Investigations of DC power supplies with optoelectronic transducers and RF energy converters

B Guzowski¹, R Gozdur, L Bernacki, M Lakomski
Department of Semiconductor and Optoelectronic Devices, Lodz University of Technology, Wolczanska 211/215, 90-924 Lodz, Poland

¹E-mail: bartlomiej.guzowski@p.lodz.pl

Abstract. Fiber Distribution Cabinets (FDC) monitoring systems are increasingly popular. However it is difficult to realize such system in passive FDC, due to lack of source of power supply. In this paper investigation of four different DC power supplies with optoelectronic transducers is described. Two converters: photovoltaic power converter and PIN photodiode can convert the light transmitted through the optical fiber to electric energy. Solar cell and antenna RFwPCB are also tested. Results presented in this paper clearly demonstrate that it is possible to build monitoring system in passive FDC. During the tests maximum obtained output power was 11 mW. However all converters provided enough power to excite 32-bit microcontroller with ARM-cores and digital thermometer.

1. Introduction
Fiber optic technology is used in ever-increasing applications due to its inherent advantages (lower weight, EMI/RFI immunity, higher bandwidths and distances) over copper. Billions of packets of digital data wend their way around the world, through switches, long haul optical fibers, metro rings, and assorted other access topologies. At each node incoming fibers are patched from Fiber Distribution Cabinets (FDC) to equipment and back again. Hundreds of fibers can be installed in cables taking relatively little space. However, terminating these fibers with connectors increases the required space in Optical Distribution Frames (ODF).

Large Data Centers have also a hundreds of thousands of optical fiber cables and connections, and there is a need to track the connectivity of these trunk and jumper cables to assure proper network interconnection among the servers, switches, routers, and storage equipment. Therefore, it is extremely hard to track and maintain the topology of the network with very high accuracy given the large number of manually changeable interconnection points in the network.

Ultra – low power monitoring systems are one of solutions that can improve the efficiency and accuracy of maintaining the network connectivity. Hence these systems can be supply by optoelectronic transducers, it is possible to integrate monitoring system with passive FDC.

In this paper detailed analysis of four different DC power supplies with optoelectronic and RF transducers is described. The most suitable option is to convert light transmitted through the optical fiber to electric power. It is stable power source and it can be used regardless of weather or environment in which the FDC is placed. For that reason the photovoltaic power converter PPC – 6E by JDSU [1] and a silicon PIN photodiode BPW24R from Vishay are tested. PPC – 6E is designed to convert 790 – 850 nm light into electrical power up to 6 V, with output power up to 500 mW. Assuming temporary or permanent illumination in Data Centers or server rooms it is possible to convert the light using solar
cells. Therefore popular polycrystalline silicon solar cells are also tested. Due to the fact, that more and more devices broadcast the RF energy the ability to harvest RF energy, from ambient or dedicated sources is more likely. Hence, the last type of investigated converters was a directional antenna RF – PCB designed for GSM band 880 – 915 MHz.

2. Electromagnetic radiation energy harvesting devices
Monitoring system requires to operate electrical power. Commercially available ultra – low power microchips or sensor systems need less than 1 mW power [2, 3]. Since majority of FDC are totally passive it is necessary to introduce to cabinets some kind of power supply. Although the non-renewable energy sources, such as batteries can be used, these sources do not provide long life operating or autonomy [4]. A solution that can enable to do this is using energy – harvesting source. Great number of sources of energy and conversion devices could been considered for energy harvesting [5, 6] and in order to compare different approaches, it is useful to consider the criteria for comparison. However implementation of these system in passive FDC results in the power supplies acting on the basis of electromagnetic radiation seem to be the best option. Electromagnetic radiation converters are, either in their form of RF converters or solar cells operating in VIS or IR light. In RF converters high power electromagnetic energy from nearby source is directed to the device and converted to the voltage. However the RF converters are very strongly dependent on environment, architecture of a building and require a transmitter in a close range. In table 1 output voltage of nowadays RF converters are shown.

| Output voltage | Wavelength | Realization |
|----------------|------------|-------------|
| 3.22 V @ 3 kΩ load | 980 MHz | Arrawatia [7] |
| 3.00 V @ 100 kΩ load | 945 MHz | Saraiva [8] |
| 0.68 V @ 50 kΩ load | 1.8 GHz | Arrawatia [9] |
| 2.05 V @ 100 kΩ load | 900 MHz | You [10] |

Solar cell convert the energy of light directly into electricity. This mature technology has wide range of applications. Efficiency of outdoor solar systems depend on e.g. weather conditions or location. In indoor installation where the irradiance is around 3.5 – 20 W/m² [6] output power depends mostly on efficiency of solar cell. Since the efficiency of the best of solar cells is around 25 – 30% [11-13] it is possible to obtain 30 – 50 mW from 1 cm² [14], if the solar irradiation is 1000 W/m². However, due to the fact, that FDC and ODF are often placed in rooms without permanent illumination, or with the artificial illumination usually with low power density using a solar cells seems to be limited. Therefore photovoltaic power converters (PPC) dedicated to converting the light coming out from optical fibers have to be also considered. As mentioned before, those converters can operate in almost all environment conditions and constructions. These millimeter size structures are typically made of GaAs and dedicated to the wavelength range of 790 nm to 850 nm [15]. Illuminating PPC with 400 mW of optical power (50 W/cm²), up to 133 mW electrical power can be harvested [16]. However it must be taken into account that one or more ports in ODF will need to be separated to transfer power from light source.

3. Supply systems configurations
In order to develop a supply system using alternative energy sources, a number of experimental tests on the selected commercially available transducers, and RF/DC and DC/DC converter. Summary of the test transducer which will be used as the energy sources is shown in table 2.
Table 2. Tested converters.

| Type of converter                              | Name                        | Size          |
|------------------------------------------------|-----------------------------|---------------|
| Photovoltaic power converter 790 – 850 nm      | PPC – 6E, from JDSU          | Ø 2.39 mm     |
| Si Photodiode max. @ 900 nm                    | BPW24R, from Vishay          | 0.78 mm²      |
| Polycrystalline Si solar cells                 | AM – 5412CAR, from Panasonic|               |
| Directional antenna RF-PCB on the EGSM band 880 – 915 MHz | H 122°/В 68°, gain          | 175 x 50 mm   |

Figure 1 shows a set of optimized RF/DC and DC/DC converter systems, designed for elements listed in table 3. Using different types of converters results from the fact that each of the tested elements have different input and output parameters e.g. the range of the input/output voltage, output resistance and the limit of continuous output current.

4. Determination the power output of power supply systems
The first stage of the research was to determine maximum power transfer from supply circuits. For this purpose we used an adjustable resistive load and direct current measurement system using Agilent 3458 multimeter. In each of the cases load resistance $R_L$ was regulated in order to determine the best conditions of matching the load to the source. As a result we determined threshold value of load resistance $R_L$ at which we observed 10% drop in the value of output voltage of power supply. In addition we determined time period $t_{on}$ from the moment when we started excite the transducer until the change of logic state of PGOOD each converter. Later in the research we used as a load a real MCU system, in which the microcontroller made periodical temperature measurements in deep sleep mode. In this configuration, the system nominally charged to the power supply current of 1.1 µA.

Methods excitation of tested sensors differ depending on their type. Photovoltaic cell was excited by visible LED light with illuminance of 300 lux. The receiving system equipped with a directional antenna (H 122°/В 68°) at 880 – 915 MHz GSM band was placed at 60 cm distance from the 3 W EGSM transmitter. PPC-6E and Si photodiode were excited by a powerful IR LED array SFH4750 from OSRAM and laser source 850 nm from FIS Deluxe Mini OTDR. Optical power level
was set to 3 W for IR LED and 0.6 mW for laser source. Light coming out from laser source was
distributed to converters through 1 m length multi-mode optical fiber (MMF) OM4 class. Optical fiber
was connected to converters using ST optical fiber connectors.

The distance between the IR LED and Si photodiode and PPC – 6E was always individual set to
obtain three constant and repetitive values of illumination excitation. The results of measurements of
the load current $I_L$ at the threshold value of $R_L$, max. output power of power supply and $t_{on}$ time are
shown in table 3.

**Table 3.** Results of measurements.

| Converter                        | Energy source                                         | $I_L$ [mA] | $P_m$ [mW] | $R_L$ [kΩ] | $t_{on}$ [s] |
|----------------------------------|-------------------------------------------------------|-------------|-------------|------------|--------------|
| Photovoltaic power converter     | 0.6 mW laser source 850nm from FIS Deluxe Mini OTDR   | 0.01        | 0.04        | 380        | 30           |
| Photovoltaic power converter     | 3W SFH4750 from OSRAM                                 | 0.82        | 2.72        | 4.0        | 3           |
| Si Photodiode max.@ 900nm        | 0.6 mW laser source 850nm from FIS Deluxe Mini OTDR   | -           | -           | -          | -           |
| Si Photodiode max.@ 900nm        | 3W SFH4750 from OSRAM                                 | 2.75        | 9.08        | 1.2        | 3           |
| Polycrystalline Si solar cells   | White LED 300 lx                                      | 0.41        | 1.36        | 8.0        | 5           |
| Directional antenna RF – PCB on  | 3W EGSM 900 Transmitter                               | 2.36        | 7.78        | 1.4        | 3           |
| the EGSM band 880 – 915 MHz      | 0.6 m                                                 |             |             |            |              |

![Figure 2](image-url)

**Figure 2.** Influence of matching load $R_L$ on the output power $P_{out}$ of silicon PIN photodiode
BPW24R for different illumination excitation.
Figure 3. Influence of matching load $R_L$ on the output power $P_{OUT}$ of photovoltaic power converter PPC-6E for different illumination excitation.

Figure 4. Influence of matching load $R_L$ on the output power $P_{OUT}$ of photovoltaic power converter PPC-6E and Si photodiode for 850nm fiber source.
DC power supplies based on silicon PIN photodiode BPW24R and photovoltaic power converter PPC – 6E are the most suitable for applications in passive FDC. Therefore, the experimental curves of the matching circuit of the transducers have been presented in figures 2 – 4, respectively. The peak output power of the PIN photodiode is in the range of $R_{\text{LOAD}}$ below 100 $\Omega$ while photovoltaic power converter provides peak power for the loads exceeding 10 k$\Omega$. Influence of illumination on the output power is similar for the PIN photodiode and photovoltaic converter. The ratio of the output power attenuation equals almost 6 for the range of excitation from 3165 lx to 1280 lx.

The measurements (figure 4) confirm considerably higher efficiency of PPC-6E transducer in case of direct excitation through 0.6 mW laser source 850nm from FIS Deluxe Mini OTDR. Available peak power does not exceed 40$\mu$W, however, amount of harvested power enough to supply microcontroller system. The tested Photodiode BPW24R cannot be used in the harvesting mode when 0.6 mW laser source is applied. The highest power on the level of 18 $\mu$W is still insufficient to cover power requirements of DC/DC converter and the microcontroller. Lower efficiency of the BPW24R transducer is caused by improper coupling interface with optical fiber source.

5. Conclusions
We have built a power supply system for 32-bit microcontroller with ARM-cores and digital thermometer. Four types of converters acting on the basis of electromagnetic radiation were investigated. Each produces enough energy for proper operation of microcontroller. Moreover the output power was so high, that it is possible to expand monitoring system with new sensors. Average time $t_{\text{on}}$ needed to excite the microcontroller for almost all tested converters was 3s. Only PPC – 6E illuminated by 0.6 mW laser source 850nm FIS mini OTDR needed 300 s to produce sufficient amount of energy to excite the microcontroller. The best converters proved to be a Si photodiode and a directional antenna RF-PCB. Since our goal was to design the power supply system for FDC, the most convenient converters in our opinion are Si photodiode and PPC – 6E. By using these converters it is possible to build fully autonomous monitoring system in FDC. Despite the much longer $t_{\text{on}}$, time, even the standard laser source dedicated to MMF with PPC – 6E still were able to excite the microcontroller, which is another proof of the possibility of realization such monitoring systems. The light coming from distant laser through the optical fiber, can be converted to electric power and supply the monitoring system. Information from monitoring system can be converted in for example serial – to – fiber converter and send back through optical fiber to administrator of the network.

6. References
[1] JDSU website: http://www.jdsu.com/ProductLiterature/ppc6e_ds_pp_aa.pdf [accessed on 10.2015]
[2] Gilbert J and M Balouchi F 2008 International Journal of Automation and Computing 5(4) 334-347
[3] Mitcheson P, Sturk B, Yeatman P, Holmes A and Green T 2003 Analysis and optimisation of MEMS on-chip power supply for self powering of slow moving sensors, Proc. Eurosensors XVII, pp 48-51
[4] Starner T E 2003 IEEE Pervasive Computing 2(4) 86–88
[5] Roundy S, Steingart D, Frechette L, Wright P, Rabaey J 2004 Power Sources for Wireless Sensor Networks. Lecture Notes in Computer Science Springer-Verlag vol 2920 pp 1–17
[6] Mateu L and Moll F 2005 Review of Energy Harvesting Techniques and Applications for Microelectronics In Proceedings of SPIE – The International Society for Optical Engineering VLSI Circuits and Systems II SPIE Press vol 5837 pp 359–373
[7] Mahima Arrawatia, Maryam Shojaei Baghini and Girish Kumar 2015 IEEE Transactions on Antennas and Propagation 63(4) 1581-1588
[8] Henrique Saraiva M et al 2014 Experimental Characterization of Wearable Antennas and Circuits for RF Energy Harvesting in WBANs 79th IEEE Vehicular Technology Conference
pp 1-5

[9] Mahima Arrawatia, Maryam Shojaei Baghini and Girish Kumar 2015 Antennas and Wireless Propagation Letters PP(99) 1-4

[10] You K, et al 2011 900 MHz CMOS RF-to-DC converter using a cross-coupled charge pump for energy harvesting International Symposium on Radio-Frequency Integration Technology (RFIT) IEEE pp 149-152

[11] Mikio Taguchi et al 2013 IEEE Journal of Photovoltaics 4(1) 96-99

[12] Tatsuya Takamoto, Eiji Ikeda, Hiroshi Kurita and Masamichi Ohmori 1997 Applied Physics Letters 70 381-383

[13] Wolfgang Guter et al 2009 Applied Physics Letters 94 223504-1-3

[14] Mattos Laila S et al 2012 New Module Efficiency Record: 23.5% under 1-Sun Illumination Using Thin-film Single-junction GaAs Solar Cells 38th Photovoltaic Specialists Conference (PVSC) ISSN 0160-8371 pp 003187-003190

[15] Jan Gustav Werthen 2008 Powering Next Generation Networks by Laser Light over Fiber Optical Fiber communication/National Fiber Optic Engineers Conference OFC/NFOEC print ISBN 978-1-55752-856-8 pp 1-3

[16] Böttger G et al 2008 IEEE Photonics Technology Letters 20(1) 39-41