Metrol. Meas. Syst., Vol. 25 (2018) No. 1, pp. 235–244.

METROLOGY AND MEASUREMENT SYSTEMS
Index 330930, ISSN 0860-8229
www.metrology.pg.gda.pl

WDM POWER SUPPLY FOR IDENTIFICATION SYSTEM OF FIBRE OPTIC CONNECTORS

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Abstract

Monitoring and controlling the position of fibre optics connectors is a very important issue. Both autonomy and remote control of such a system are very desired and therefore energy independence must be provided. In this paper the design of an optical power supply system is given. A new idea of using the WDM technique in a power supply block is investigated. The electric power provided by a photovoltaic power converter and by a boost converter is shown. Moreover, in this paper the complete examination of efficiency of the system with different illuminations is given. The maximal output power of the system is 24.02 mW and the time required to identify a single fibre connector is $t_{CYCLE} = 0.65$ s.

Keywords: RFID, identification system, fibre optic transmission, power supply system.

1. Introduction

Identification of fibre optic connectors and monitoring the changes in Fiber To The X (FTTX) network topology is required by providers of IT services. Since in large data centres or switching points hundreds of thousands of optical fibres are terminated with fibre optic connectors the application of a manual identification system seems to be impossible. Solutions [1–3] using Radio Frequency Identification (RFID) tags were developed. In all these solutions, the identification system requires a conventional power supply. However, the optical distribution network (ODN) in a passive optical network (PON) does not require electricity to operate. Therefore, the use of a conventional power source (AC/DC) is not justified in ODN. The use of batteries as the energy sources is not desired because of its high cost and necessity of monitoring the battery charge level. Moreover, since the ODN are placed outdoors, harsh conditions reduce the battery's lifetime. An alternative power supply – energy harvesting – should be therefore considered during the process of developing maintenance and monitoring systems. Also, the presence of operators is not desired as it increases the cost and does not provide a full automation of the connector identification process. Therefore, the design of an autonomous and low-power communication system must be taken into account.

Powering electronic devices over optical fibre (Power-over Fiber; PoF) provide a great number of advantages such as: low attenuation, electro-magnetic immunity or high galvanic isolation.

Article history: received on Nov. 06, 2017; accepted on Dec. 16, 2017; available online on Mar. 26, 2018, DOI: 10.24425/118172.

Typically, a PoF is designed to work in a range of 790–980 nm [4, 5]. However, this range is not supported in long-distance/core optical networks and optical *Local Area Networks* (LAN) called *Fiber To The Home* (FTTH) or *Fiber To The Desk* (FTTD) networks. The second disadvantage is the high level of attenuation (2–3.5 dB/km) of these wavelengths, which is up to sixteen times bigger in comparison with the 1550 nm wavelength distributed over an optical fibre. To reduce power losses in the optical path, the wavelengths 1300–1650 nm should be considered for power transmission, since the attenuation for these wavelengths is below 0.5 dB/km.

In this paper an optical power supply system for the identification system (IS) of fibre optic connectors is presented. Full investigation of the electric power provided by a photovoltaic power converter (PPC) is given. Moreover, evaluation of the whole optical power supply system with a boost converter is described.

2. Study of Power-over-Fiber technology

Power-over-Fiber (PoF) is an optical technology where the electromagnetic waves are transmitted and converted into the electric energy by photovoltaic-power converters (PPC) which are kinds of DC/DC converters. This is a mature technology of which the first application [6] was reported in 1978. Since then a great number of applications such as a powering communication system [7], a powering and controlling beam steering system [8] or a power supply of the sensing system for Internet of Things [9] have been presented.

In the PoF technique three elements are used: high-powered lasers (HPL), optical fibres and PPCs. There are some issues concerning HPLs that remain to be solved. The first issue is the degradation of the cladding caused by high power [10]. Standard, bend-sensitive glass fibres subjected to 2–5 mm radii of bending and power levels of 1–2 W in the near-infrared wavelength window can fail in a few minutes [11]. Therefore, double-clad fibres [12, 13] or multi-core fibres [7] are used, which are not employed as typical optical fibres in FTTX networks.

In an HPL, its beam combination [14], power stability [15] and its optical efficiency [16] are other important issues which are continuously investigated. All these works increase the price of HPL in comparison with the standard optical sources.

The last issue related to the PoF to be considered is the typical range of operation wavelengths of PPC, which is an array of tiny solar cells. These solar cells are connected in series and the level of output voltage V_{out} depends on the elements used in fabrication of PPCs. Usually, wide band gap materials such as GaAs and InP are used since they provide up to 1 V of V_{out} per one solar cell which enables obtaining several volts at the PPC output. However, these elements provide the detection light in a range 790–980 nm. These wavelengths are not used in single-mode fibres (SMFs) which significantly decreases the provided length of networks. Moreover, large attenuation of these wavelengths causes an average loss of half the power transmitted over 1 km of optical fibre.

In this paper new approaches towards the design of an identification system of fibre optic connectors are presented. The first one is designing a PPC to operate on wavelengths from within a range 1.3–1.6 μm. These wavelengths have the lowest attenuation – 0.18–0.5 dB/km – within the whole telecommunication spectrum and therefore significantly less power is lost in optical fibres. Moreover, these wavelengths are supported in FTTX and core networks, so that the standard infrastructure can be used to power supply a chosen ODN. Another novel approach is the choice of standard and cheap Fabry-Perot (FP) laser diodes with a low optical power output (50 mW) as the energy sources of IS. In this paper the wavelength division multiplexing (WDM) technique is investigated to increase the spectrum range which is to be converted to the electric energy.

As the last approach the design of an autonomous IS based on ultra-low power elements and the analysis of its energy consumption are presented.

All mentioned approaches enable to prove that it is possible to power supply distant ISs using standard elements with minimal adaptation of the existing infrastructure. Such an idea enables to decrease the cost of the whole IS and increase the chance of launching it on the market.

3. System architecture

In the developed IS the main assumption was its full autonomy which means that the IS should be able to operate with small adaptation of the existing infrastructure in almost any part of the network based on SMFs. Therefore, the power supply system, remote control and communication with the IS have to be properly designed. In the presented IS an electromagnetic transducer is used since f electromagnetic waves are always present. To enable the remote control two wireless communication systems are provided: the radio frequency identification (RFID) technology to identify an optical fibre connector, and the Bluetooth Low Energy (BLE) standard. The BLE provides transfer of the collected data to a host controller.

A schematic of IS is presented in Fig. 1. It consists of three parts: a power supply block, a supervisory system and an Optical Distribution Frame (ODF) placed in an Optical Distribution Cabinet (ODC). The power supply block contains two FP laser diodes: 1310 nm (LPSC-1310-FC) and 1550 nm (LPSC-1550-FC) ones, both from Thorlabs. A typical output optical power of each laser – P_{source} is 50 mW. As the WDM coupler a WDM1x2/1310/1550/900 from Optomer is used. To power the electronic circuits a DC/DC converter placed in a dedicated PoF port (marked as P.PoF in Fig. 1) in ODF is used. We decided to use a KPC8-T from Kyosemi, which provides the maximal output electric power $P_{\text{out}} = 34$ mW (at $\lambda = 1480$ nm and $P_{\text{source}} = 100$ mW). Moreover, the power supply block contains a supervisory system of energy management – Power Management Integrated Circuits (PMIC) S6AE102A from Cypress. To store the electric energy a supercapacitor DMF3Z5R5H474M3DTA0 from Murata is used. The supervisory system mounted in ODF has two elements; the first one is a Programmable System on Chip (PRoC) CYBLE-022001-00 with a microcontroller ARM cortex M0 SoC and

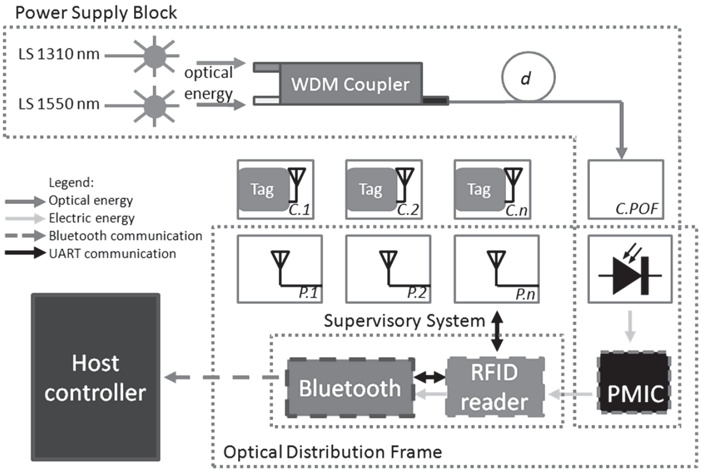

Fig. 1. Architecture of the identification system.

an integrated BLE transceiver. The second element is an RFID module CR95HF acting as the RFID/NFC transceiver in a 13.56 MHz band. At the patch panel of ODF the adapters (marked as P.1, P.2…P.n) are equipped with an antenna ANFCA-1510-A02 from Abracon. The optical connectors have LXMS33HCNG-134 passive tags (marked as C.1, C.2,…C.n) from Murata Electronics. In the whole system the standard G.652 SMF is used.

The energy requirements of the whole IS can be divided into three groups: the energy required by the PMIC module E_{PMIC} to manage the electric power during one cycle of identifying a single fibre optic connector, the energy needed to supply the RFID reader and one tag E_{RFID} during this cycle, and the energy E_{PROC} required to send the identification of a single tag in the BLE standard to the remote host controller. In [17] we have shown that the total energy required by the whole IS to identify a single fibre optic connector $E_{\mathrm{TOT}} = E_{\mathrm{PMIC}} + E_{\mathrm{PROC}} + E_{\mathrm{RFID}}$ is equal to 15.6 mJ.

4. Evaluation of power supply system

4.1. Measurement setup and characterization of PPC

The full autonomy of the IS cannot be obtained without the required amount of energy. Therefore, a detailed power budget had to be calculated. At first, the maximal electric power provided by PPC was calculated. A diagram of the measurement setup is shown in Fig. 2. Three configurations were considered to calculate the electric power. In the first one only an LPSC-1310-FC laser was connected to the PPC, while in the second an LPSC-1550-FC laser was used. Since the range of operating wavelengths of PPC is wide (1.3–1.6 μm), we decided to investigate how the WDM technique increases the offered electric energy. Therefore, in the third configuration a WDM coupler was used to enable the illumination of the PPC by both specified laser sources. As the voltmeter and ammeter Picotest M3510A devices were used. The insertion loss (IL) of the connection of the 1310 nm or 1550 nm laser with the PPC was 0.6 dB (two fibre optic connectors FC/PC marked as C) since the attenuation of a 2 metre length of SMF is negligibly low. The IL of the whole optical path for the third configuration is bigger – 1.5 dB since four fibre optic connectors are used and the IL of the WDM coupler is 0.3 dB. Due to the IL of optical path the optical powers $P_{\mathrm{IN\ OPT}}$ which illuminated the PPC were lower than P_{SOURCE} at the outputs of the lasers and had to be determined. To measure these powers a Thorlabs PM100D optical power meter with an S122C sensor was used.

In Figs. 2–5 P_{OUT} of PPC as a function of V_{OUT} determined for different values of $P_{\mathrm{IN\ OPT}}$ are shown. As presented in Fig. 2, the maximal obtained P_{OUT} for the 1310 nm wavelength is 13.74 mW for $V_{\mathrm{OUT}} = 3.11$ V. The average efficiency of the energy conversion is 28.3%.

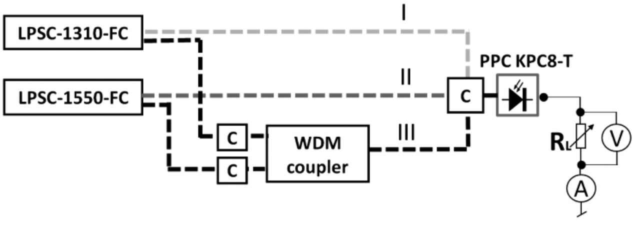

Fig. 2. The measurement setup used to characterize PPC.

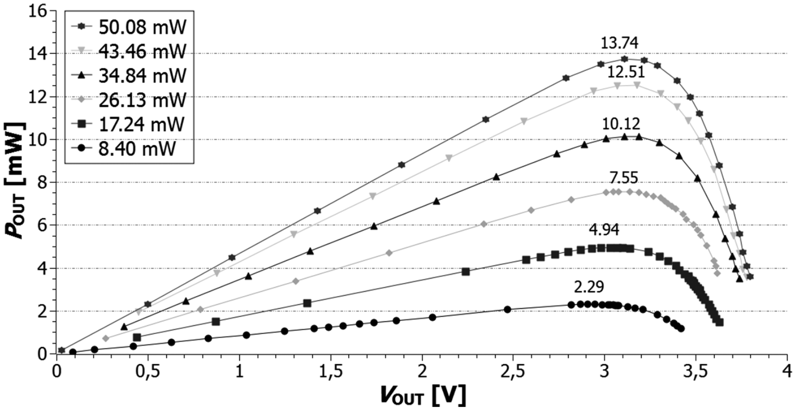

Fig. 3. PPC KPC8-T output power P_{OUT} as a function of the converter voltage V_{OUT} for different values of the optical input power $P_{IN\ OPT}$ determined for the 1310 nm wavelength.

Characteristics in Fig. 4 were determined when the PPC was illuminated by the 1550 nm laser. The maximal P_{OUT} is 15.86 mW for $V_{OUT} = 3.09$ V and the average efficiency of the energy conversion – 31.9% is bigger than that for the 1310 nm light source.

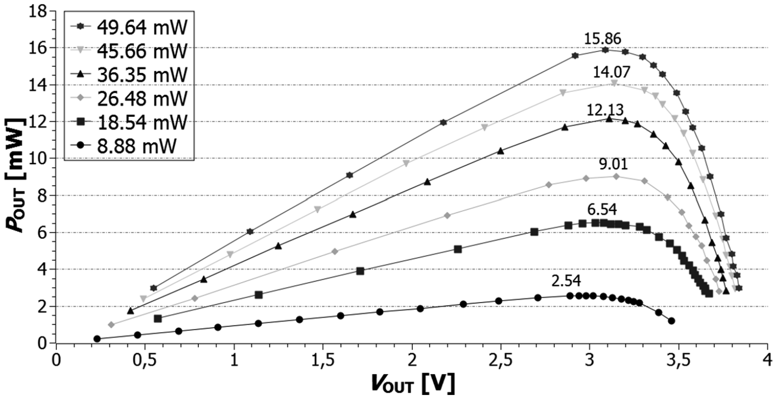

Fig. 4. PPC KPC8-T output power P_{OUT} as a function of the converter voltage V_{OUT} for different values of the optical input power $P_{IN\ OPT}$ determined for the 1550 nm wavelength.

Characteristics shown in Fig. 5 were determined when the PPC was illuminated by both wavelengths: 1310 nm and 1550 nm. As the previous calculation of the power budget has shown, the IL of the optical path for the third configuration was the highest. Therefore, the optical energy converted to the electric form is lower, despite the same power at the outputs of both lasers. However, due to a high efficiency of the energy conversion – 37.6 %, the maximal $P_{OUT} = 27.96$ mW (for $V_{OUT} = 3.04$ V) is almost the algebraic sum of the maximal P_{OUT} determined for each laser. This is a very good piece of information, since it means that the increased IL of the optical path is almost reduced by a wider spectrum of waves used in the energy conversion.

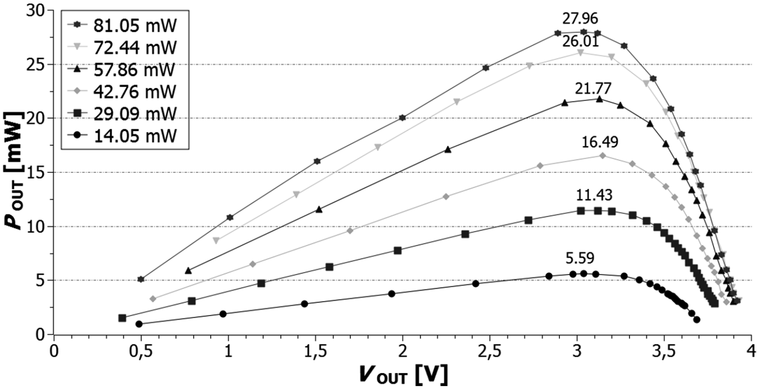

Fig. 5. PPC KPC8-T output power P_{OUT} as a function of the converter voltage V_{OUT} for different values of the optical input power $P_{IN\ OPT}$ determined for the wavelengths of 1310 nm and 1550 nm.

4.2. Power supply system characterization

To power supply the IS a stable source of energy is required. Therefore, a synchronous boost converter Linear LTC3459EDC was used and the output voltage of the converter $V_{\mathrm{OUT\ CON}}$ was set to 3.3 V. Moreover, the LTC3459EDC can be used as a supercapacitor in a situation when the power provided by the PPC is higher than the power requested by the IS. To determine the output power $P_{\mathrm{OUT\ TOTAL}}$ provided by the boost converter Picotest M3510A voltmeter and ammeter were used. In Fig. 6, $P_{\mathrm{OUT\ TOTAL}}$ as a function of $P_{\mathrm{IN\ OPT}}$ is shown. The relation between $P_{\mathrm{OUT\ TOTAL}}$ and $P_{\mathrm{IN\ OPT}}$ is almost linear for all wavelengths. The power provided for the IS decreased in comparison with PPC P_{OUT}. For the 1310 nm wavelength the maximal power dropped by 21% – to 10.89 mW, whereas for 1550 nm it dropped by 14% – to the value of 13.60 mW. The maximal $P_{\mathrm{OUT\ TOTAL}} = 24.02$ mW is also 14% lower than the maximal P_{OUT} for the WDM system and the obtained values are almost the same as the algebraic sum of $P_{\mathrm{OUT\ TOTAL}}$ for 1310 nm and 1550 nm. This means that from the IS point of view, the WDM power transfer provides the same amount of power as two separate optical fibres.

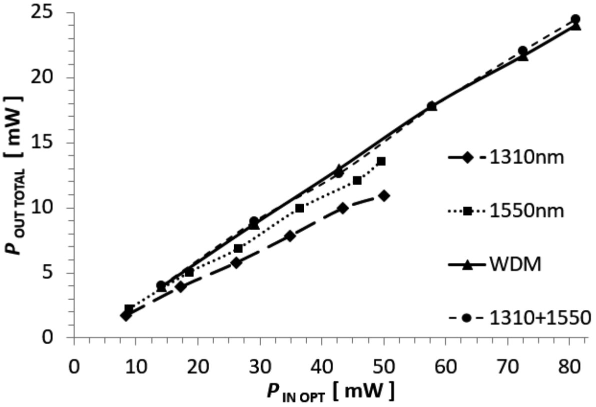

Fig. 6. A boost converter output power $P_{\mathrm{OUT\ TOTAL}}$ as a function of $P_{\mathrm{IN\ OPT}}$ for different wavelengths.

In Fig. 7, $P_{\text{OUT TOTAL}}$ as a function of R_{LOAD} is given. The maximal $P_{\text{OUT TOTAL}} = 24.02$ mW (at 450 Ω) is obtained when the WDM system is used. When the PPC is illuminated with 1310 nm and 1550 nm, the maximal $P_{\text{OUT TOTAL}}$ is reached for 1 kΩ and 0.8 kΩ, respectively.

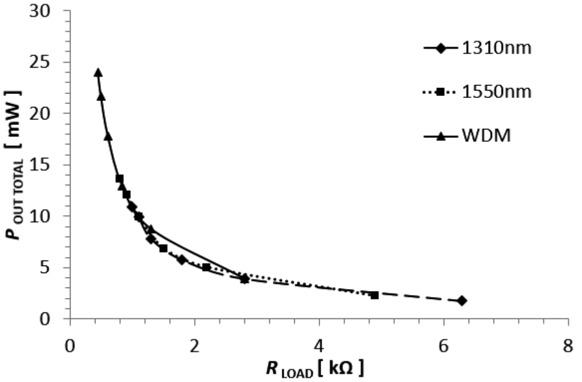

Fig. 7. A boost converter output power $P_{\text{OUT TOTAL}}$ as a function of R_{LOAD} for different wavelengths.

Finally, $P_{\text{OUT TOTAL}}$ as a function of the total initial electric power P_{IN} required to power supply lasers is given (Fig. 8) to calculate the efficiency of the whole optical power supply system. The highest efficiency is observed for the 1310 nm wavelength – on average of 3.5%, while for 1550 nm it is equal to 1.7%. For the WDM system the average efficiency of the whole optical power supply system is 2.1%.

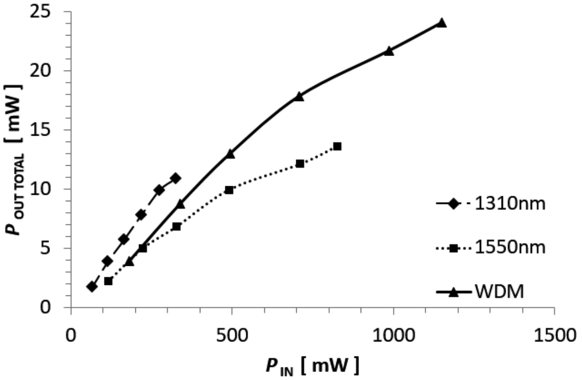

Fig. 8. A boost converter output power $P_{\text{OUT TOTAL}}$ as a function of the initial electric power P_{IN} for different wavelengths.

4.3. Discussion

Knowledge of the total electric power $P_{\text{OUT TOTAL}}$ provided by the optical power supply system is required to calculate the time t_{CYCLE} needed to charge the supercapacitor to a level necessary to identify a single fibre optic connector. Assuming that the length of the fibre in the designed IS is negligibly small (several metres) and the power supply is provided by 1310 nm laser, the time $t_{\text{CYCLE}} = 1.44$ s. The shorter time is obtained for illumination of PPC by the 1550 nm laser

– $t_{\mathrm{CYCLE}} = 1.15$ s. When the WDM power supply is used, the time of identification of a single connector is the shortest: $t_{\mathrm{CYCLE}} = 0.65$ s. However, t_{CYCLE} will increase when the optical power supply system is implemented for a distant IS due to IL of optical networks. In Tab. 1, t_{CYCLE} calculated as a function of the optical part length is given with the assumption that only the length of the optical fibre is changing and attenuation values of optical fibre are 0.5 dB/km for 1310 nm and 0.25 dB/km for 1550 nm. As shown in Tab. 1, the maximal distance when the WDM system provides higher $P_{\mathrm{OUT\ TOTAL}}$ for all types of laser sources is 22 km. For longer distances the shortest t_{CYCLE} is provided by illumination of the PPC with a single 1550 nm wavelength without the WDM coupler. The relation between t_{CYCLE} and the distance of optical fibre for different wavelengths is shown in Fig. 9.

Table 1. t_{CYCLE} calculated for different distances and illumination conditions.

Distance [km]	**Wavelength [nm]**	$P_{\mathrm{OUT\ TOTAL}}$ **[mW]**	t_{CYCLE} **[s]**
1	1310	10.03	1.56
	1550	12.84	1.22
	WDM	18.58	0.84
2	1310	8.94	1.74
	1550	12.12	1.21
	WDM	17.11	0.91
5	1310	6.33	2.47
	1550	10.20	1.53
	WDM	13.43	1.16
10	1310	3.56	4.39
	1550	7.65	2.04
	WDM	9.11	1.71
22	1310	0.89	17.46
	1550	3.83	4.07
	WDM	3.84	4.06
50	1310	0.04	438.53
	1550	0.76	20.40
	WDM	0.65	23.98

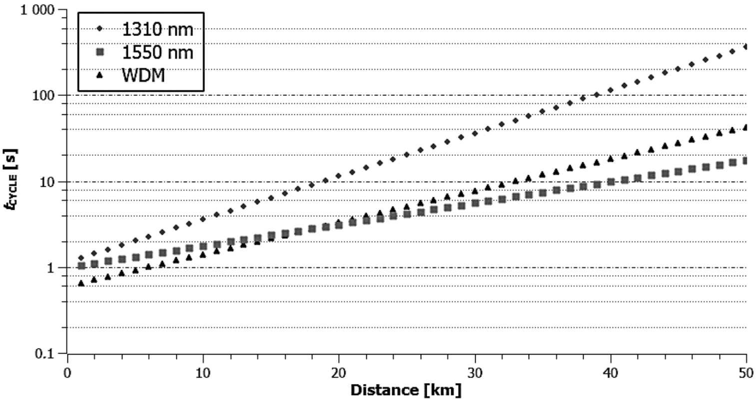

Fig. 9. t_{CYCLE}as a function of distance for different wavelengths.

5. Conclusion

In this paper the design of an alternative power source for the identification system of fibre optic connectors is shown. The maximal power offered by PPC $P_{\mathrm{OUT}} = 27.96$ mW was obtained with the WDM system and it dropped to 24.02 mW behind the LTC3459EDC boost converter. Since $E_{\mathrm{TOT}} = 15.6$ mJ, the shortest time required to identify a single fibre optic connector $t_{\mathrm{CYCLE}} = 0.65$ s. Moreover, we have shown that the WDM system provides the higher amount of power for the distance of up to 22 km. For longer distances more power at the end of the optical path is obtained by sending optical power with only the 1550 nm wavelength.

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