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Hybrid Fiber Optic Temperature Sensor Powered by Optical Radiation

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ABSTRACT

The possibility of creating a hybrid fiber-optic sensor design, in particular, a temperature sensor for use in high-voltage systems, for the purpose of galvanic isolation of information and power circuits, is considered. Structural schemes of fiber-optic temperature sensor based on photovoltaic converters made on LEDs are proposed. The use of sensor data in a wide temperature range is analyzed and the possible influence of pulse noise caused by corona discharges on the thermometer readings is checked.

Key words: optical radiation, electric power, led, photovoltaic Converter, step-up voltage converters, temperature sensor.

1. INTRODUCTION

A power industry often faces a challenge of monitoring temperature and other parameters of components and devices under high voltage. Use of a hybrid fiber optic temperature sensor is one of possible and low-cost solution for this task [1]. The sensor comprises of a measuring electronic module connected with a duplex fiber cable to a main electronic unit. One fiber of the duplex fiber cable transmits optical power to the measuring module, which uses a photovoltaic transducer (PVT) to convert it into electrical power to supply a sensor electronic circuitry. The measuring module also contains an optical transmitter which transmits a data signal to the main module processing and indicating the measured data.

There are two major problems to be solved to build such systems. They are: to ensure effective conversion of the optical radiation into the electric power and as low energy consumption of the measuring module as possible.

2. METHODS

First of these problems can be solved using photovoltaic transducers manufactured by a number of companies. YCH-L200-300 transducers (MH GoPower, Taiwan) [2] are manufactured based on silicon and designed for operation with radiation within the range of 915 nm to 980 nm. They provide electrical power up to 300 mW without heat spreading and have conversion efficiency 22% to 25%. AFBR-POCxxxL transducers (Broadcom, USA) [3] have efficacy of 40% to 50% and electric power up to 600 mW at 808 nm wavelength of incident radiation. KPC8-T transducers (Kyosemi, Japan) [4] operate with 1300 nm to 1600 nm radiation and have conversion efficiency 30% to 35%. They are pigtailed with a single-mode fiber and provide electric power up to 60 mW at 3 V input voltage.

A major drawback of the above converters is high cost of up to 500$ to 600$. In the most cases this makes building of the hybrid system cost-inefficient.

Below we show simple and cheap methods using generally available components to solve the problem of electronics power supply from optical radiation source.

3. RESULTS

The measuring module power consumption is mainly reduced by using micropower electronic components and selecting optimal method of measurement data coding for transmission via optical channel.

Let's skip detailed consideration of microelectronic sensors, which can be used in the hybrid measurement system, and focus on temperature sensors, particularly having digital and frequency outputs as the most suitable for transmission of the sensor output signal via the fiber. Most of the leading electronic component manufacturers produce digital temperature sensors. However, the sensors are generally designed for operation with microprocessors and have I2C and SPI format of the output signal, which are not satisfactory for remote sensor location and require an external clock pulse generator making a measuring module structure more complicated.

Temperature sensors having PWM output signal are the most suitable for the hybrid measuring systems. Such sensors are manufactured by a number of companies: Analog device (TMP05-06), Smartec (SMT172), Maxim (MAX6673 and etc.). These sensors transmit the measured temperature data by output pulse duration (or relative pulse duration). Figure 1 presents an example of a measuring module build for the temperature sensor. The figure also shows a form of the signal at check points.

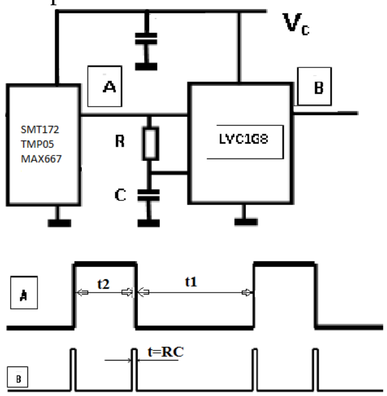

Figure 1: Example of a temperature sensor build version

It is preferable to use SMT172 microcircuit having low current consumption (mean current consumption makes 0.22 µA at one measurement per second), low voltage of power supply (starting from 2.7 V), the highest accuracy of measurement (1 deg. or higher) and wide range of measured temperatures (from -55°C to 130°C). Such parameters are suitable for almost all kinds of applications in power industry even for operation of the equipment in the Arctic.

For measured time intervals t1 and t2, the temperature is calculating using the formula T = -1.43 DC2 +214.56 DC - 68.6, where DC=t2/(t1+t2).

Mean electric power consumed by the measuring module does not exceed 0.3 mW at pulse current 30 mA to 40 mA (τ≈ 100 ns) via the optical transmitter (e. G. HFBR1414) connected to point B (Figure 4).

The measuring module power supply is provided by using AlGaAs-based LEDs with 850 nm to 870 nm emission wavelength as the photovoltaic transducers. As demonstrated in [5], the LEDs (e. G. AL118) have perfect photovoltaic characteristics to become a base for converters with 1.23 V to 1.25 V output and photovoltaic conversion efficiency of up to 50% at 808 nm radiation of up to 50 mW.

See [6] for a procedure of AL118 LED transformation into the photovoltaic transducer having fiber input. Further increase of voltage up to 3.3 V to supply the measuring module microcircuit is provided by standard use of an inductor-based boost converter manufactured by many companies, e. g. MAX1724, LTC3105, TPS61222 and others. It should be taken into consideration that current consumption of the inductor-based converter is significant at operation start, therefore the optical power to PVT at the start shall be 1.5 to 2 times higher as compared to the operation.

Since PVT in the device in question shall operation in the whole range of measured temperatures, temperature-dependent characteristics of PVT were measured within the range of -60°C÷+60°C.

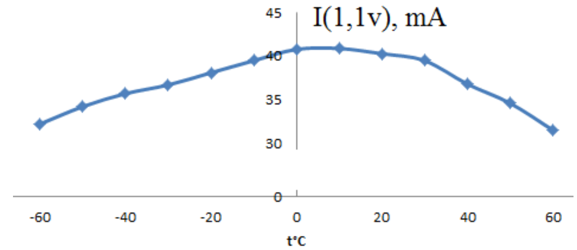

Figure 2: PVT output current dependence on temperature at output voltage of 1.1 V

Figure 2 presents dependency of PVT current on temperature at output 1.1 V (under load) and optical power of 120 mW. The above dependency shows that the electrical power transmitted by PVT to the load at operating voltage of 1.1 V slightly varies within the temperature range of -20°C÷+40° C and decreases by 20% at temperatures of -60°C and +60°C. Measurement on 20 samples of PVT showed that the decrease in the conversion efficacy is especially critical at high temperature. This is related both to reduction in open-circuit voltage down to 1.21 V to 1.22 V (1.35 V to 1.36 V at -60° C) and to reduction in short circuit current.

Taking into consideration the small power consumption of the measuring module, the proposed PVT ensures power supply to the aforesaid temperature sensor at source optical power up to 100 mW, the PVT can be used with various types of 808 nm lasers manufactured in the industry, e. g. WSLP-808-150m-M-PD laser. HFBR-1414TZ module is used to transmit optical pulses, and AFBR-2418TZ is used to receive them, which ensures reliable data transmission via a fiber line up to 2 km length.

SFH4235 or SFH4250 LEDs are other option of PVT for the temperature sensor. These LEDs feature a semiconductor structure with two successive p-n transitions resulting in 2.5 V to 2.6 V generated in photovoltaic mode, and this allows using them for the measuring module power supply even without the boost converters. A spectral photoresponse characteristics of these structures is given in Figure 3.

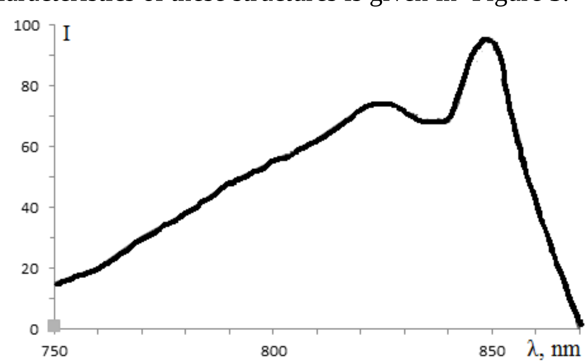

Figure 3: Spectral dependence of SFH4250 LED photoresponse

At room temperature and 808 nm optic power of 30 mW, voltage at a structure output made 2.56 V to 2.58 V and short circuit current made 4.5 mA to 5 mA. Such characteristics ensure photovoltaic conversion efficiency of 30% to 35% at 808 nm wavelength. At 850 nm wavelength correspondent to maximum response of the structure, the efficacy increases up to 45% to 50%.

SFH4250 LED-powered temperature sensor was built using TS555MD timer and 135-104LAF-J01 thermistor in a time-setting circuit. A diagram of this temperature sensor version is given in Figure 4.

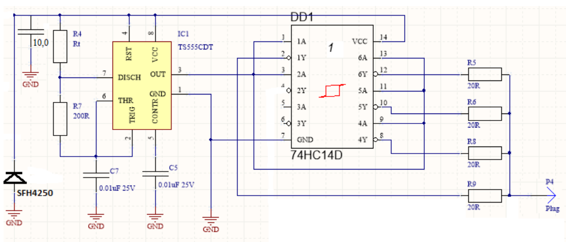

Figure 4: Diagram of a thermometer based on TS555MD timer.

Implementation of this thermometer diagram showed that the mean current consumption does not exceed 150 µA. Provided for the circuit power supply from SFH4250 LED, this ensures reliable operation of the thermometer at optical power of 5 mV to 10 mV and power supply laser wavelength 808 nm.

Figure 5 presents dependency of output pulse frequency on temperature within the range of -60°C÷+60°C for the thermometer build using the diagram of Figure 4. This dependency can be approximated with good accuracy by the formula: T= 20.11ln(F)-130.03

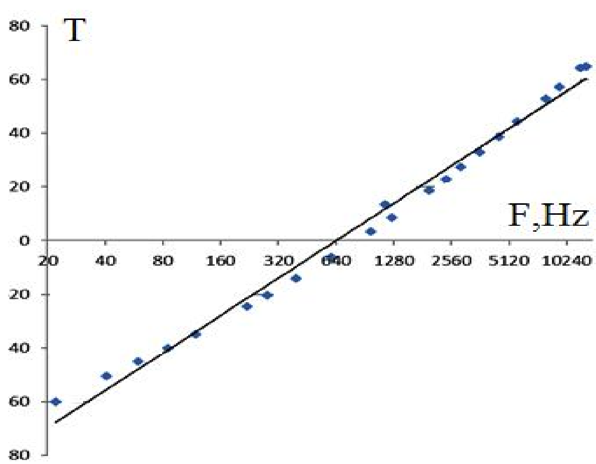

Figure 5: Calibration curve of the temperature sensor.

Possible effects of pulse noise on thermometer readings due to corona discharge were checked in the process of measurement. No effects of pulse noise on the thermometer readings were noted at changes of voltage at a thermometer body from 10 kV to 80 kV initiated by the corona discharge.

5. CONCLUSION

This work demonstrates that simple LED-based photovoltaic transducers can be used to build practicable structures of hybrid fiber optic temperature sensors, particularly those for application in high-voltage systems.

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