METHOD FOR COMPENSATING OF ERROR ARISED BY PHOTOMETRICS MEASUREMENT WITH SI – PHOTODIODE

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This paper suggests method for this error compensation due using of second Si – photodiode. His spectral response has maximum in the near IR domain, where the main (human eye spectral response corrected) has unneeded spectral response. When there is known the spectral distribution of measurement radiation than with mathematical calculations can distinguish what ratio the error is.

There are developed and described mathematical model of photometrical measurement process. There are achieved relationships, which help to compensate the error with proprietary processing of photodiode's signal.

The idea of the method is that from signal of first photodiode is extracted a signal from the second one photodiode with multiplication ratio. This ratio is calculated analytically prior the measurement with respect of spectral distribution of measured radiation and spectral response of second used photodiode. This is possible for practical realization because mainly there are measured radiations with known spectral responses such as a sun, bulbs and so on.

For testing the effectiveness of suggested method is made a calculation in software environment Mathcad. There are present the results for accuracy of photometric measurements by method with two photodiodes and have made notices for hardware implementation of the method.

1. INTRODUCTION

Illumination measuring is necessary in many fields of science, industry and art (cinema, photography). This measuring is realized by a sensitive element on which the electromagnetic flow falls and converts this flow into electric signal. This signal is processed and is used to define the levels of illumination on the sensor. Usually sensor has the shape of measuring head, which is located in the area of illumination measuring.

Nowadays, contemporary electronic industry provides large variety of photodiodes with different spectral sensitivity. Depending on technology, the size of sensitive area and spectral filter in front of it have different price. Photodiodes are used for precise photometric measuring with corrected spectral response of sensitivity so that it is a maximum close reproduction of the one of the human eye. It's a

complex technological process to make such filter that's why photodiodes with corrected filters have higher price in comparison to other filters.

The possibilities of using algorithmic and hardware solutions in signal processing from photodiodes, with spectral sensitivity different from the one of human eye, are subject of the report.

2. PROBLEM

The dimension of illumination E is $\mu W/cm^2$, when the whole spectrum of electromagnetic radiation is measured and *Lux* (which is lm/m^2), when measuring in the optical (visible) spectrum, where human eye is sensible. The result is affected mainly by the spectrum of electromagnetic flow witch irradiates the surface. Generated photocurrent of the photodiodes is given by the equation:

$$i_{ph} = \int_0^\infty R(\lambda).\Phi(\lambda).d\lambda \qquad (1)$$

Where $R(\lambda)$ is spectral sensitivity of photodiodes, $\Phi(\lambda)$ – spectral density of falling and converted into electrical signal. The falling electromagnetic flow on the photodiodes is proportional to illumination $E(\lambda)$ on the surface where the surface of the photosensitive area $S_{Ph.d}$ is located.

$$i_{ph} = S_{Ph.d}.\int_0^\infty R(\lambda).E(\lambda).d\lambda \qquad (2)$$

Equation (2) gives the connection between generated photocurrent and illumination of surface. Spectral sensitivity of photo-receivers is given in absolute units - *A/W*, therefore the result of photocurrent measuring would be in the units of energetic illumination W/cm^2.

In order to get proportionally to the photocurrent generated by photodiodes in *Lux* (respectively lm/m^2) is necessary its spectral sensitivity to be the same as the one of human eye. In that way equation (2) will be:

$$i_{ph} = S_{Ph.d}.\int_0^\infty V(\lambda).E(\lambda).d\lambda \qquad (3)$$

Photodiodes have different spectral response of sensitivity depending of the technology of production. Typical photodiodes spectral responses are illustrated in figure 1 witch are used for electromagnetic flow measuring.

The characteristic of photodiodes with filter, witch corrects spectral response, is shown too so that it's the same as the one of human eye.

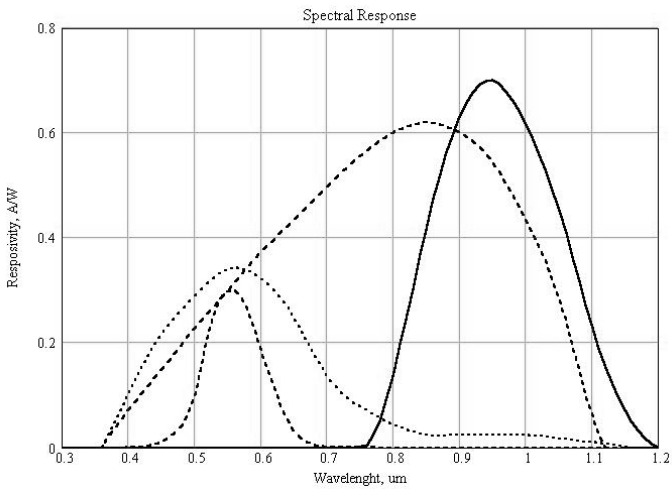

Figure 1 Spectral responses of different type photodiodes without correcting filters

In Fig. 1 is shown that photodiodes, without any correcting filters, have essential differences in spectral response in comparison with the spectral response of human eye. Their use in direct measuring purposes will give results with big error.

3. SUGGESTED SOLUTION

Photodiodes of type BPW21 has the closest to human eye response of sensitivity. Main reason for the error in light flow measuring is the existence of sensitivity in the close infrared area – in the range from *0,8μm* to *1,1μm* .To minimize that error second photodiodes can be used, witch has maximum of his spectral sensitivity in this range. Such is the photodiodes BP104, product of Siemens, Fig. 1.

In many practical measurements we know the type of the source of electromagnetic flow witch photometric parameter is measured. Such sources are: natural light –Sun, Moon, reference source of type A, thermo-sources whit certain temperature, different kinds lamps and others. In order to obtain signal, equal to real value of light illumination by using photocurrents of two, we can use the equation:

$$i_{ph-sum} = i_{BPW\ 21} - K_{opt}.i_{BP\,104} \qquad (4)$$

Where: i_{ph-sum} is total photo current, i_{BPW21} - photocurrent of photodiodes BPW21, i_{BP104} - photocurrent of photodiode BP104. Using that equation, the photocurrent of second photodiode must be multiplied by calculated coefficient K_{opt}. And to subtract it from the photocurrent of first photodiode – measuring photodiodes. It is necessary to know the spectrum of falling flow for the calculation of coefficient K_{opt}.

Coefficient K_{opt} can be determined from following preconditions: photo-current from silicon photo-receiver BPW21, with spectral response identical to that of the human eye Fig. 1 will be calculated from the equation:

$$i_{ph-V} = S_{Ph.d}.R_{max.BPW21}.E_{max}.\int_{0,38\,\mu m}^{0,72\,\mu m} V(\lambda).E^*(\lambda).d\lambda \qquad (5)$$

Where : $S_{Ph.d}$ - area of photo receiver, $R_{max.BPW21}$ – maximum of spectral sensitivity of photodiodes BPW21, E_{max} – maximum value of spectral density of illumination, $V(\lambda)$ – spectral sensitivity of eye in relative units, $E(\lambda)$ – spectral density of illumination in relative units.

The value of the photocurrent generated by the real BPW21 photodiode, brought to the same illuminance is:

$$i_{ph.BPW21} = S_{Ph.d}.R_{max.BPW21}.E_{max}.\int_{0,35\,\mu m}^{1,1\,\mu m} R^*_{BPW21}(\lambda).E^*(\lambda).d\lambda \qquad (6)$$

Where: R^*_{BPW21} is the spectral sensitivity of BPW21 photodiode in relative units; for the photocurrent of BPW104 photodiode, irradiated with the same electromagnetic stream, the following equation could be written:

$$i_{ph.BP104} = S_{Ph.d}.R_{max.BP104}.E_{max}.\int_{0,35\,\mu m}^{1,1\,\mu m} R^*_{BP104}(\lambda).E^*(\lambda).d\lambda \qquad (7)$$

Where: R^*_{BPW104} is the spectral sensitivity of BPW104 photodiode in relative units.

Due to the difference of the spectral characteristics of the human eye sensitivity and BPW21 photo detector sensitivity, there will be a difference in the photocurrents and:

$$i_{ph\_BPW21} > i_{ph-V}$$

In conformity with equations (5), (6) and (7), also substituting $i_{ph-V} = i_{ph-sum}$ we obtain the following equation for K_{opt}:

$$K_{opt} = \frac{S_{Ph.d}.R_{max.BPW21}}{S_{Ph.d}.R_{max.BP104}}.\frac{\int_{0,35\mu m}^{1,1\mu m} R^*_{BPW21}(\lambda).E^*(\lambda).d\lambda + \int_{0,38\mu m}^{0,72\mu m} V(\lambda).E^*(\lambda).d\lambda}{\int_{0,35\mu m}^{1,1\mu m} R^*_{BP104}(\lambda).E^*(\lambda).d\lambda} \qquad (8)$$

The functions under the integration sign in equation (8) interpret the spectral sensitivity characteristics of both photodiodes and the human eye sensitivity. These characteristics in *1,2 μm* range are shown in Fig. 2.

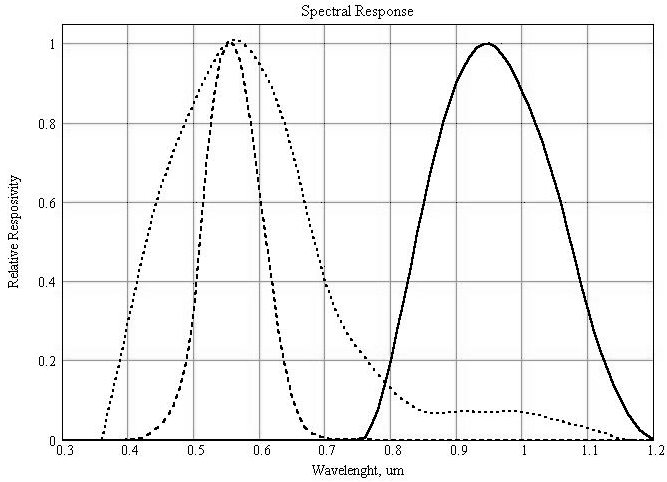

Figure 2 Spectral sensitivity characteristics of the photodiode: BPW21, BP104, and the human eyesensitivity .

In order to do calculations over equation (8) is necessary to know the type of the sources for which amendments must be introduced in the results for the measured photometric quantities.

4. RETURNS OF THE MATHEMATICAL MODELING.

Aiming verification of the suggested method for amendments introduction and also for evaluation of the quotient K_{opt} for practical usage, equation (8) was solved in MATHCAD environment. Purposefully two types of light sources were chosen: Black Body with temperature *5800K* – spectral characteristic closest to the one of the sun light; source of type A with temperature *2856K* – spectrum closest to the one of an incandescent lamp.

The relation describing the spectral distribution of the electromagnetic stream of the chosen heat source is given by the Planck's equation (9):

$$E(\lambda,T) = \frac{C1.10^{12}}{\lambda^5\left[e^{\left(\frac{C2}{\lambda.T}\right)}-1\right]}.\left[\frac{watt}{m^2.\mu m}\right] \qquad (9)$$

Where: $C1 = 3{,}744.10^{-4}$, $W/\mu m^2$; $C2 = 1{,}439.10^{4}$, $\mu m.K$; ($C1$ and $C2$ are constants); T – temperature in Kelvins ; λ – wavelength in micrometers.

On Fig. 3 are shown the spectral characteristics of the chosen sources and the spectral sensitivity of the photodiodes in relative units. As we can see the maximum of the spectrum of wormed body with temperature *5800K* corresponds to the maximum of a human eye spectral sensitivity. This fact explains the greater value for K_{opt}, estimated for this source in comparison with the source with temperature *2856K*.

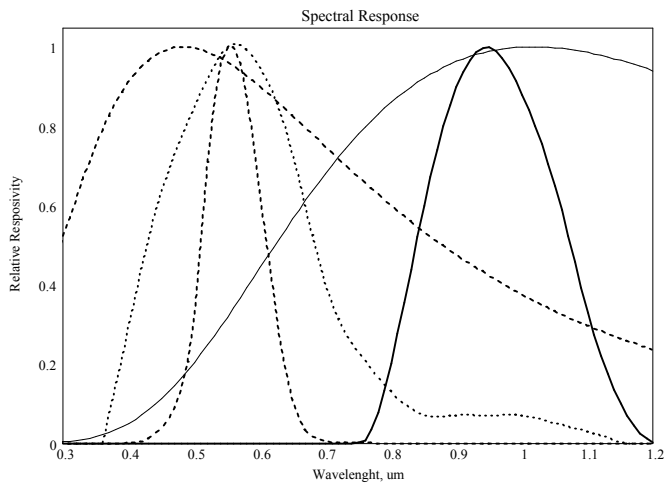

Figure 3 Spectral sensitivity characteristics of the photodiodes and spectral characteristics of the chosen sources.

The specific values of the amendment quotient K_{opt} are:

- For source with temperature *5800K*: $K_{opt} = 0,343$
- For source with temperature *2856K*: $K_{opt} = 0,231$

5. CONCLUSION

The suggested consistency of mathematical transformations and evaluated quotient give the opportunity to amend the error, which comes from the difference in the spectral sensitivity of the photodiodes. Precision in photometric quantity measurements with the error amendment method can be obtained by using couple photodiodes. The final result of the measurements must be achieved by solving equation (4). Such a calculation can be done by using microcontroller based systems.

6. REFERENCES.

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