

Spectrally Selected Linearity Measurement of a Radiation Thermometer Using High-brightness Light Emitting Diodes

Chul Woung Park, Dong-Joo Shin, Dong-Hoon Lee, and Seung-Nam Park
Photometry and Radiometry Group, Korea Research Institute of Standards and Science,
Yuseong, Daejeon 305-600, Rep. Korea

1. Introduction.

Radiation thermometers play an important role as a spectral radiance comparator in the realization of International Temperature Scale (ITS-90) based on fixed points. To extend the temperature scale beyond the fixed point temperature, various uncertainty components should be measured by experiment [1], among which the linearity of radiation thermometers is of particular importance.

Linearity of a detector, in general, is the property that the responsivity of the detector remains constant within a specified range of radiation input, and can be measured without calibration by a method referred to as the flux addition [2]. Recently, a novel scheme of linearity tester is reported which is based on the flux addition method using two light emitting diodes (LEDs) as light source [3]. The scheme includes an algorithm for correcting the systematic error caused by flux instability so that the high accuracy is ensured over a wide dynamic range even with simple setup and short measurement time. Furthermore, as LEDs can provide intrinsically quasi-monochromatic light of high brightness, the linearity tester using LEDs enables a spectrally selected test of the linearity.

In this article, we present a spectrally selected linearity measurement of a radiation thermometer using high-brightness LEDs. The linearity is measured at two different wavelengths of 625 nm (red) and 880 nm (IR) with an uncertainty as low as 10^{-4} in a dynamic range over 3 decades. The results show that the non-linearity of the radiation thermometer is significantly observed in the infrared.

2. Measurement setup and results.

Fig. 1 shows schematically the experimental setup. Two LEDs of the same type are required, which are mounted on separate heat sinks without controlling the temperature and power-supplied separately by two current sources (Keithley, Model 2400). Two different types of LEDs are used in the experiment: one pair is red LEDs with a peak emission wavelength of 625 nm (Opto Technology, OTLH-0040-RD), and the other pair is IR LEDs of 880 nm (Opto Technology, OTLH-0070-IR). The spectral bandwidth (FWHM) of the red and the IR LEDs is specified to be 20 nm and 30 nm, respectively. The radiation thermometer under test is the model LP4 manufactured by KE-Technologie GmbH, Germany. A beam splitter is used to add the radiant flux of one LED to each other. The flux ratio from both LEDs is adjusted by aligning the beam splitter so that the photocurrent signals of LP4 for each LED are approximately the same when the LEDs are driven at a same current value. After the initial configuration, the whole measurement is automatically processed by a computer program.

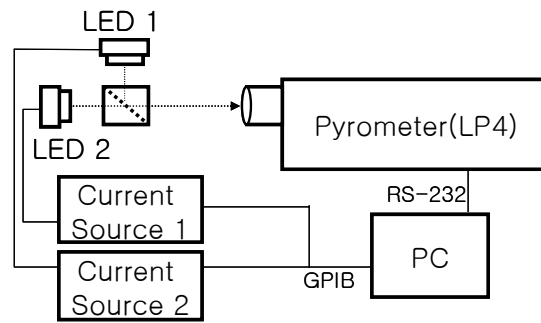


Fig. 1. Schematic setup for linearity measurement of a radiation thermometer using LEDs as light source.

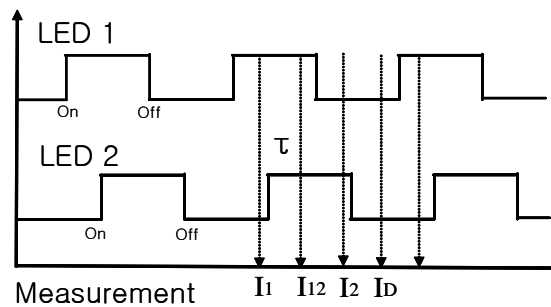


Fig. 2. Switching and data-reading sequence of the linearity measurement using LEDs.

The measurement method and data-acquisition algorithm of the linearity tester using LEDs are in detail described in Ref. 3, which are here only briefly summarized. Figure 2 shows the switching and data-reading sequence of the measurement. First, one of the LEDs, e.g. LED 1 in Fig. 1, is turned on and the photocurrent I_1 from the radiation thermometer is measured at a time t_1 . Then, the second LED, LED 2, is also turned on without turning off the LED 1 and the photocurrent I_{12} is measured at a time t_2 . Finally, LED 1 is turned off while LED 2 remains on so that the photocurrent I_2 is measured at a time t_3 . The dark current I_D of radiation thermometer is detected while LED 1 and LED 2 off. To evaluate the linearity of the device under test, the linearity factor at the given flux level is determined from the measured current values as

$$L_{12} = \frac{I_{12}(t_2)}{I_1(t_1) + I_2(t_3)}. \quad (1)$$

However, this linearity factor contains a systematic error caused by flux instability of the LEDs: when the radiant flux of, e.g., LED 1, varies within a measurement cycle, the value of I_1 and the contribution of I_1 to build I_{12} is measured at the different moments of t_1 and t_2 , respectively. To resolve this, it is necessary to repeat the current measurement as described above, but with the switching sequence of both LEDs interchanged. The second linearity factor is then determined as

$$L_{21} = \frac{I_{21}(t_2)}{I_2(t_1) + I_1(t_3)}. \quad (2)$$

By taking a geometric mean of Eq. (1) and Eq. (2), we obtain the new linearity factor

$$L \equiv \sqrt{L_{12}L_{21}}, \quad (3)$$

which is now free from the systematic error caused by the flux instability of the LEDs [3]. The linearity factor L is measured at different flux levels by adjusting the injection current for LEDs, and plotted against the signal current value $\sqrt{I_{12}I_{21}}$ of the detector.

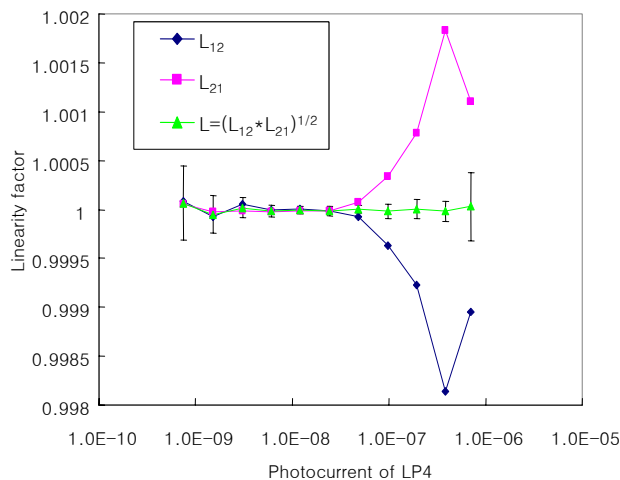


Fig. 3. Measured linearity factors L_{12} (filled diamonds; equation 1), L_{21} (filled squares; equation 2), and L (filled triangles with error bar; equation 3) using the red LEDs (625 nm) as a function of the LP4 photocurrent.

Figure 3 shows the result of the linearity measurement for the radiation thermometer LP4 using the red LEDs at 625 nm. Note that the axis for the photocurrent is in the logarithmic scale. In the experiment, we measured first the set of L_{12} according to Eq. (1). Then the measurement is repeated with the switching sequence of the LEDs interchanged to obtain L_{21} according to Eq. (2). Finally, the linearity factor L is calculated from the geometric mean of both linearity factors as defined in Eq. (3). The error bars for L indicate the standard deviations derived from the standard deviations of the related currents. As clearly shown in Fig. 3, the deviation of the conventional linearity factors L_{12} and L_{21} from unity, which should be caused by the flux-dependent instability of the LED radiant flux, is mostly eliminated in the mean linearity factor L . From the standard deviations for L , we estimate a measurement uncertainty of the linearity factor as low as 10^{-4} in the whole dynamic range over 3 decades.

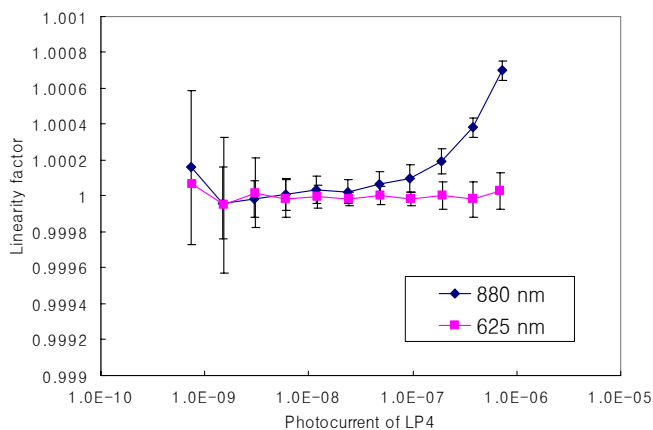


Fig. 4. Comparison of the linearity factors measured using LEDs at two different wavelengths of 625 nm (filled squares) and 880 nm (filled diamonds).

Fig. 4 shows the result of the wavelength selected linearity measurement, where the linearity factors L of the radiation thermometer LP4 measured using the red LEDs at 625 nm and using the IR LEDs at 880 nm are plotted together for comparison. For photocurrent values above approximately 5×10^{-7} A, the LP4 shows an increasing

nonlinearity with the IR LEDs, which is in contrast to the case with the red LEDs. This can be explained by the fact that the nonlinearity of silicon detectors is in general much higher in the IR spectral range than in the visible [4]. From this result, it is strongly recommended to consider the nonlinearity effect when the radiation thermometer with a silicon detector is used for high temperature measurement at an IR detection wavelength.

3. Conclusion

We measured the linearity of a radiation thermometer at two different wavelengths of 625 nm and 880 nm by using high-brightness LEDs. With the measurement algorithm eliminating the systematic error caused by flux instability of LEDs, the linearity factor of the radiation thermometer could be measured with an uncertainty of as low as 10^{-4} in a dynamic range over 3 decades. The wavelength selected measurement of the linearity produced a result that the radiation thermometer with a silicon detector has better linearity when operated in the visible spectral range than in the infrared. In conclusion, the linearity measurement presented in this work is expected to be an important experimental tool in the precision radiation thermometry.

Acknowledgement

The authors would like to acknowledge the technical support of Mr. B.H. Kim and Mr. K. L. Jeong during the experiment, as well as useful comments of Mr. Ekkehard Schreiber and Mr. H.-J. Menz of KE-Technologie GmbH.

References

- [1] Fisher J., Battuello M., Sadli M., Ballico M., Park S. N., Saunders P., Zundong Y., Carol Johnson B., Van der Ham E., Sakuma F., Machin G., Fox N., Li W., Ugur S. and Matveyev M. 2003 Uncertainty budgets for realization of ITS-90 by radiation thermometry *Temperature: Its Measurement and Control in Science and Industry 7*, pp 631-638
- [2] Budde W 1983 *Physical detectors of optical radiation* (Orland, FL: Academic Press) chapter 3
- [3] Shin D-J, Lee D-H , Park C-W, and Park S-N , “A Novel Linearity Tester for Optical Detectors using High-brightness Light Emitting Diodes”, *Metrologia* 42, 154 (2005)
- [4] Private communication with Ekkehard Schreiber of KE-Technologie GmbH, Germany.