectral irradiance of the collimated beam was measured between the wavelength of 250 and 1100nm using a calibrated CCD spectrometer (GetSpec 2048) with resolution of 2.4 nm. Figure 2 (right) shows the spectral wavelength of the main light source and the Hg(Xe) lamp after the collimating tube. All experiments were performed after 20 minutes heating to stabilize the lamp.
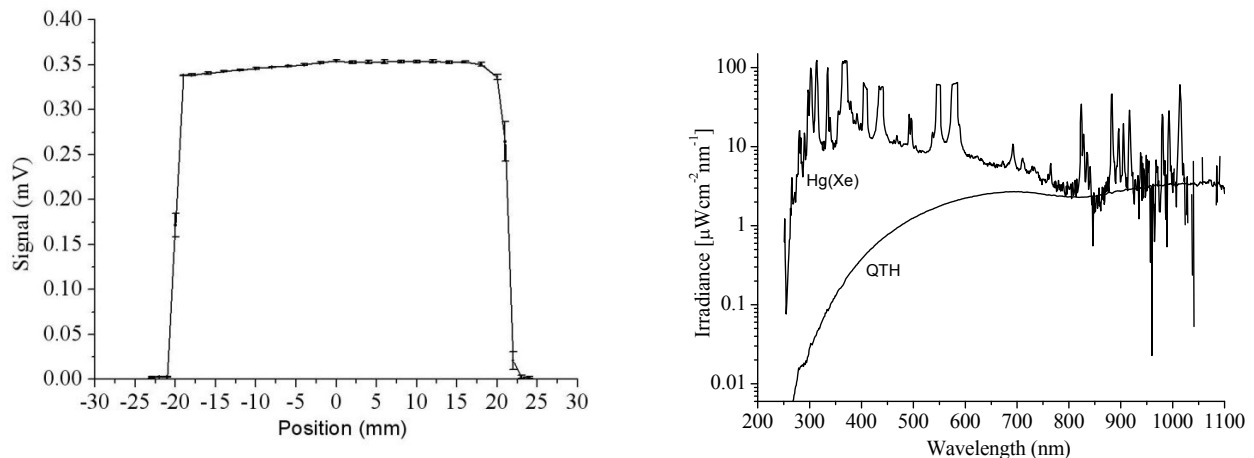

Figure 2 : Left - Profile of the light beam at the end of the collimating tube. Right - Spectral irradiance of the light sources after the last aperture of the system.
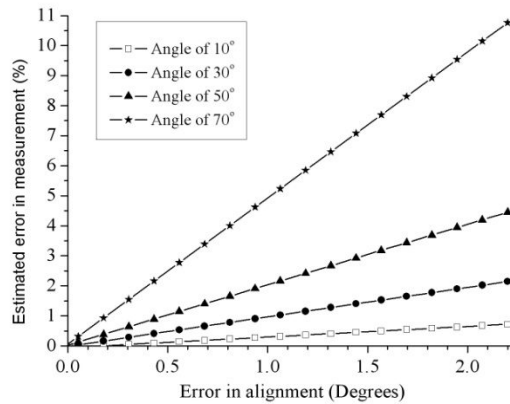
Figure 3: Estimated errors in the measurement simulated in the ZEMAX program.

The optics of this system was simulated in the ZEMAX program to estimate errors due to alignments in positioning of the radiometers. It was considered in this simulation an ideal radiometer and errors up to 5% in the measurements at large angles were verified for misalignments of 1°. Figure 3 resume these estimated errors at four angles of measurement for errors in the positioning of the radiometers up to 2.2^o.

2.2 Radiometers measurements

In this study were measured the angular response of several radiometers that are being used in monitoring towers installed recently in our Institute . Some commercial radiometers from LICOR and Kipp&Zonen and one radiometer developed in our laboratory were measured and errors were calculated according ref. [2] and [3]. The radiometer to be measured is positioned on the goniometer through manufactured supports for each type. The positioning is done so that the rotation axis pass through the input optic of the radiometer (typically, a diffuser). This positioning is not critical, since during the rotation of the radiometer the input optic remains within the uniform region of the beam. Once positioned, the initial alignment is accomplished with a mirror placed on the support base or in front of the radiometer. The final alignment is verified by analyzing the symmetry of the angular response curve relative to normal incidence light beam. If the curve is asymmetric, or the input optics of the radiometer presents problems or it was not properly aligned. The first case can be dismissed by making measurements at other azimuth angles. Figure 4(A, B, C) shows the angular response of three quantum radiometers : two radiometers for global radiation measurements from 400 to 1100 nm (K&Z and LI-COR) and one PAR sensor for measuring photosynthetically active radiation (400 to 700 nm) from K&Z. All curves are consistent with the errors established by manufacturers and small changes can be attributed to the time of use of these radiometers. The large error bars in the PAR response curve is due to low signal from this sensor, perhaps by the presence of a inside filter to match the spectral response of the Si-photodiode with the photosynthetic one. Figure 4D and 4E show the response of the UV-A radiometer from K&Z and the CMP11 thermopile radiometer (300 to 2800nm) that is a secondary standard, respectively. Figure 5 shows the angular response of a UVA (315nm to 400 nm) prototype radiometer developed in the laboratory. The input optics of this radiometer was optimized using the non-sequential module from the program ZEMAX [4]. This figure shows the average response from measurements of several azimuth angles (0°, 90°, 180° and 270°) and from -90° to 90° that demonstrates the correct alignment of its assemble. The large error bars is due to the presence of an inner filter and the non optimized electronics, that contribute to low signals.

To test the possibility of the system to measure the angular response of radiometers with different wavelengths, it was used the global radiometer from LI-COR (Figure 4C) and a lock-in amplifier to detect the very small signals. Figure 6 shows the result of the angular response of this radiometer for 600 nm and 1000 nm. The curves show the error

in the wavelength measurements in respect with the curve of Figure 4C. Just for large angles (> 60°) it is possible to see some difference, that cannot be considered because of large errors in these positions.
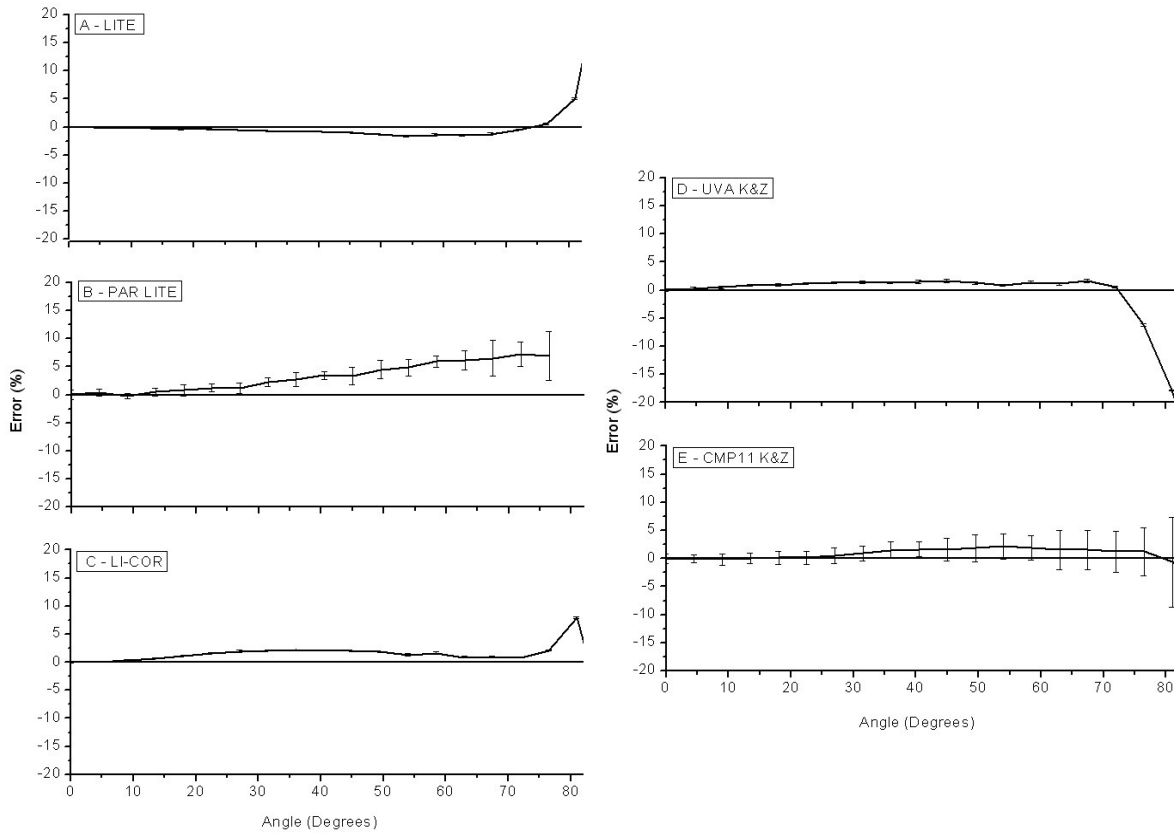

Figure 4: Angular response of radiometers used in monitoring towers: A – Global radiometer from K&Z; B – Par radiometer from K&Z; C – Global radiometer from LI-COR ; D – Ultraviolet radiometer from K&Z; E - CMP11 thermopile radiometer from K&Z.
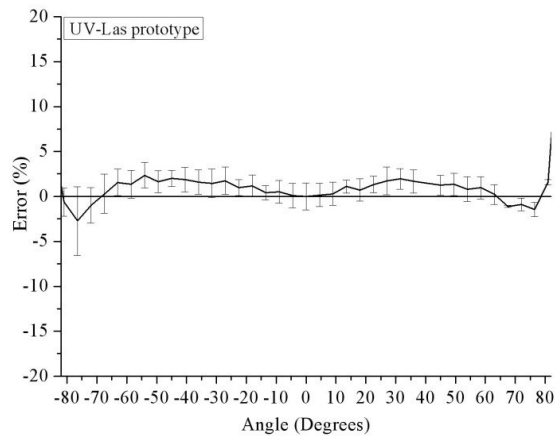

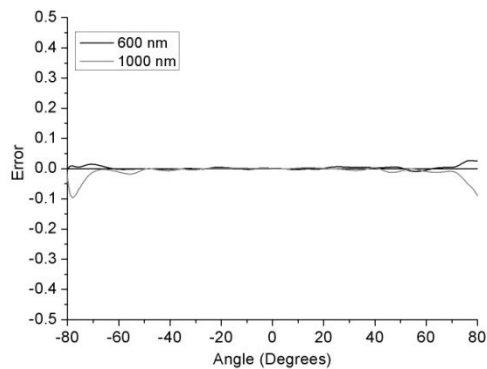Figure 5: Angular response of the UVA prototype radiometer developed in the laboratory.

Figure 6: Angular response difference for two distinct wavelengths for the global LI-COR radiometer.

3. DISCUSSION AND CONCLUSIONS

A system for measuring the angular response of radiometers developed by the laboratory was assembled, characterized and tested. Some commercial radiometers were measured and their responses are consistent with the errors introduced by manufacturers. Some variations found can be attributed to the time of use of the radiometer. The prototype UVA mounted in the laboratory showed good response compared to the commercial ones, however improvements in its electronics need to be performed. The system measures the angular dependence of the response with different wavelengths, but due to the use of interference filters the signal is very low compared to that radiometers are designed to measure.

Acknowledgements

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