Counting method for calibration and linearity checking of photometry devices

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Abstract
The possibility of calibration and check linearity optical detectors in a wide dynamic range by method of counting separate parts of energy is investigated. Counting method permits nonselective change energy of measuring optical pulse more, then \(10^5\) times. A construction of working source of radiation with GaAs LED is described. Results of experimental investigation are presented.

Keywords: Optical measurement, check linearity, energy meter, calibration, pulse count

1. Introduction
It is known that lasers and pulse lamps have very unstable power and energy from pulse to pulse. So it is very difficult to measure such sources. Method of averaging of pulse energy in series of 10, 100, 1000 pulses permits us to decrease nonstability of measurements. For this purpose a device for measuring the energy of each pulse was designed. The readout of device made as a counter. So one can easily show average value from 10, 100, 1000 and so on pulses by moving comma to the left on one digit for each ten times increasing of counting pulses. Such device can be calibrated by calorimetric etalon device with a big time constant. For instance, if we have series of 1000 pulses with common energy \(10^{-3}\) J measuring by colorimeter, a single pulse will have \(10^{-6}\) J energy and device readout will be \(10^{-6}\) J as average from 1000 pulses. It will be a rather stable value. So we can precisely decrease energy of measuring pulse in \(10^3\) times if we used only one pulse for measuring. Nonselective pyroelectric energy meters were calibrated in the same manner. Instead of calorimeter, measuring energy, a calorimetric power meter can be used. In this case a frequency of pulse source must be stable and well known. If average power, measuring by etalon power meter is divided by frequency and ratio of period between pulses to their duration, we shall have energy of single pulse.

2. Counting method
The next modification of counting calibration method uses pulse source with changing energy in each measuring pulse. Decreasing or increasing energy in each pulse and in series of pulses can be made by different ways. The most popular is changing of pulse duration when a period between pulses is constant. It can be made an analog ways by changing duration of each pulse with a constant period of time between pulses, but better the length of each pulse in measuring series of pulses fulfilled by some number of short counting pulses with a stable energy in each counting pulse. The waveform of counting pulse does not matter. If you change a number of short counting pulses during duration of pulses in measuring series, you can change energy in each pulse and in whole series. In a series of 100 measuring pulses, for example, with a repetition rate of 10 milliseconds and common length of 1 second, short counting pulses with duration less 1 microsecond is situated inside of duration each measuring
pulse. It is very useful to have an interval between pulses for LED working in a good temperature conditions. More power and energy can be received in each measuring pulse. The duration of measuring pulse does not exceed 1 millisecond. If we change a number of short counting pulses from 1 to 1000 we change energy in measuring pulse and in whole series in $10^3$ times. Of course duration of measuring pulse will be changed from 1 microsecond to 1 millisecond. A sensitive pyroelectric energy meter with a time constant of $2-3*10^{-3}$ second measures an average energy from 100 measuring pulses, as it was described above. If we know number of counting pulses we can calculate energy of each counting pulse. If the whole series is in interval of 1 sec, it can be measured also by etalon calorimeter with time constant about 30 sec. A small error of this measurement can be calculated. In a whole we can change energy series pulses in $10^5$ times in this example. Pyroelectric energy meter can be calibrated by etalon calorimeter and we have energy-calibrated pulses with low level of energy for another purposes. LED can be used for such operation. The more convenient LED is GaAs unit with wavelength of radiation 910 nm. Of course we can use an averaging energy meter for measuring energy of a single measuring pulse. The number of counting pulses can be increased in this case, but it takes big time constant of measuring device and low repetition rate. It must be a special designed device. But in this case number of counting pulses can be increased till $10^6$ and more.

Such method permits to receive any energy levels, corresponding from 1 counting pulse to maximum value. Method permits to check linearity of energy meters and detectors with a time constant more, then duration of measuring pulse in a wide dynamic range. It is very useful in cases when we have not calibrated optical filter especially in a wide spectral range nonselective source and energy meter. Sometimes we have not possibility to measure transmittance and reflectance, if optical filters and attenuators in a far infrared region of spectra, where nonlinear detectors must be used (photo resistor, bolometer and so on.) In this case from the very beginning tests linearity of detector and then measurements take place. Counting method is very useful in this case. Infrared semiconductors lasers and LEDs with nanosecond rise time were designed in the last time. This allows using such source in this region of spectra also. We can use pulse-illuminating source for measuring transmittance or reflectance of samples or check detectors and preamplifier linearity.

3. **Calibration by photodiode trap detector**

Such LED pulse source can be calibrated also by self-calibrating trap photodiode etalon [1]. A sensitivity of trap diode is in power or radiation flux units. So it is necessary to have some comparison photometer, which can transmit sensitivity in power units into sensitivity in energy units. A very simple circuit (Fig. 1) does this operation.

![Fig. 1. Calibration circuit.](image)
Detector (Si photo diode or vacuum diode) is loaded parallel resistor R and capacitance C, which must be precisely measured. Values of R and C are chosen to obtain required time constant RC for precise energy measurements. It must be 3-5 times more than measurements pulse duration.

A voltage on resistor R and capacitance C is measured by oscilloscope or by peak voltmeter in a case of pulse radiation, as well as direct current voltmeter in a case of continuous wave CW radiation. Sensitivity of comparison photometer (Fig. 1) in power units is measured by usual way. (Fig. 2) Lamp 1 is imagined into input split 2 of monochromator 3 by lens 4. There is another lens 5 after output split 6, which imagines a grate or a prism surface 7 of monochromator into detector 8. So the uniform illumination takes place in a plate of detector. The same diaphragm 9 is mounted before trap detector and then before calibrated detector of comparison photometer. The last one is stayed on the same place, as a trap detector. Wavelength of monochromator is choosing in a visible range of spectra (usually 0.5-0.7 microns), where quantum efficiency of trap detector is the maximum value. The relative sensitivity of comparison photometer detector in spectral range of 0.5 – 0.95 microns must be measured before.

Then a sensitivity of comparison photometer detector in power units $S_p$ is calculated at 0.910 microns wavelength. Sensitivity for CW radiation $S_p$ is equal to $S_p=U_R/R\Phi$, where $U_R$ is the voltage on resistor R and $\Phi$ is the radiation flux (power) on the input surface of detector.

In a pulse regime sensitivity $S_q$ is equal to $S_q = UC/Q$, where $U$ voltage on capacitance C and Q is energy of measurement pulse of radiation. Relative change of detector sensitivity $S_p$ and $S_q$ shows nonlinearity of light characteristic of detector. We must have linear regime in all dynamic range of measurements. In this case the sensitivity $S_p$ is equal to the sensitivity of $S_q$ and $Q/\Phi = RC (U_c/U_R)$. Because all values in this equation are measured we can calculate energy Q. One can obtain also from this equation the sensitivity $S_p (A/W) = C S_q (V/J)$. The last equation is very useful for energetic calculations.

![Fig. 2. Optical diagram of measuring unit.](image)

4. **Counting source application**

According to this calibration method the sensitivity in term of power is multiplied by time constant RC and as a result one can obtain the sensitivity in term of energy. Comparison photometer calibrates energy source of radiation with the short pulse duration, which can be considered as $\delta$ - pulse source for this photometer. So we receive small level energy etalon for energy meter calibration. Such $\delta$ - pulse source can be above-mentioned source with a single fulfilled pulse. If energy of single $\delta$ - pulse is not enough for some energy meter calibration, the number of fulfilled pulse may be increased, if time constant of calibrated energy meter is enough. An error of such calibration may be 2-5% in a wide dynamic range. The most precisely error calculation is made in paper [2]. It must be mentioned there is no optical filters or other optical attenuators in use. Therefore there is no problem with a scattering light. In the most cases it is not required dark conditions for work, because energy meters are not sensitive...
to CW radiation. Described source is acceptable for calibrations in terms of energy where the form of pulse does not matter. Sometimes rise time of lasers or LED is not enough and front of pulse will be delayed. If we used linear parts of dynamic range this circumstance does not matter, so the decay of pulse will be delayed also and common area of pulse will be the same. But if we are not sure we can put another LED with a good rise time in series and compare ratio of sensitivities for both diodes. Current through diodes will be the same in this case.

If we want to calculate a result of calibration in terms of power, there will be some difficulties. In common case it is necessary to add some coefficient depending on form of measuring pulse. So it is desirable to have illuminating source with rectangular pulse which duration is proportional number of fulfilled counting pulse. Then power $\Phi$ can be calculated as $\Phi = \frac{Q}{t}$, where $t$ is rectangular pulse duration.

5. Experimental investigations and equipment

We have used GaAs LED in our experimental equipment. A LED put into pulse generator with constant amplitude of pulse. Radiation of LED measures by Si photodiode and oscilloscope. We can change current through diode. It was fixed some current and then we defined decreasing top of pulse with increasing of pulse duration. The frequency of pulses was not more then 1 Hz. So we defined an optimal current and duration of pulse. It was current 2A in a pulse and pulse duration $1 \times 10^{-2}$ sec for our LED AL107B type. The more powerful diode with rise time of radiation $1.5 \times 10^{-8}$ sec was chosen. Maximum wavelength of radiation is 910 nm; power in pulse is 60 mW and maximum energy is of $6 \times 10^{-4}$ J. So low rise time permits escape error under calculation energy of radiation for shortest pulse duration. Power amplifier is used as power supply for this diode, which allows us to receive maximum energy $6 \times 10^{-3}$ J and minimum $6 \times 10^{-8}$ J.

![Fig. 3. Schematic diagram of experimental unit.](image)

Such LED with corresponding power supply can compare sensitivity all mentioned energy meters and permits to calibrate one of it by another.

One of possible circuit such source shown on Fig. 3. Monostable multivibrator contains counter divider CT2 with integrated circuit ICs1 (561IE16) has 2 inputs R and C. Input C connected with output “and gate” ICs2 (561le5). One input of ICs2 connected with one of outputs of ICs1. High potential on output ICs1 does not permit to go the counting pulses from counting pulse generator 1 through ICs2, until appear triggering pulse from repetition rate generator 2. Appearing on the one of outputs zero potential permits the counter ICs1 to begin
to work. After counts $2^5$ counting pulses on the first output ICs1, corresponding $2^5$ pulses positive potential stopped counts. The same operation takes place, when input ICs2 connected to another output ICs2, but output pulse will be in 4,16,64 and 256 times longer. This pulse puts in power amplifier 3 with a LED on its output. Divider 4 decreases frequency of counting pulses and increased duration output measuring pulse. Described monostable multibibrator changes duration of output pulse step by step from 1 to 2560 times. Using divider 4 with more times of dividing we can increase this number. In experimental circuit counting pulse generator was stabilized by quartz with frequency 3515 kHz, that corresponding output 1 pulse duration is 8,890 microseconds.

Naturally such unit can be made on the basis of microprocessor circuit. Usually it is required one or few pieces of unit so design of program are expensive. Microprocessor chip has a lot of pins and it is necessary to use manufacturing technology for PC board made and soldering it. A common number of soldering points are not more in described unit, then in case of microprocessor chip.

6. Conclusion

Possibility of adding part of radiation energy in time allows simplifying checking linearity of energy meters. Using described counting source allows us to precisely know parts of energy. It is especially convenient in far infrared region of spectra, where there are no calibrated filters and attenuators of radiation. Sometimes it is difficult to divide calibration and linearity checking, especially in a wide dynamic range, more than $10^6$. In this case used two etalon energy meters for linearity checking. The ratio of readouts for etalons energy meters is compared with ratio of readouts for checking device. Difference between these ratios shows no linearity of checking device. Simultaneously calibration takes place in this case automatically.

References