Power over Fiber for Internet of Things

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1 INTRODUCTION

Power over Fiber (PoF) allows transmitting power to some applications using optical fiber. It is a good solution for powering **Internet of Things (IoT)** devices because by definition they have low energy consumption, especially for IoT devices in unconventional applications.

Although PoF is a diverse set of technologies without strict standards, usually a few most common features can be identified. Typically a system consists of a laser diode, which generates optical power, an optical fiber, and a photovoltaic cell, which converts optical energy back into DC power. The efficiency of the entire system is a product of the efficiency of each particular component. [8, 9]. Besides that, in this paper we will present two examples of possible applications of the PoF system in the industry and everyday life. We will highlight its features that make it possible to use it in multiple areas.

2 HISTORICAL OVERVIEW

The concept of PoF emerged in the 1970s in AT&T company, where scientists wanted to power telephones using optical fiber. The first work covering the subject of PoF was published in 1978 by B.C. DeLoach. One year later, Robert Miller and R.B. Lawry implemented a bidirectional speech communication between an electrically powered station and an optically powered station.

In 1982, R. Miller developed speech-television communication over a single optical fiber, which used PoF as a remote station telephone emergency power supply. An important aspect that led to the successful development of those systems was a photovoltaic converter based on Gallium-aluminum-arsenide (GaAlAs).

During the years 1993-2005, there was a rapid increase in continuous wave laser PoF lasers with single-mode output (which also led to corresponding growth for lasers with multi-mode output). This was caused by the development of high brightness semiconductor diode pumps. Another significant factor that contributed to having higher laser power was the Large Mode Area (LMA) technology, and doping silica fibers with Ytterbium. These events caused an increase of diode powers, while decreasing its cost.

In 2014, Rivael Strobel Penze researched powering Passive Optical Network (PON) extenders using PoF. The research utilized semiconductor optical amplifiers to amplify Gigabit-capable PON signals. One year later, Jing Yan investigated the usage of PoF in unfavorable environments (flammable, explosive, with high voltage or strong magnetic field) [3, 10].

3 ELEMENTS OF A POF SYSTEM

3.1 Transmission side – HPLD

High Power Laser Diodes (HPLD) are an important component of a PoF system. HPLD is considered the best technology for converting power in these systems. The development of HPLD caused a significant increase in available output power, lifetime, and reliability. It allows the usage of wavelengths in the range of 400nm to 2000 nm and offers output power up to 300W. For the temperature of the heat sink higher than $0°C$ and power in the range 2-5W the values of power conversion efficiency have their peak for wavelengths in the range of 940-980nm. The highest value reported was 76% for λ = 975nm, but efficiency over 70% was reported for λ = 790 nm, λ = 1060nm and the whole range of 900-1000nm [2].

Important aspects that have to be considered when implementing a PoF system using HPLD are the compatibility between HPLD wavelength, converter efficiency and optical fiber attenuation, and the influence of temperature on the system performance.

3.2 Optical transmission medium

PoF is usually based on multi mode optical fibers and transmission takes place in the 1st transmission window around 800-850 nm, as this is most effective for transmission over short distances, although usable data transmission speed is limited.

The main problem in transporting energy via optical fiber is attenuation loss. For longer distances (over 1.3 km), transmission with single-mode fiber in the third window is preferred due to better attenuation parameters [Table 1]. However, this results in the inability to transport large amounts of energy due to a smaller effective area [8].

Table 1: Wavelengths and attenuation

λ [nm]	Attenuation [$\frac{db}{km}$]
790-850	2.5
915-980	4
1400-1550	0.2

Another issue of PoF is heat generated in fibers, especially when the fiber is being bent or stretched. It can be partly resolved by using hermetic copper or aluminum coatings which provide better heat dissipation and resistance to bending and stretching.

The coating material should have a high thermal conductivity to better dissipate heat. The copper coating can withstand temperatures as high as 600 °C, making it superior to aluminum (400 °C maximum) [1]. Metal coatings, however, make fiber-optic glass cable gain conductive disadvantages and expose terminal equipment to additional voltage.

One more difficulty would be simultaneous transmitting large amounts of energy and data in one fiber. Traditional single-mode optical fibers are unable to transmit high energy due to their narrow diameter (typically 62.5 μm).

In order to solve this problem, **double-clad fiber (DCF)** was invented. The DCF consists of a single-mode (SM) core without mod dispersion surrounded by a multi-mode inner cladding with a high core effective area. Usable data is transmitted by SM core while energy is transported by inner cladding [7]. The diameter of the DCF is 250 μm, so it is more resistant to bending. DCF attenuation is about 3.3 $\frac{db}{km}$.

3.3 Receiving side – PPC

The **Photovoltaic Power Converter (PPC or PV)** is the main element that makes PoF possible. In simple terms, it is a photovoltaic panel such as we know from the roofs of our houses.

Structurally, a PPC is a collection of plates (concentrator solar cells) [Figure 1] that convert light into a voltage difference, consequently into the current. The most important parameter of PPC is its efficiency, which tells how much delivered optical energy is converted into electrical energy.

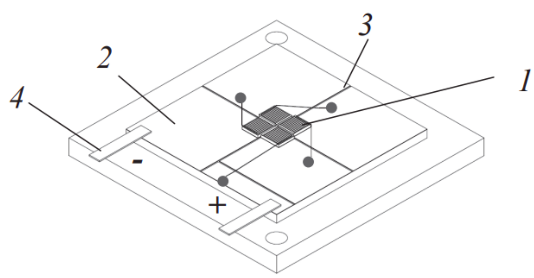

Figure 1: Module with 4 PPC converters: 1 - PPC cell; 2 – conducting coating; 3 – isolation; 4 – contact.

Most often plates are made of Gallium Arsenide (GaAs), Aluminium Gallium Arsenide (AlGaAs), or Indium Phosphide (InP). Each of these materials has a specific wavelength, for which its efficiency is the best [4]. Such data is presented in Table 2.

Table 2: Materials, wavelengths and efficiencies of PPC [12]

Material	λ [nm]	Efficiency [%]
GaAs	790-850	52
InGaAs	915-980	34
InP	1400-1550	26

The limited surface area of PPCs in IoT devices (usual cells' active area of the PPC is 1.76 mm^2 [11]) means that the light intensity must be increased to transmit more energy. However, high photocurrent density results in a decreasing efficiency. The connection is presented in Figure 2.

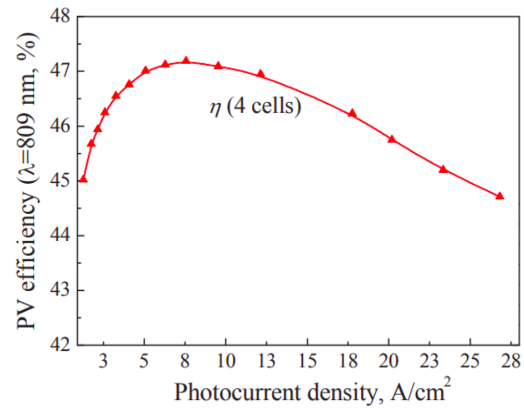

Figure 2: The PPC effectiveness by photocurrent density.

4 APPLICATION EXAMPLES

4.1 PoF in Hazardous Environment

Since 1978, when the first work about powering remote loads using optical fibers appeared, there has been a growing interest in available solutions among industry institutions. Hazardous areas, of which examples are power plants, factories, or laboratories with flammable liquids and gas storage tanks outline many requirements that are needed to provide safety and reliability of constant powering. [6] In this context, optical fibers are a perfect solution that might be used in these areas. For instance, broken fiber does not produce sparks, and what is more, they are not affected by most of the substances that react with metals. These are only a few examples of why we might successfully use fiber's features in such areas.

Power over Fiber is a good candidate in this situation where all IoT sensors and access control systems need to be securely powered and monitored. PoF has many advantages over traditional power supply systems - no need for changing batteries, or independence from fluctuating energy in the case of solar or wind power. Many factors that can lead to fire are made by human errors. Optical fibers present fireproof characteristics (Standard IEC 60332-1), which coupled with monitoring of variables like temperature, pressure, gases proportions can eliminate the risk of certain accidents. Some sensors for PoF technology are presented in Table 3 with their power consumption and possible application.

Designer of PoF system in the hazardous area should take into consideration several things:

- Converter efficiency and temperature influence on the system
- the possible amount of nodes remotely powered
- efficiency of optical coupling

The amount of nodes remotely powered via PoF depends on the maximum optical power that can be pushed into the fiber which depends on the fiber Mode Field Diameter (MFD). An additional factor is the power usage of these remote sensors.

However, there are some limitations as well, hazardous environments need safe operating conditions while PoF systems operate on high powers. Therefore there is a safeguard mechanism that

Table 3: Power consumption of some sensors and their possible application

Sensor type	Consumption [mW]	Application
AMG88	30	Temperature detection
MG-7217-TC	150	Methane concentration
VQ548MP	297	Gas detection

minimizes that risk. For example, detecting if the fiber is connected to the HPLD. This can prevent the HPLD from becoming the source of the fire and causing damage to the workers.

To sum up, a hazardous environment is a perfect destination for Power-over-Fiber (PoF). We can use its advantages such as high electromagnetic interference immunity or powering on-demand remote nodes.

4.2 Fishing camera system

Because of MMORPGs games, fishing hobbyists wanted to be able to actively view the scenery underwater. [5] For this purpose, fishing cameras were developed. A typical set consists of a camera, transfer fiber, a fishing rod, and a smartphone as the display. Main idea is in Figure 3.

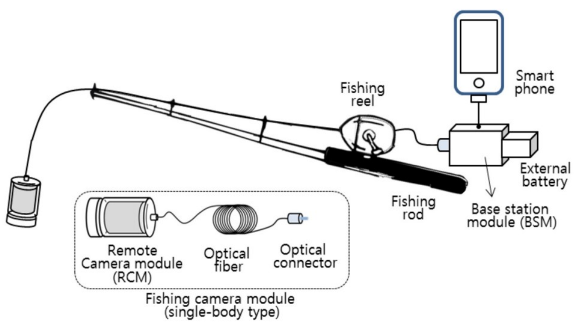

Figure 3: Conceptual schematic for the fishing camera system.

As a transmission medium and a fishing line coaxial or copper cables are used. However, they have large diameters, they are heavy, quite expensive, and exposed to corrosion. Wi-Fi is a technology that was also considered as a transfer medium but it has a short transmitting distance in water. Typically all these transfer media solutions use internal batteries, which causes less waterproof casing, and a much heavier module. These difficulties can be overcome by using fiber optic cable. It is thin, light, cheap, and rugged enough to lift a Remote Camera module (RCM). It can also fix problems with powering the camera, by using Power over Fiber technology.

Figure 4 shows the architecture of the system. Optical fiber in this system has three applications: it is simultaneously used to transfer video, to power up the camera, and as a fishing line. It can be achieved by using WDM. The data can be sent within the fiber at a wavelength of 1310 nm. Its capacity allows users to watch a video in high quality on smartphones. It is a huge advantage of this solution over other transmitting media. In the experiment 820nm wavelength was used for power. This wavelength is considered to be in the optimal range for GaAs PPC.

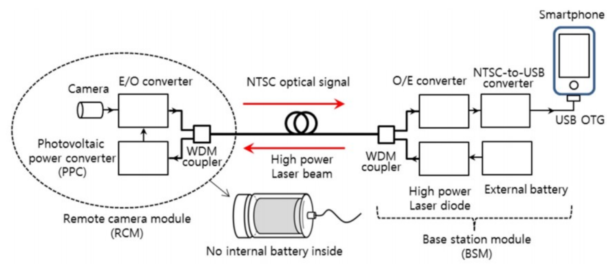

Figure 4: Structural schematic of the fishing camera

The camera needs 291 mW and the electrical-to-optical (E/O) converter uses 122 mW. This means that all parts of the RCM consume 413 mW of power. Considering the efficiency of PPC (Lumentum PPC-6E), measured at 32.6%, we need to inject 1270 mW of the optical power. This amount can be provided by a simple stack of batteries or a power bank. Moreover, the attenuation and the power reduction depend on using fiber as a fishing line, because it generates problems related to bending and tensile stress of a fiber, which can be overcome with special coatings and other methods. The best practice to reduce losses is to increase the diameter of the mandrel (decrease bending curvature) and use a holder.

To summarize, power over fiber can be successfully used to connect the camera with a fishing rod. It can be used as a fishing line, an energy supply, and a transmission medium at the same time. Using fibers in that area can be cheaper and give us higher quality than coaxial or copper fibers or Wi-Fi.

5 CONCLUSION

The energy transferred is small, comparing to that of the electrical socket, although it can reach several watts for multi-mode fiber. Depending on the study, the effectiveness of the overall system is from 10% up to 20%, but usually around 12% (as shown on Figure 5).

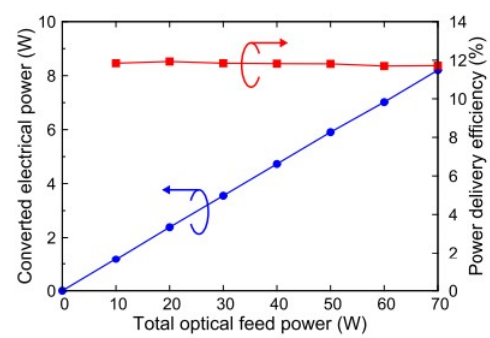

Figure 5: Converted electrical power and power delivery efficiency as a function of total optical feed power

It hardly depends on used components and fiber length. It is mainly due to the PPC and the attenuation of the optical fiber.

PoF offers a variety of usage that some examples were presented in this work both for the industrial (4.1) and small (4.2) scale. It is an especially good alternative to copper for Internet of Things installations, which by definition needs little power so that the energy supplied is completely sufficient. This technology is still under a constant process of development. Every part of this system is under research, which will result in more power consumption savings and an increase in efficiency of this system in the future.

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