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Research into Methods of Energy Use Reduction for Optical Schemes of Target Location Measurement

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Abstract

The current trends in the development of energy use metering devices have brought into life digital devices, which, alongside with traditional metering instruments, provide a number of additional features. Among them are the following: correction of the energy use readings, logging function, interaction with metering devices to control the readings through various interfaces (both wired and wireless). These instruments are autonomous devices, working on battery supply of 2 – 3,5 A·of capacity, which can be replaced during the device calibration. The run-time between autonomous power supply replacement periods ranges between 5 and 10 years. The main consumers are microprocessor, measuring circuit and display devices. The power consumption of the microprocessor and the display devices are known from the technical documentation and can be minimized by choosing the optimum operating mode. This paper dwells on the methods for reducing the energy consumption of a measurement system consisting of an optical pair of an emitter (an infrared LED) and a receiver (phototransistor). The characteristics of the system power use at various parameters of the scanning pulse, optical circuits and the components used as measuring circuits in metering energy. Oscillograms of the effects and responses of the optical system are given for different durations and options to reduce energy use. A method for reducing power consumption by reducing the pulse width, which, on the other hand, leads to an increase in the LED current, is considered. Besides, options for restoring waveforms based on amplifiers and comparators with low power consumption are considered.

Keywords: Optical emitters; metering devices; measuring circuits.

INTRODUCTION

Efficiency enhancement in energy resources usage and distributing has affected the sphere of housing and utility sector (HUS). This lead us to the need to solve the tasks of accounting for energy consumption by metering devices using the automated utility metering system [1, 2]. In modern metering devices, optical pairs like emitter-receiver are used to measure the number of revolutions made by the impeller under the influence of the flow of water (water consumption meters) or the translational motion of the membrane for gas metering devices. Optical circuits are more preferable than magnetic ones, which measure changes in magnetic fluxes, since they are less sensitive to changes in the temperature and the magnetic environment, although they have more power consumption than magnetic circuits. The main consumers in the energy accounting devices are a microcontroller, a device for displaying information and a direct system for retrieving the information of consumed resources. Controller consumption can be reduced by decrease in the clock frequency of the core, power management of the periphery and directly by disabling the clock of the microcontroller core. The consumption of the information display device can also be controlled by reducing the clock frequency. There are LCDs that consume 4-20 μA, which numbers are acceptable for energy accounting.

Consumption of the optical system, operating both in transmission and in reflection modes, ranges from 10 to 50 mA [3-5] in the continuous wave mode. This consumption is too high, which leads to the necessity to use the pulse regime of the system operation. In this case, the pulse duration is limited both by parasitical system capacity and by the signal frequency of recombination of carriers in the optical receiver. As it was shown below, the acquisition signal of frequency depends on both the parasitical system capacity and the direction pattern of the system, and also on the current of the LED and the optical transistor. Thus, the main purpose of the metering device's work is to reduce its own energy consumption.

The aim of the research is the choose the optimal pair of transmitter / receiver that will provide the lowest total power consumption, to study ways to reduce the energy consumption for the selected optimal pair. It is also necessary to consider possible methods of reducing power consumption in the final device.

MAIN PART

For the experiments, the test setup shown in Pic. 1 was used. The debugging layout consists of the ODI.DevKit baseplate, the visual appearance of which is presented on (Pic. 2), as well as the ODI.LedKit circuit board set (Pic. 3). The circuit board is intended for soldering LEDs, infrared diodes, photodiodes and phototransistors in various enclosures.

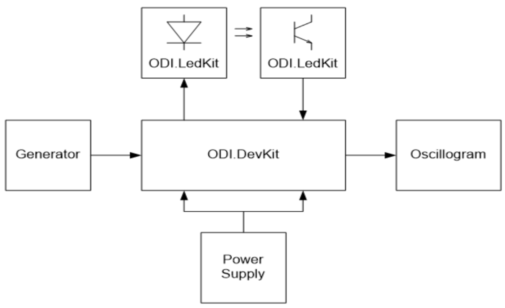

Figure 1 - Connection diagram of the test setup.

The enclosing package has CMOS keys for switching LEDs and IR diodes, as well as for generating output logic levels of photodiodes and phototransistors. On each of the circuit boards is mounted one of the sets of LEDs and IR diodes, photodiodes or phototransistors, optical pair may be generated from the resulting set for determining their mutual characteristics (minimum LED current, which provides the required parameters phototransistor switch).

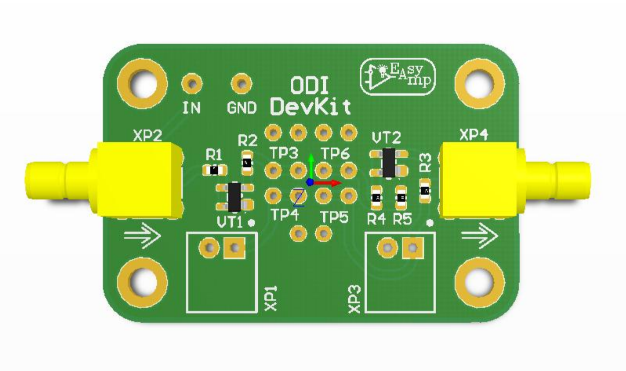

Figure 2 - Visual appearance of the debugging layout

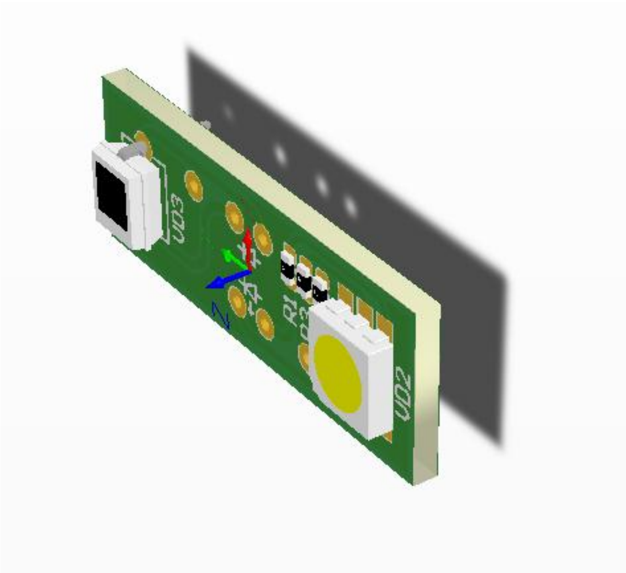

Figure 3- circuit board set of the debugging layout

The following components were considered as emitter/receiver pairs:

Emitter: KP-3216F3 [3]; Receiver: TEMT1000[6]; Emitter : KM2520SF4C03[4]; Receiver : TEMT1000[6]; Emitter: SFH4200[5]; Receiver: KP3216P3C[7]; Emitter: SFH4200[5]; Receiver: BPW17N[8].

Based on the analysis of technical documentation, it can be concluded that the optimal radiators will be KM2520SF4C03 or GL100MN1MP [9].

Let's look at Fig. 4 and Fig. 5, which show the diagrams given in the technical documentation of the product [4, 9].

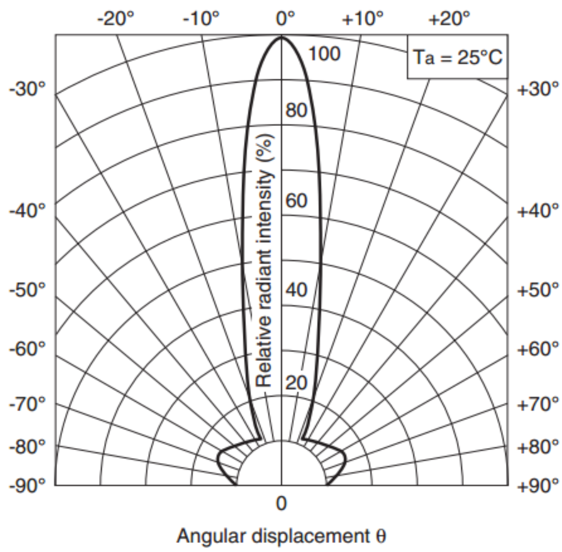

Figure 4 – Radiation Diagram GL100MN1MP

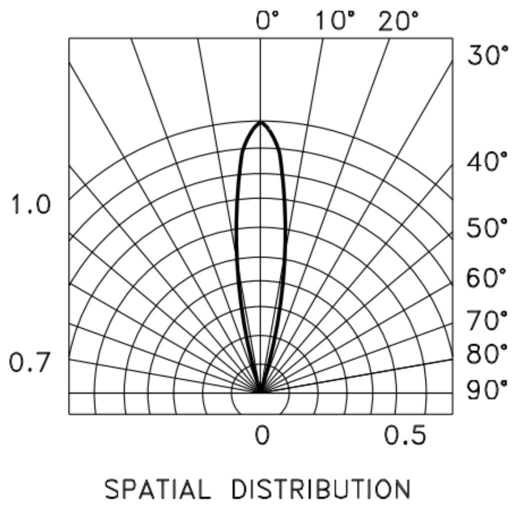

Figure 5 – Radiation Diagram KM2520SF4C03

As can be seen from the figures, the width of the directional characteristic is about 8 degrees at the level of 0.7, which ensures a high flow capacity in the photodetector direction. This suggests that achieving the desired luminous flux requires fewer LED current and the direct current flowing through the collector-emitter circuit of the phototransistor, as well as in a narrow radiation pattern will not stray light in adjacent receivers. The optimal emitters according to the theory will be BPW17N or TEMT1000. Firstly, this is due to the fact that these emitters have a short response time (fig.. 6 emitter TEMT1000 [6]), which allows the photodetector to respond more promptly to the impulse from the emitter, thereby creating the potential to reduce the pulse duration through the LED and, accordingly, the average current consumption.

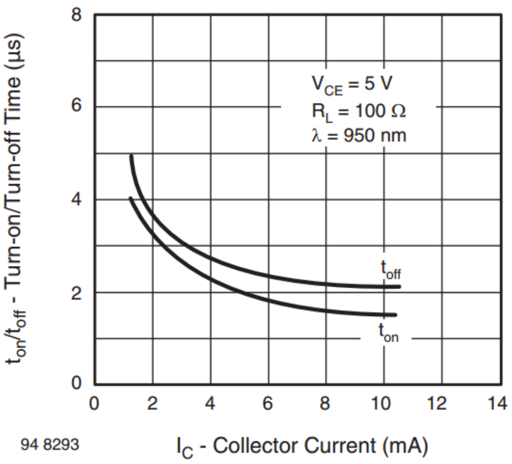

Figure 6 – Response time of the TEMT1000 photodetector from the collector current

In addition to the short response time, this pair of photodetectors, according to the technical documentation, has a narrow directional pattern, which avoids parasitic stray lighting.

Let us consider the experimental results with the given above emitter / receiver pairs. The experimental conditions were the following: pulse duration fed to the LED: 10 µs, 50 µs, 100 µs; pulse repetition period 10 ms. The results of the experiment are provided in Tables 1 to 4.

Table 1. Emitter: KP-3216F3C; Receiver: TEMT1000

τ_u, µs	$I_{mean\ diode}$, µA (pulse duratio= 10 ms)	$I_{mean\ transistor}$, µA (pulse duration = 10 ms)
10	23,6842	5,1
50	23,9362	11,0
100	46,3918	22,0

Table 2. Emitter: KM2520SF4C03; Receiver: TEMT1000

τ_u, µs	$I_{mean\ diode}$, µA (pulse duration = 10 ms)	$I_{mean\ transistor}$, µA (pulse duration = 10 ms)
10	2,9032	4,4
50	10,0000	11,0
100	20,0000	22,0

Table 3. Emitter: SFH4200; Receiver: KP3216P3C

τ_u, µs	$I_{mean\ diode}$, µA (pulse duration = 10 ms)	$I_{mean\ transistor}$, µA (pulse duration = 10 ms)
10	6,9231	6,5
50	11,3924	11,0
100	22,5000	22,0

Table 4. Emitter : SFH4200; receiver: BPW17N

τ_u, µs	$I_{mean\ diode}$, µA (pulse duration = 10 ms)	$I_{mean\ transistor}$, µA (pulse duration = 10 ms)
10	4,5	5,6
50	13,8462	11,0
100	27,6923	22,0

Based on the results, it appears that the most suitable emitter in terms of power consumption is the KM2520SF4C03 (or similar in characteristics of the emitter GL100MN1MPx). This component provides a satisfactory signal level at the output of the photodetector at a lower current, in comparison with other emitters. In addition, as described above, it has a narrow radiation pattern, which allows the entire luminous flux to be concentrated in a narrow beam and don't stray light in adjacent receivers.

Experiments with the optical pair GL100MN1MPx and TEMT1000 gave similar results in pulse shape and consumption, as the pair KM2520SF4C03 / TEMT1000.

The photodetectors have approximately the same power consumption, since it is determined mainly by a resistor in the phototransistor emitter circuit. The most suitable are BPW17N, TEMT1000, because they have a narrow radiation pattern in comparison with other phototransistors. In contrast, the TEMT1000 surpass the BPW17N since it has a faster response time.

Let us consider a possible way of reducing the power consumption of the selected optimum pair of emitter / receiver. The first thing that causes an increase in power consumption is the protracted trailing edge of the rectangular pulse observed on the resistor in the emitter circuit of the photodetector Fig. 7

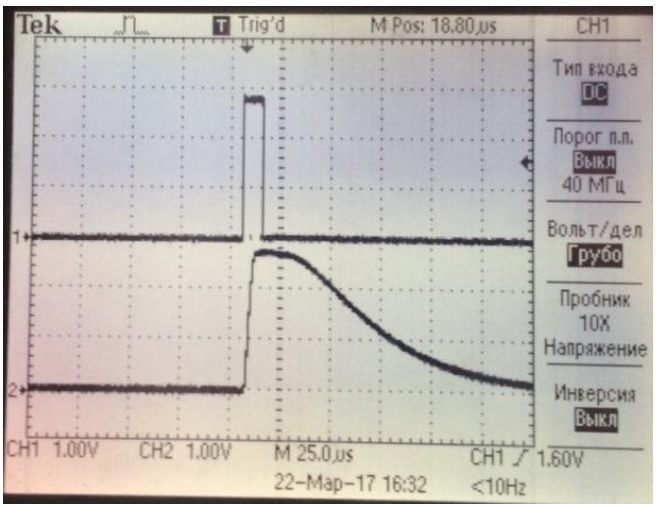

Figure 7. Protracted trailing edge of the pulse at the output of the phototransistor.

In this situation, the power consumption of the optical pair can be reduced by controlling the power of the phototransistor. This

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scheme can be implemented on FETs, or, in order to reduce the number of components, it is possible to use MC outputs, since they provide sufficient current for the optical pair. Thus, the duration of the trailing edge can be "cut off" by turning off the power of the phototransistor in Fig. 8.

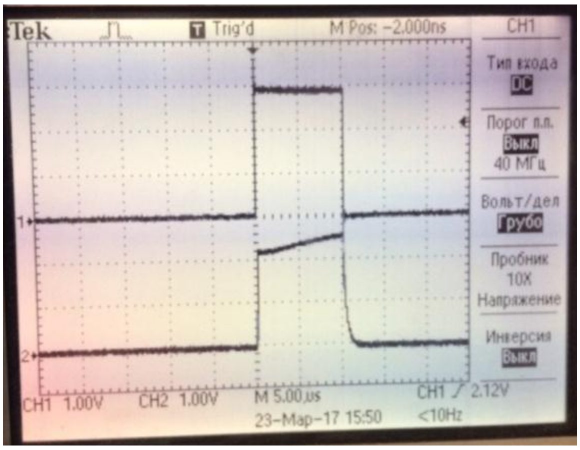


Figure 8. Signal on the emitter and the output of the receiver while controlling the power of the phototransistor.

Experiments have revealed problems associated with the emerging transient process at the time the power was applied to the phototransistor. Fig. 8 shows a pulse on the LED and at the output of the receiver that demonstrates that it is possible to reduce the duration of the trailing edge of the pulse [16, 17]. However, when the power is turned on, there is a transient process, shown in Pic. 9. The following parasitic pulse occurs when the supply voltage is applied to the phototransistor in the absence of stray light from the LED.

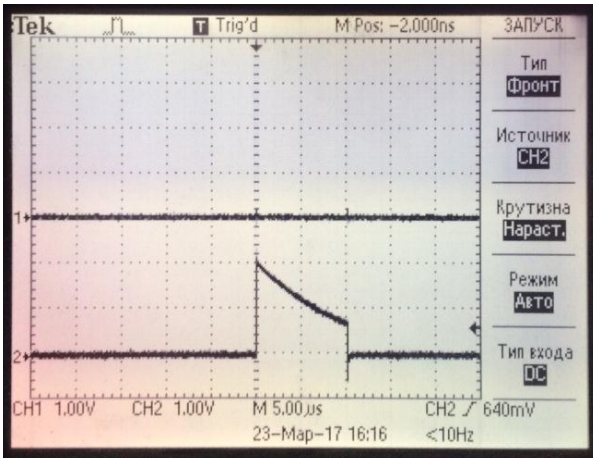
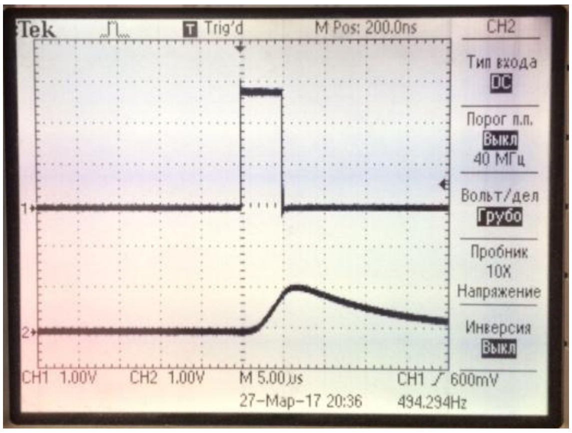


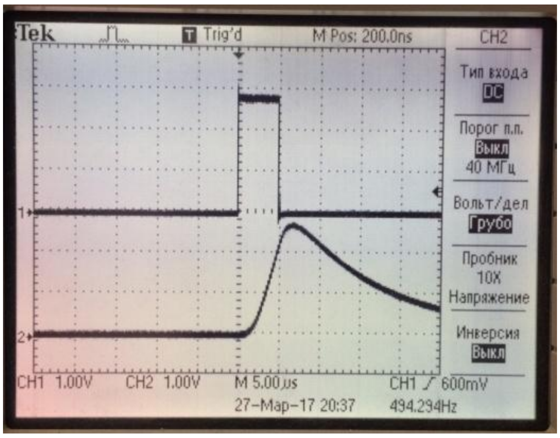
Figure 9. The signal at the output of the phototransistor when the power is switched (there is no emitter signal)

This fact can be explained by the transient process arising in the RC differentiating chain, which is formed by the parasitic capacitance of the p-n junctions and the resistor in the emitter circuit. As a result, this approach is inapplicable for practical use.

The introduction of an amplifier makes it possible to improve the response of a phototransistor and shorten the duration of the probe pulse, thus allowing the use of higher resistors in the circuit of the emitter and receiver [11,12,13]. Figure 10 demonstrates the results of the tests with the duration of the pulse as long as 5 µs. Major fault of the system is dramatic increase in energy consumption by the amplifiers respective to the bandwidth extension and high consumption of about 47 µA, which totally eliminates the advantage.



a)



b)

Figure 10. The response of a phototransistor with a pulse duration of 5 µs
a) Prior to the amplifier b) after amplification

The stuation can be improved by using the comparators with low power consumption of about 0.5 - 10 µA, with a configurable threshold or a fixed one. This allows fixing a pulse of small amplitude, such as is shown in Fig. 10a. In addition, it is possible to use the comparators that are part of microcontrollers, which simplifies the recording of pulses and does not lead to a significant increase in the energy consumption of the device as a whole.

When using two optic pairs the metering device (the first pair participating in the measuring process, the second one being needed to detect the presence of a countercurrent), the target shown in Figure 11 is applied.

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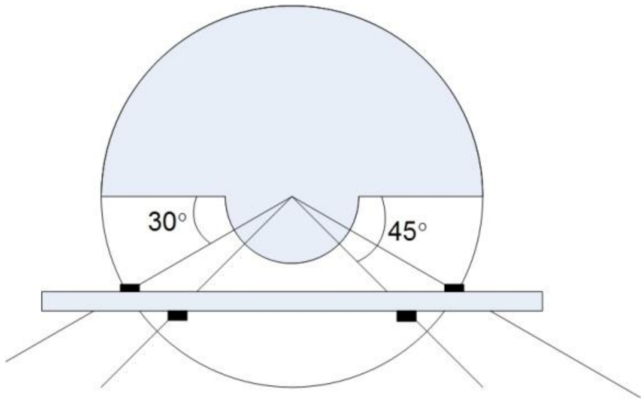

Figure 11. The target appearance of the water meter measuring part

A distinguishing characteristic of the counting mechanism of the water meter is a wide range of revolutions, within which the correct measurements should be ensured. As is required the water flow shall be measured from 0.03 to 3 m ^ 3 / h, with the impeller revolutions being accordingly equal to: 0.36 - 36 r / s. For the target type in use the optical pairs should work under the pulsed mode with a period of 5-6 ms (which is due to the geometric dimensions of the target). When measuring the consumption by the ultimate device, the ratio of the system active time and hibernation totalled to 5 microseconds and 6000 microseconds respectively. The consumption graph is presented in Figure 12.

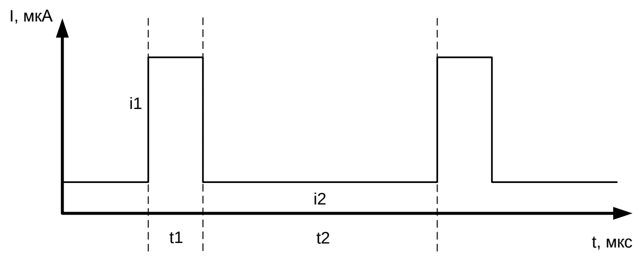

Figure 12. Water meter consumption graph

The average consumption is calculated by the formula:

$$Paverage = \frac{i1*t1+i2*t2}{t1+t2}, \quad (1)$$

Where i1 – is the consumption in the active mode, i2 – is the consumption under the "hibernation" mode, t1 – is the consumption time under the active mode, t2 – is the consumption time under the "hibernation" mode. In this case having 8 μA under the minimum device consumtion and 10 μA under the maximum one, the average consumption shall result in 13,33 μA.

Estimated energy consumption for the device entire lifetime on a single power supply unit reaches 23 μA, which means that ultimate consumption shall not exceed this value. Currently we face the following: the metrological system takes up over 50% of the permitted current without taking into consideration the indication device and the performance of the kernel.

This may be improved by introducing the dynamic operation of the water meter measuring part. This is what it appears to be: in case we determine the impeller idle time , we believe the tap is closed, which means there is no point in the optical part running on the highest report rate, thus we may reduce the rate by a factor of 10 times, so as not to miss the impeller's breakaway torque. If a revolution is noticed the report rate is increased back to maximum. With this approach the billing metering becomes more sophisticated, requiring statistical data on water meters' idle time and active time (namely, water consimption metering).

According to the regulations per capita consumption is 6 m^3per month, which, if divided by 30 days, will get us 0.2 m^3per day. Supposing that the user consumes the entire volume of water for one tap opening, and he does not fully open the tap, and until the nominal water flow is 1.5 m^3 / h, we get 7.8 min, or 468 s. Now let us calculate the average current consumption when the meter is idle by the formula 1. We get the average consumption at 8.83 μA, now we can calculate the average current consumption by the meter, considering that the nominal flow lasts 468 s per day. We also carry out the calculation using expression 1, however we now take the consumption pulses daily periodicity. We get - 8.85 μA, average consumption by the counter for a day.

Thus we manged to reduce the power consumption by the meter's metrological part to 38 % of the total authorized meter consumption. This is achieved by introducing two types of metrological part report rates. It is obvious, that if intermediary reports are introduced (such as minimum, nominal and maximum consumption) , the power consumption could be reduced even further. However, it can hardly go below 8 μA. Moreover, introducing additional reports would result in controller computational expenses, thus increasing the average consumption.

CONCLUSION

The major means of energy consumption reduction in the optical system that were taken into consideration included choosing emitters and receivers, reducing pulse duration, controlling power supply of the phototransistors and using amplifiers and comparators. Among the options above, using comparators is preferable not only due to energy efficiency, but also to the costs of the low-consume operational amplifiers with the required bandwidth. Moreover, the energy consumption of the emitters can also be further reduced. For this purpose they can be connected consecutively, with a single signal source being used for a pair of emitters. It was possible to achieve an average consumption of a metering system of 14 μA.

When assessing the performance of the metering system in the ultimate device the power consumption value of 13.33 μA was achieved. However, in order to decrease the average power consumption by the metering system the dynamic report method was used and resulted in the consumption reduction to 8.85 μA.

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