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Article *in* Proceedings of SPIE - The International Society for Optical Engineering · November 2013

DOI: 10.1117/12.2027039

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Angular distribution of the averaged luminous intensity of low power LEDs transfer standards

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ABSTRACT

A goniophotometer to characterize the angular distribution of the averaged luminous intensity of LEDs has been developed at Optics Institute of CSIC. Distributions of for four low-power LEDs transfer standards (red, blue, green and white) for luminous flux and luminous intensity are shown. A proper characterization of the angular luminous intensity distribution allows measurement uncertainties to be better determined. The instrument has got a photometer placed on a ruled optical bench to vary the source-detector distance and a CCD camera to carry out the alignment of the LEDs respect to the centre of geometrical reference system. Measurements were taken at a distance of 316 mm (condition A of the CIE) to different LEDs by varying the polar angle between 0º and 90º with a step of 5º and the azimuth angle between 0º and 180º with a step of around 11º. The red LED is the most Lambertian, whereas the blue, green and white LEDs have a different behavior. Finally, to identify systematic errors, a comparison with the measurements of a similar goniophotometer in *Physikalisch-Technische Bundesanstalt* (PTB) was carried out.

Keywords: LED, Averaged Luminous Intensity, Angular Distribution, Low Power LED.

1. INTRODUCTION

The raising awareness on energy saving has led to the development of more efficient light sources such as solid state *Light Emitting Diodes* (LEDs)-based sources. In recent years, the utilization of these illumination devices has exponentially increased, creating the need to photometrically characterize them. New methods of measurement are required, because these sources have different emission characteristics than traditional lighting sources.

The Institute of Optics in CSIC (IO-CSIC) has recently developed a goniophotometer to measure the angular distribution of the averaged luminous intensity[1] of LEDs. In order to give more reliability to the measurement results and to identify and correct systematic errors of our goniophotometer four low-power LEDs transfer standards (red, green, blue and white hue) were measured. Moreover, a comparison of our measurements with the ones performed at *Physikalisch-Technische Bundesanstalt* (PTB)[2] with a similar goniophotometer was carried out. The LED transfer standards used in the comparison were developed by the company CMS-SCHREDER.

8th Iberoamerican Optics Meeting and 11th Latin American Meeting on Optics, Lasers, and Applications,
edited by Manuel Filipe P. C. Martins Costa, Proc. of SPIE Vol. 8785, 87858W

2. METHODOLOGY

2.1 System Description

The goniophotometer (Figure 1) developed in IO-CSIC is composed of two URS75BPP stepper motor-based rotation stages of Newport Company. According to its manufacturer, their angular motion range is 360^o, being 1º the minimum increase in the displacement. It also has a positioning accuracy of $0.030^o \pm 0.015^o$ and a rotation eccentricity of 3 μm $\pm$ 1.5 μm. These stages provide the system with two degrees of freedom θ and φ (azimuth and spherical polar coordinates). The illuminance can be measured in any direction, except in a small occlusion field behind the source.

The LED transfer standard J-1019 was compared with four different LEDs: F126 (green), F132 (polar white), F108 (red) and F107 (blue). All of them with a 7 mm shell diameter. The stability of the flux emitted by J-1019 is maintained by controlling its temperature. The voltage fluctuation can be monitored via an Agilent 34970A digital multimeter.

To measure the luminous intensity, a temperature-stabilized P11S0T luminance photometer manufactured by *LMT Lichtmesstechnik GmbH* was used. The circular area of this photometer is 100 mm^2, which allows the averaged luminous intensity to be assessed at the two configurations A and B recommended by the *International Commission on Illumination* (CIE). Two baffles are located on front of the photometer to avoid stray light. A CCD camera (LA VISION) with a 50-mm lens is orthogonally located for alignment purposes.

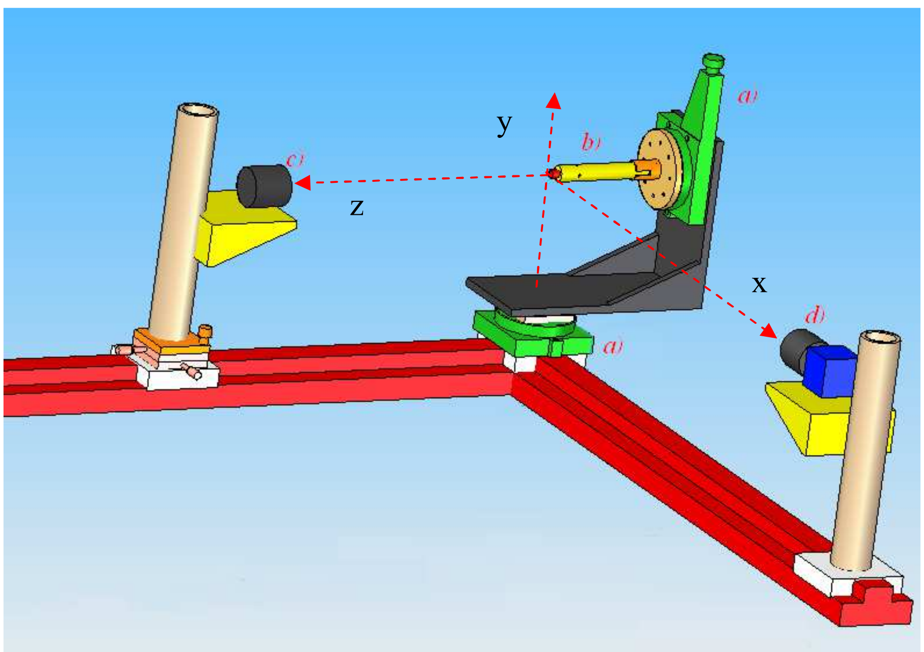

Figure 1: Goniophotometer developed by IO-CSIC. a) Rotation stages b) LED-J1019: LED Transfer Standard, c) photometer and d) CCD camera.

2.2 Measurement procedure

The alignment of the LED respect to the centre of rotation of the reference system is accomplished with an iterative process in which the LED is observed alternately between two orthogonal perspectives by the CCD camera. The alignment ends up when no shift of the LED tip is observed in the image while varying the azimuth angle.

The emission of the LED is registered for measurement geometries from $\theta = 0^{o}$ to $\theta = 90^{o}$ (10^{o}step) and from $\varphi = 180^{o}$ to $\varphi = -180^{o}$ (step of around 11^{o}). To save time, the azimuth stage rotates from $\varphi = -180^{o}$ to $\varphi = 180^{o}$ for the first polar angle and afterwards from $\varphi = 180^{o}$ to $\varphi = -180^{o}$ for next polar angle, and so on. The photometer response is continuously sampled during the azimuth rotation, which allows 32^{o} uniformly-distributed acquisitions for every polar angle. The accuracy of this non-stop-and-go procedure was checked by comparing with a stop and go procedure. The measurement procedure is automatically run by the workstation until reaching $\theta = 90^{o}$.

3. RESULTS

Figures 2, 3, 4 and 5 show the angular distribution of the averaged luminous intensity corresponding to the LEDs F126, F132, F108 and F107, respectively. They were supplied with a stable electrical current $I_{LED} = (20.00 \pm 0.02)$ mA. Chip's temperature was $T_{LED} = (32.0^{o} \pm 0.1)\,^{o}C$ and the voltages were $V_{LED} \cong (3.0 \pm 0.1)$ V, except for the LED F132 whose $V_{LED} \cong (2.3 \pm 0.1)$ V Data were normalized to the average measurement at $\theta = 0^{o}$ and the estimated relative uncertainty is 0.2 %. The acquisitions were interpolated in order to compare with PTB's measurements where measurement steps were $\Delta\theta = 0.5^{o}$ and $\Delta\varphi = 0.5^{o}$.

Figures 2.a, 3.a, 4.a 5.a show the results in a three-dimensional plot, where the polar projections of the emission with respect to polar angle (θ) are plotted in the XZ and YZ planes, and the polar projection of the emission with respect to azimuth angle (φ) is plotted in the XY plane. Figures 2.b, 3.b, 4.b and 5.b display the measurement as a color map.

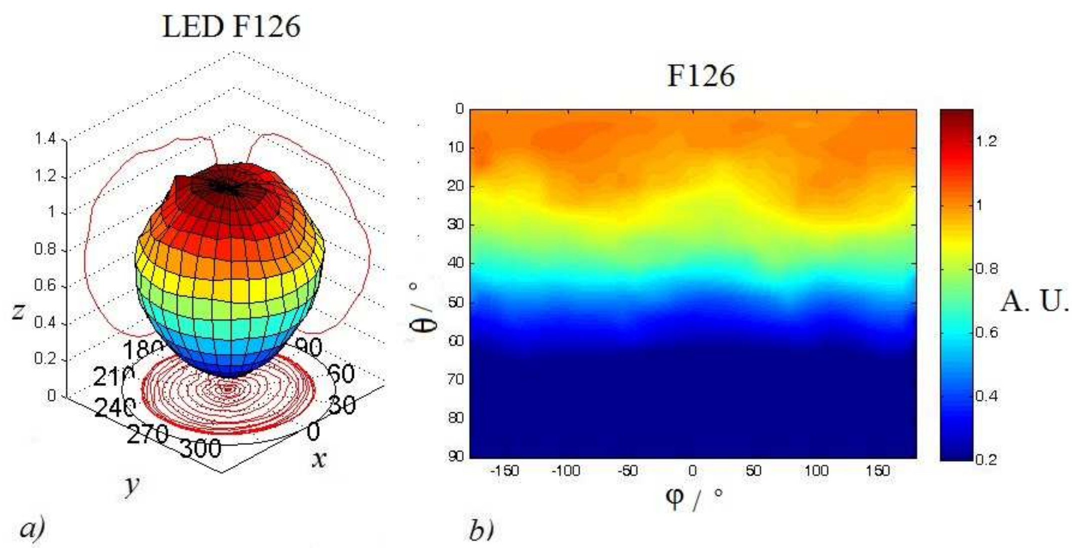

Figure 2: Angular distribution of the averaged luminous intensity for the LED F126 in a 3D plot (a) and in a color map (b).

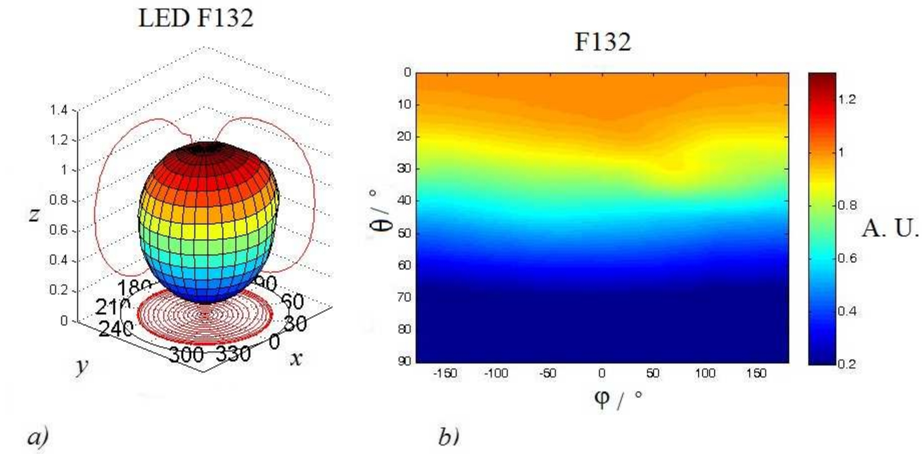

Figure 3: Angular distribution of the averaged luminous intensity for the LED F132 in a 3D plot (a) and in a color map (b).

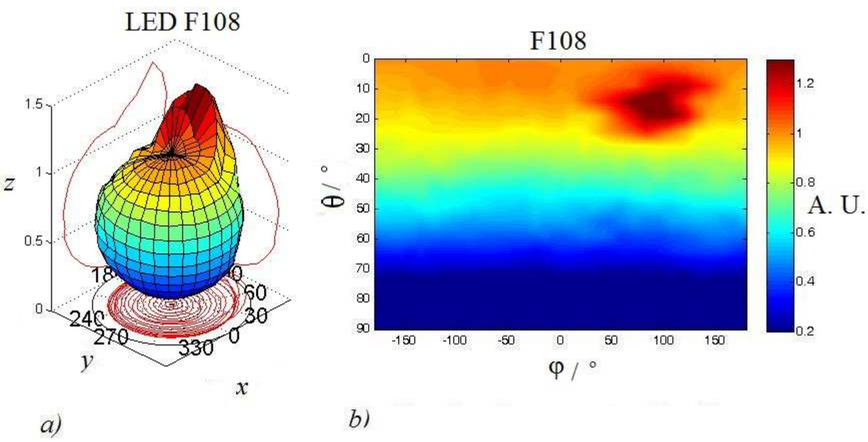

Figure 4: Angular distribution of the averaged luminous intensity for the LED F108 in a 3D plot (a) and in a color map (b).

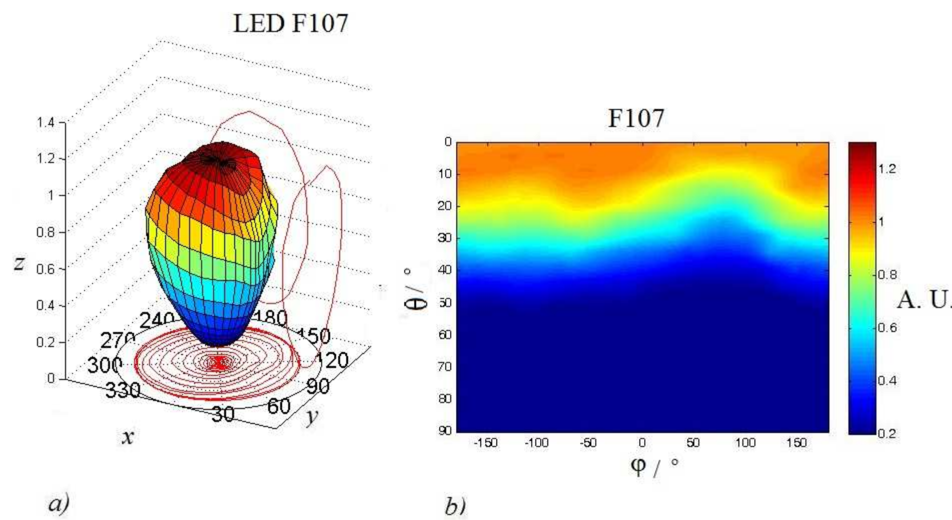

Figure 5: Angular distribution of the averaged luminous intensity for the LED F107 in a 3D plot (a) and in a color map (b).

4. DISCUSSION AND CONCLUSIONS

The relative difference (in per unit) between IO-CSIC and PTB measurements are shown in colour maps with a logarithmic scale in Figure 6 (Figure 6.a for F107, 6.b for F108, 6.c for F126 and 6.d for F132). The azimuth-averaged differences are shown in Figure 7. The relative difference is approximately 1.5 % independently on the LED up to $\theta = 40^o$. For higher angles, a fast relative difference increase is observed. The comparison yields an excellent result for LED F132 at almost all polar angles, with just a 3% difference at angles below 70^o and less than 6 % difference up to 85^o. So far, we do not have any contrasted explanation about why the comparison is much worse in the other LEDs at high polar angles.

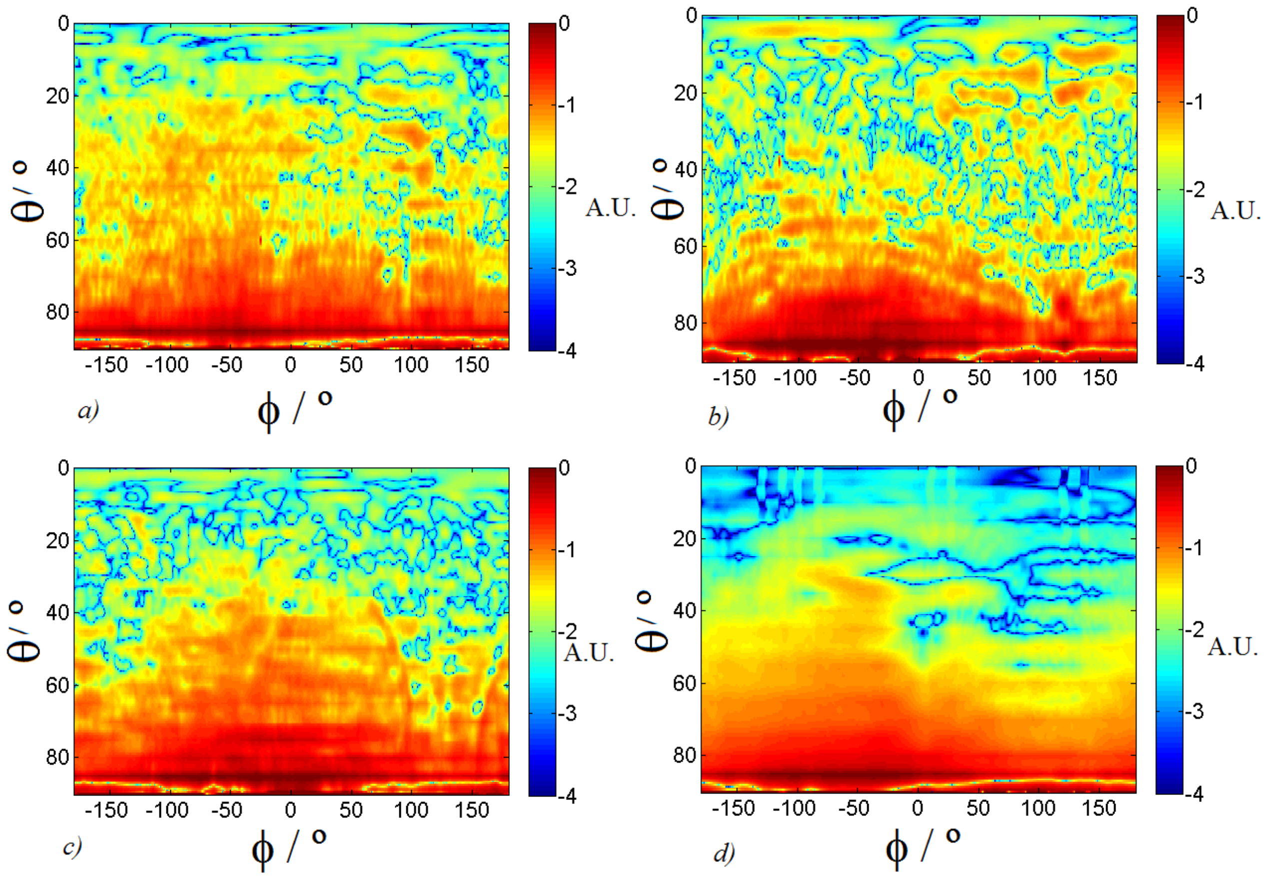

Figure 6 : Comparison between measurements made in both laboratories (logarithmic scale). a) F107; b) F108; c) F126 y d) F132.

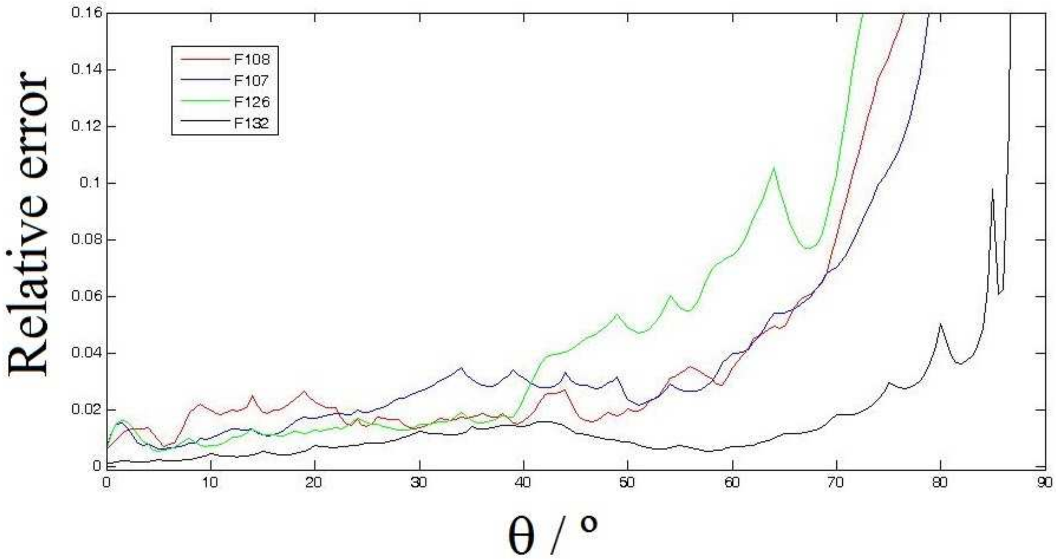

Figure 7: Relative error between the measurement carried out at PTB and IO-CSIC for all LEDs.

To evaluate lambertianity of these LEDs, the function $I_0 * \cos^g(\theta)$ was fitted both to the IO-CSIC's and to the PTB's experimental data, where I_0 represents the averaged luminous intensity at $\theta = 0^o$, and g is the Lambertian coefficient of the source ($g = 1$ for Lambertian sources). Fittings coefficients are shown in Figures 8 (I_0) and 9 (g), as a function of the azimuth angle. Dashed lines represent the coefficient uncertainty due to the fitting. It can be observed that the value I_0 obtained for both laboratories is included in the expanded uncertainty interval. This Figure 8 shows that the flux emitted from the source varies with the azimuth angle.

Regarding the g Lambertian coefficient, two different behaviours are observed in Figure 9. As expected, there was some correlation between the coefficients, but it can be concluded that LEDs F108, F132 and F126 are the most Lambertian while F107 LED is the least Lambertian (Table 1).

Table 1 shows the anisotropy of the emission (calculated as the relative standard deviation of I_0 over all azimuth angles). LED F108 (with $g = 1.38$) is the most isotropic, followed by LEDs F126 and F132 (with $g \cong 1.7$) while LED F107 (with $g = 3.64$) is the least isotropic. This indicates there isn't a correlation between lambertianity and anisotropy of the source.

Table 1. Resulting Lambertianity and anisotropy descriptors from both IO-CSIC and PTB.

	Lambertianity [averaged g]		**Anisotropy [std(I_o)/mean(I_o)]**	
LED	**IO-CSIC**	**PTB**	**IO-CSIC**	**PTB**
F107	3.64	3.54	0.052	0.047
F108	1.38	1.31	0.069	0.065
F126	1.86	1.76	0.016	0.015
F132	1.62	1.62	0.014	0.015

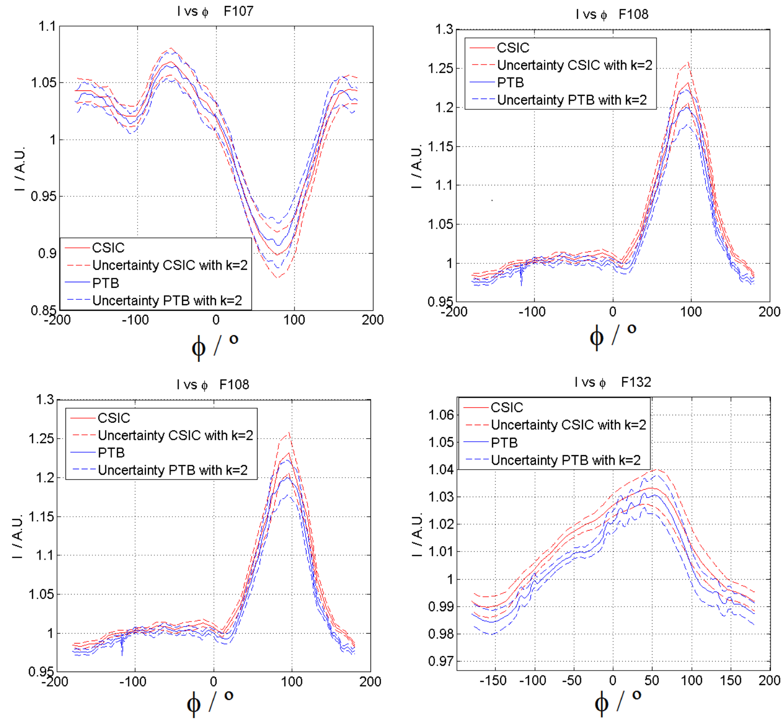

Figure 8: Fit intensity coefficient for a) F107; b) F108; c) F126 and d) F132.

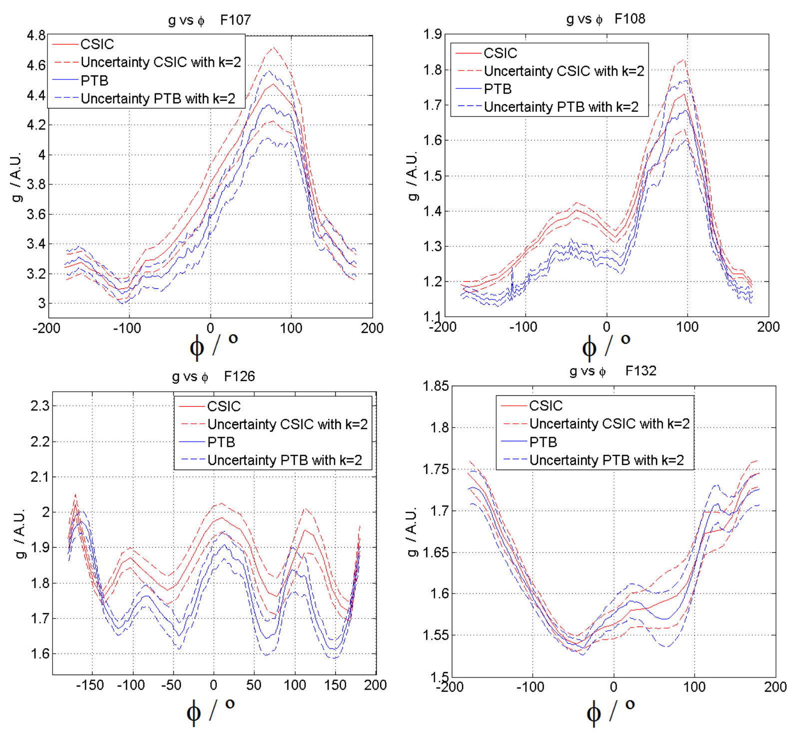

Figure 9: Fit lambertianity coefficient for a) F107; b) F108; c) F126 and d) F132.

5. ACKNOWLEDGEMENTS

Some of the authors thank to Comunidad de Madrid for having subsidized a contract FACTOTEM-2, to EMRP program by the project grant SSL-ENG05 and to CICYT for the grant of the project FIS2010-19756. We would also like to acknowledge the cooperation offered by the PTB for the comparison.

6. REFERENCES

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