Passive Optical Sensor Network with Energy Harvesting

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Abstract - **We have considered an optical communication system for data transfer from sensor node powered by an energy harvesting system. The advantages of this data transfer method, compared to RF modules, are the greater distance of transferred data and the resistance to electromagnetic interference.**

Keywords – **Passive optical sensor network, energy harvesting, sensor node.**

I. INTRODUCTION

In the principles of energy harvesting systems, as a means of communication are accepted for use RF modules characterized by low consumption, which is a primary and basic requirement for the design of these sensor systems. The use of RF modules for communication in the conditions of strong electromagnetic fields or radiowaves, proves to be a tall order, having in mind the interference as a basic phenomenon in such environments. When the disturbances are greater, communication errors occur. This necessitates the use of a greater transmit power, respectively a higher consumption, which contradicts the basic principle of energy harvesting: maximum energy economy and effectiveness [1].

II. ENERGY HARVESTING FOR SENSOR NODES

The sensor node is the basic energy consumer in the energy harvesting process. The power consumed varies from tens of milliwatts to ones of microwatts, depending on the working mode. When the supply is provided by the environment, the converter of energy, for example photovoltaic, transforms the solar energy into electric with a certain effectiveness. For the normal functioning of a system in the energy harvesting process, it is necessary for the power gained from the environment to be greater than the average consumed power of the sensor node. The energy is stored in a rechargeable battery or a supercondenser, and the inconsistency of the energy derived from the environment needs to be taken into account. The use of a DC/DC convertor makes it possible for the photovoltaic to work at a maximum power point (MPP) and thus to increase the gained energy [2]. We have used switching DC/DC convertors with hysteresis control of the output voltage in order to achieve low consumption of the convertor with high effectiveness.

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III. PASSIVE OPTICAL SENSOR NETWORK (POSN)

The building of sensor networks allows flexible solutions for monitoring, control and management of different parameters of physical environments. The value which are observed, are: temperature, humidity, lighting, pressure, vibrations, noise level, etc. The presence of powerful electromagnetic interference strongly restricts the possibility of normal RF communication. As a solution to this problem is suggested the building of a passive optical sensor network which consists of: base station, optical fibers, splitters and smart sensors.

A. Fiber-optic communication for sensor node

A block scheme of an optical communication system with optical fiber, suitable for sensor nodes with energy harvesting is shown in fig.1. It consists of a transmitter and a receiver. In order for communication to take place along a fiber, a passive optical splitter 1x2 is used. At the two ends, the receiver and the transmitter are plugged, and at the input of the splitter is the optical fiber along which the information is transmitted to the base station.

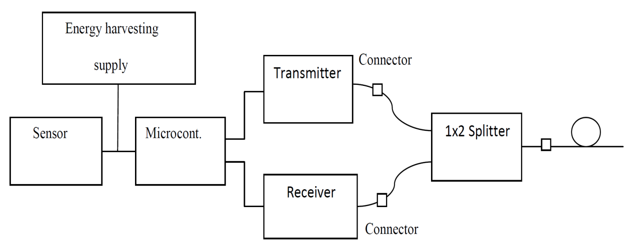

Fig.1 Sensor node

B. Transmitter

In order to transmit the optical signal, is used a highly effective infrared laser OPV314YAT, with wavelength 850 nm and an in-built photodiode for precise control of the optical power. The high speed of data transmission (2,5 Gbps), the great optical power 600μW (-2,2 dBm) and the low consumption 7 mA at a working voltage of 1,6 V to 2,2V makes it perfect for application in the energy harvesting systems. In order to manage the impulse mode and control of the output optical power of the laser, is used a driver of the type iC-NZN. In fig. 2 is given the model scheme of the optical transmitter. The Driver iC-NZN is designed to maintain the control of the optical power of all laser configurations (N, P or M).

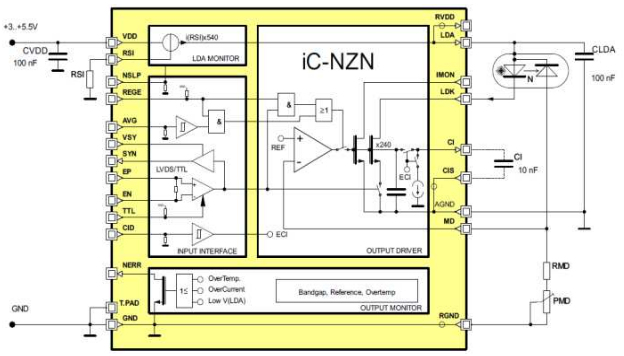

Fig. 2 Transmitter

The optical power level of the laser is chosen with the aid of the resistor R_{MON}=R_{MD}+P_{MD}. In order to calculate R_{MON}, one should know the value of the monitor electricity IM of the laser diode. It is actually the reverse current through the photodiode of the laser and depends on the optical power. R_{MON} needs to be chosen in a way that the monitor electricity generated by the desired optical power, creates a lowering of voltage of 500 mV along the whole length of R_{MON}. The monitor electricity I_M of the laser OPV314YAT is 30µA.

$$R_{MON} = \frac{V_{MP}}{I_{MP}} = \frac{0.5}{0.03} = 16k\Omega \quad (1)$$

A higher standard value can be chosen. iC-NZN also controls the average laser electricity running from the output of LDA. The restriction of the electricity through the laser is set through the resistor of pin R_{SI}. Sizing of the resistor R_{SI} :

$$I_{\max(LDA)} = 540.\frac{0.5}{R_{SI}} \quad (2)$$

$$R_{SI} = 540.\frac{0.5}{I_{\max(LDA)}} = \frac{270}{0.007} = 38.57k\Omega \quad (3)$$

The lower standard value is chosen.When it is in working mode, iC-NZN is characterized by lower consumption (10÷15 mA), sleep mode - 5µA, with supply voltage 3÷5 V.

C. Receiver

The receiver HFBR-2412TCZ in fig.3 includes a photodetector, DC amplifier and Schottky output transistor. The receiver is designed to work with supply voltage of 3÷5 V

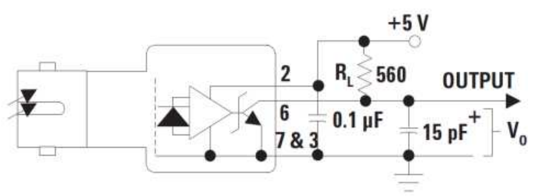

fig. 3 Receiver

and maximum electricity up to 10 mA. The input optical power varies from 0,1µW (-40 dBm) at a high level and 120 µW (-9,2 dBm) at a low level.

D. Base station

The base station is a device controlling the data transmission from different smart sensors in the network, as well as their re-programming. Through a serial interface, the data received from the sensors are transmitted to a computer, where monitoring is done. In fig. 4 is shown a block scheme of the base station.

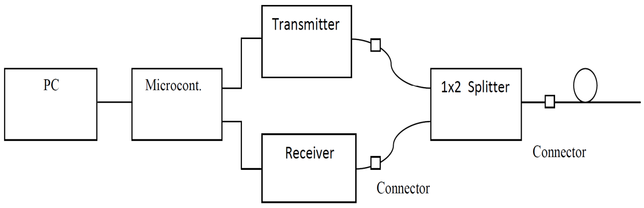

Fig. 4 Base station

The microcontroller of the base station controls and manages the processes in the sensor network. It makes a query to each sensor for data availability and transmits the received data to the computer. Through the microcontroller to the computer can be carried out a distance re-programming of each smart sensor separately. With the aim of a greater compatibility, the communication part of the base station is similar to the one of the intelligent sensor. It consists of an optical receiver HFBR-2412TCZ, and the transmitter is an infrared laser OPV314YAT, controlled by the driver iC-NZN.

F. Working principle of passive optical sensor network

The base station is connected, through a multi-mode optical fiber 62,5µm, to the input of the passive optical splitter [3]. On the other side, the 32 outputs of the splitter are connected to 32 sensors – one at each sensor is an autonomous product, independent on the other sensors and most of the time it is in sleep mode. When the measured value changes, the sensor is activated, it records the respective change in the memory and switches to economical (sleep) mode again. Each sensor has its own address to which it responds. The base station queries for data availability to the first sensor with address S1, the optical signal is received by all sensors, but only the one to which the query was sent, responds, in this case, S1. When there are data in the memory, the sensor sends them and switches to sleep mode again. The query continues to the next sensor with address S2, the sensor is activated and if there are no data in the memory, it responds “NO”. If a sensor does not respond to the query sent to its address, the base station alarms for the absence of this sensor. The queries continue until the last address, in this case S32. After that, this query cycle finishes.

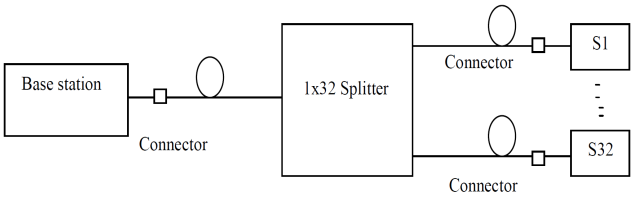

Fig. 4 Passive optical sensor network

A new query cycle begins in a certain time, which is defined during the design of the sensor network, depending on the change frequency of the measured value. The number of sensors in the network depends on the number of outputs in the optical splitter. Except for splitters with 32 outputs, such with 8, 16 and 64 outputs are also produced.

G. Design of passive optical sensor network (POSN)

When designing a passive optical sensor network (POSN) [4] one needs to calculate the total energy losses as a sum of the losses in all network components:

$$B = n_{connector} B_{connector} + n_{splice} B_{splice} + (z_1 + z_2) b_f + B_{32splitter} + 2B_{2splitter} + B_{re} \quad (4)$$

where: $n_{connector}$= 4 is the number of connectors from the sensor to the base station, $B_{connector}$ = 0,5dB are the losses in the connectors, n_{splice} = 5 – number of splies in the optical fiber, B_{splice}= 0,1 dB are the losses in the splices of the optical fiber, bf = 2,3 dB are the losses through a multi-mode 62,5μm optical fiber when the light wavelength is 850 nm [5]. The total length of the optical fiber in the system is z=(z1+z2), where z_1 is the length of the optical fiber from the base station to the 1x32 optical splitter, and z_2 is the length from the splitter to the respective sensor. The losses in the optical splitters are $B_{Nspliter}$ and they are calculated by the formula:

$$B_{Nsplitter} = IL + 10 \lg N \quad (5)$$

where - N is the number of outputs from the splitter, Insertion Loss are given by the manufacturer IL= 3[dB]. B32spliter= 18 [dB] – the losses in the 1x32 optical splitter, B2spliter= 6 are the losses in the 1x2 splitters (one in the base station and one in the communication system of the sensor). Bres is provided in case of additional losses (unexpected bends, pollution of the connectors, extra splices, etc.). The energy design amounts to the verification of the condition:

$$B \le P_{owerBudget} \quad (6)$$

$$P_{owerBudget} = P_{TX} - P_{RX\,\min} \quad (7)$$

On the basis of the calculations above, we can calculate the maximum length of the optical fiber with the given parameters:

$$z = (z_1 + z_2) = \frac{B - n_{connector} B_{connector} + n_{splice} B_{splice}}{b_f} + \frac{B_{32\,splitter} + 2B_{2\,splitter} + B_{res}}{b_f} \quad (8)$$

During the design of POSN with the devices described above: PTX = -2,2 dBm, PRXmin= -40 dBm, for the energy budget from expression (7) is derived PowerBudget = 37,8 dB. When this is substituted in condition (6), the total losses should be B ≤ 37,8 dB. If we accept B= 37,8 [dB], it means that the energy use is at the upper limit for data transfer and each loss increase means interruption of the communication along the optical fiber. When the results in expression (8) are substituted, the maximum admissible length of the optical fiber zmax=1 km is derived. For stable communication, we need to choose an optical fiber with a length smaller than zmax, for example up to 950m, which is a distance 8 times greater than the RF module. When the fiber length is 950m from expression (4) for the total losses we derive B=37,7dB, which means that condition (6) is fulfilled. The low power consumption of the proposed optical communication systems meet the basic criteria for energy harvesting. The total consumption in data transmission is 22mA, 10mA in receive mode, while in sleep mode is 5μA at a supply voltage of 3÷5V. A comparison of the power consumption of the examined optical communication system and a RF module MRF24J40MA, both in transmitting and receiving mode is given in the following table.

TABLE I
Comparison of consumption

	Optical communication system		RF module MRF24J40MA	
	TX	RX	TX	RX
I_{CC} (mA)	22	10	23	19
V_{CC} (V)	3÷5	3÷5	2.4÷3.6	2.4÷3.6

H. Network protocol

The block algorithm of Network protocol, by which the communication in POSN is carried out [6], is given in fig. 6.

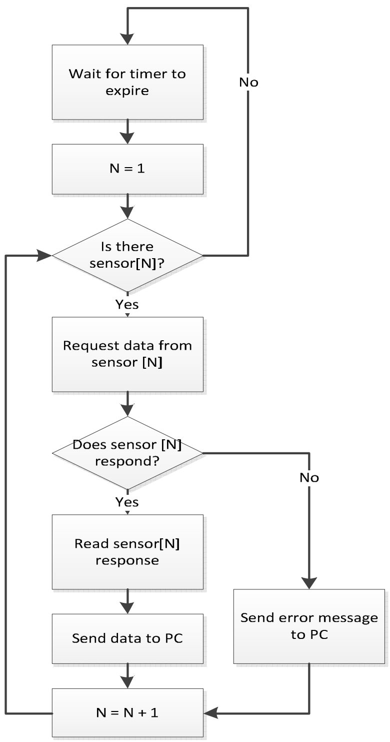

Fig. 6. Working principle of the base station

I. Working principle of sensor

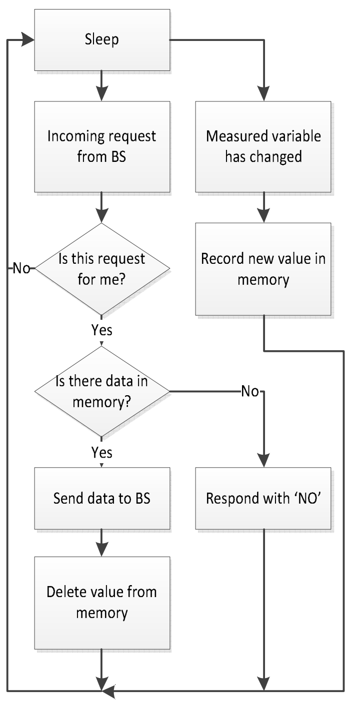

Fig. 7. Working principle of each sensor

Most of the time, the sensor nodes are in economical sleep mode. When the physical phenomenon changes, the sensor wakes up, measures the variable quantity, records the measured data and switches to sleep mode. When there is a call from the base station with its address, it is activated, sends the data (if there are no data from new measurements, it responds NO) and goes back to sleep mode. The block algorithm of the working principle of each sensor is given in fig. 7.

IV. Conclusion

The low consumption of electric energy is the main parameter on which is focused the design of the suggested energy harvesting sensor system. An order is proposed for the design and calculation of the maximum fiber length, considering the energy budget with guaranteed reliability of communication in conditions of strong electromagnetic interference. Except in conditions of strong electromagnetic interference, the optical communication system can replace the RF module, when required a greater distance between the sensor node and the base station. We have developed algorithms for managing the network and sensor activity.

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References

[1] Zahariev P., Hristov G., Tsvetkova I.,. An Approach towards Balanced Energy Consumption in Hierarchical Cluster-based Wireless Sensor Networks.// Journal of Computing and Information Technology Vol.20, 2012, No 3, pp. 159-165, ISSN 1330-1136.
[2] Oscar López-Lapeña, Maria Teresa Penella, A New MPPT Method for Low-Power Solar Energy Harvesting Student Member, IEEE, and Manel Gasulla, Member, IEEE,Vol. 57, No. 9, September 2010 p.p. 3129-3138
[3] Calvin C. K. Chan, Passive Optical Networks Principles and Practice, The Chinese University of Hong Kong, 2007,
[4] Mitzev C., Dimitrov K., Optical Communications seminar exercises guide, Technical University, Sofia, ISBN:978-954-438-77-8, p.p. 10-27, 2013.
[5] Corning Incorporated, Corning Clear Curve Multimode Optical Fiber Product Information, , p.p.2-4, 2011.
[6] Michael P. McGarry, M. Reisslein, M. Maier, Ethernet Passive Optical Network Architectures and Dynamic Bandwidth Allocation Algorithms, University of Akron Arizona State University, IEEE CS&T, Vol.10, October 2008, p.p. 46-60.