# Powerless Sensor for Non-Intrusive Multi-Fiber Traffic Monitoring

João Casaleiro, António Serrador, Sérgio André, Pedro Fazenda
DEETC,
Inst. Sup. Eng. Lisboa - ISEL
Lisbon, Portugal
{joao.casaleiro, antonio.serrador, sergio.andre, pedro.fazenda}@isel.pt

João Casaleiro
Centre Technology and Systems-CTS
NOVA School of Science & Tech.
Caparica, Portugal

2022 International Conference on Control, Automation and Diagnosis (ICCAD) | 978-1-6654-9794-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICCAD55197.2022.9853963

***Abstract*— The rapid expansion of fiber optic networks and services, which sees a large number of circuits enabled and disabled each day, introduces a significant complexity for operators to identify fibers that have and do not have attached clients. The service level agreements prevent operators from disconnecting circuits without absolute assurance that no clients are attached. We propose a non-intrusive multichannel fiber detector to facilitate the operation and maintenance of the optical networks. The optical distribution frame usually does not have any power available, thus, the proposed device operates without batteries and is powered by near field communication (NFC). Device installation does not require fiber disconnection or communication interruption, and introduces less than 1 dB insertion loss to detect optical signals down to -30 dBm. In order to read multiple fiber channel status, an NFC-enabled smartphone is used to power the device and measure the signal levels of each channel.**

***Keywords—Live fiber detector; Multi-fiber; traffic monitoring, optical networks, Near-field communications, powerless.***

## I. INTRODUCTION

In the last decade, optical networks have grown rapidly. Fiber-optic network operators require a non-intrusive, low-cost device to monitor their fiber links on a periodic or permanent basis. A number of solutions exist on the market for optical network analysis and performance, but most require the disconnection of the link, which operators can't do due to service level agreements. There are commercially available solutions for a single channel [1] but allows only to monitor a single channel and cannot be installed permanently in the optical distribution frame due the required space and cost.

Other related solution is described in [2], however it is not able to be installed and powered such the one that is being presented in this work.

In this work, we propose a new method (Fig. 1) to easily identify and monitor, in both directions, multiple live optical fibers without intercepting even at optical transmission power as low as −30 dBm at 1310 nm wavelength, which is expected to be the lowest for usual optical transmission systems, while insertion loss is kept lower than 1.0 dB at 1550 nm wavelength.

The proposed device allows simultaneous traffic activity monitoring in terms of load and in both directions. Thus, if traffic flows, it is detected in real time by the smartphone user.

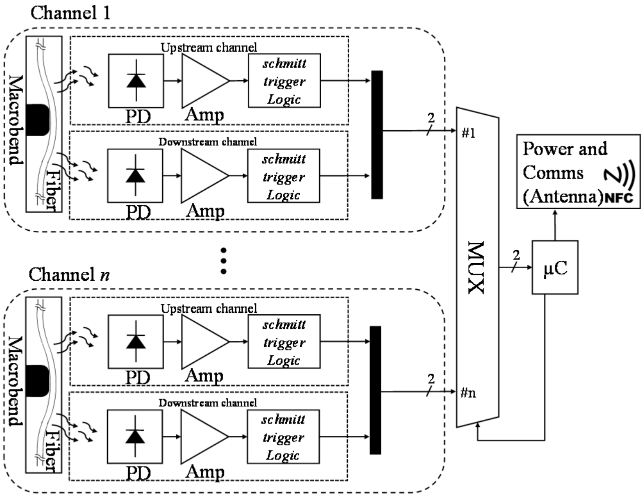


Fig. 1. Block diagram with *n* channels. Each channel monitors both directions simultaneously with a photodiode (PD), Amplifier (Amp) and a logic gate for each direction.

This paper is organized as follows: in Section II the traffic flow detection in optical fibers is discussed, in Section III, detecting solution specifications and implementation details are presented. In Section IV, measurements are presented that present the sensor performance. We close the paper with major conclusions in Section V.

## II. LIVE FIBER DETECTION METHOD

To detect optical signals in fibers, a fraction of the light transmitted in the optical fiber is extracted, without interrupting the connection. Hence, active, and inactive fibers will be distinguished in a non-intrusive manner. A bend in the fiber can be used to deform the core in order to remove some of the light that propagates in it. Part of the light will be allowed to exit the fiber.

### *A. Macrobending technique*

The macro bending technique consists of applying a bend to the fiber in order to deform the core and allow part of the optical power to be extracted, as shown in Fig. 2. A portion of the power injected into the fiber, $P_i$, will be extracted, $P_e$, and the remaining power, which is referred to as output power, $P_o$, continue in the core. The reduction of the output power due to the bending, known as insertion loss, must be kept below 1 dB.

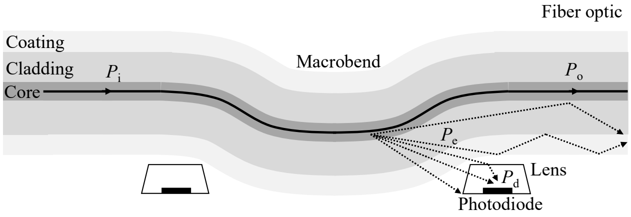


Fig. 2. Fiber design with radius of curvature and representation of optical signals

By definition, the insertion loss ($IL$), is the ratio between the inserted and output powers in the fiber, or in decibel units is their difference [3], given by

$$IL_{[dB]}=P_{i[dBm]}-P_{o[dBm]} \tag{1}$$

Note that the $IL$ includes the losses due to the fiber, $IL_f$, plus the loss due to the bending, $IL_b$,

$$IL_{[dB]}=IL_{f[dB]}+IL_{b[dB]} \tag{2}$$

The coupling loss ($CL$), is the ratio between input and the optical power detected by the photodiode, $P_d$, given by

$$CL_{[dB]}=P_{i[dBm]}-P_{d[dBm]} \tag{3}$$

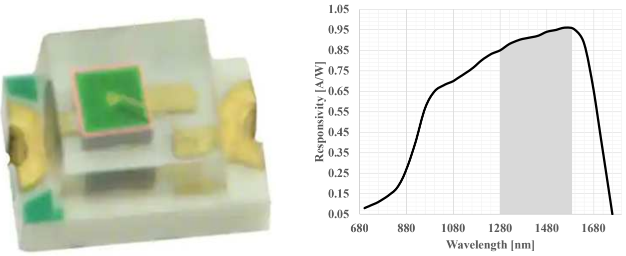
The power extracted from the core can be indirectly obtained through the $IL_b$, if the excess losses are primarily due to the power extracted. Nevertheless, the power detected by the photodiode constitutes a small portion of the power extracted. The detected power depends, among other factors, on the photodiode's active area, the angle between the fiber and the photodiode, and their relative location. All factors are aggregated in the coupling loss to simplify the problem.

### *B. Optical Sensors*

There are several types of photodetectors available commercially (PIN and APD photodiodes, phototransistors, etc.), but only PINs and APDs have the characteristics needed for telecommunications applications.

The avalanche photodiode or APD (avalanche photodiode) is a widely used photodetector in optical communications. Each incident photon generates an electric current, which is amplified within the device. A gain is obtained through the process of avalanche multiplication. However, avalanche multiplication requires a stronger electric field than the PIN photodiode does. As a result, the APD photodiode is polarized with an inverse voltage that is much higher than the one used in the PIN, which is not suitable for the low power consumption required for the proposed solution.

The p-i-n photodiode (PIN), was chosen for the proposed solution because of its lower voltages, which is adequate to the low power requirements of the proposed solution. However, in comparison with APD there are no multiplication process and therefore the optical-electrical conversion efficiency called quantum efficiency is less than 100%. This can be confirmed in the photodiode characteristic responsiveness, $R_\lambda$ which relates the photodiode electrical current, $I_p$, with the incident optical power, $P_d$. Since the wavelengths used in optical network, e.g. Gigabit Passive Optical Network (GPON) and Synchronous Digital Hierarchy (SDH), are between 1310 nm and 1550 nm, the most suitable photodiodes are those with intrinsic material InGaAs that have a responsiveness above 60% between 1200 nm and 1700 nm [4].



(a) (b)

Fig. 3. The photodiode photograph (a) and responsivity (b) adapted from [5] and with shaded area marking wavelengths from 1280 nm to 1600 nm which are the typical band used for telecommunications.

The photodiode SD003-151-001, see the photograph in Fig. 3a, was chosen due to is responsiveness greater than 0.85 A/W in the wavelength range of optical networks [5], see Fig. 3. In the responsiveness graph (Fig. 3b) the shaded area identifies the wavelength window used in optical networks, 1300 nm to 1600 nm.

## III. PROTOTYPE IMPLEMENTATION

The most important requirement considered in the development of the mechanical parts for the prototype was the minimum power margin in the fiber. Usually, on telecommunication operator a 1 dB margin is considered. The margin is the power level above the sensitivity of the optical receiver, that e.g. for a GPON is, -30 dBm for class C+ and -28 dBm for class B+ [6]. For the SDH the worst case it also -30 dBm [7].

The requirement for the electronics was the power consumption that is supplied by the Near-Field Communication (NFC) field.

### *A. Signal conditioner sizing and optical signal detection*

The amplifier that interconnects to the photodiode, in order not to influence the measurement, must have an input impedance greater than the shunt resistance of the photodiode and leakage currents at least ten times lower than the current produced by the photodiode when irradiated with the minimum optical power to be measured. The operational amplifier LMP2231 was chosen, which has a leakage current of less than 20 fA, an output offset of less than 150 μV and a typical current consumption of 10 μA at the inputs [8]. To maximize the input impedance, a non-inverting topology was chosen, see diagram in Fig. 5.

The amplifier voltage gain was empirically defined, and it was found that to detect optical signal levels below -20 dBm with an insertion attenuation close to 1 dB (attenuation introduced by the macro bending) a gain greater than 40 is required.

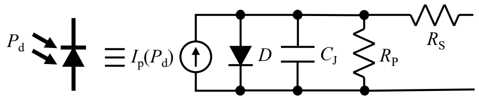


Fig. 4. Diode equivalent model.

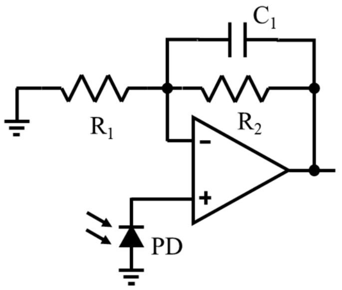


Fig. 5. Amplifier circuit

To minimize the circuit current reached the ratio R1=150 kΩ and R2=6.2 MΩ, which generates a gain of 42. The capacitor C1 serves to limit the amplifier's bandwidth and attenuate approximately 40 dB the 50 Hz signal from the electrical network that can be injected into the circuit by ambient light or by electromagnetic induction effect.

After amplification, the photodiode signal is converted to digital through one of the inverter logical gates with Schmitt trigger input of the CD74AC14M96.

## *B. Processing and sending the status of optical channels*

Having the 24 digitized signals, these are measured sequentially through three dual-channel CD4052BM multiplexers, the result being saved in the microcontroller's RAM memory (MCU) for later sending by NFC.

Signal processing is done by the LPC8N04 (from NXP) microcontroller which has NFC connectivity [9]. This microcontroller was chosen for its ability to power itself by the NFC electromagnetic field connection and to power the remaining circuit. In this way, the fiber monitor is energy independent and does not require permanent power. Considering the number of sensors in a technical room, this is a significant advantage.

When approaching an NFC device (NFC reader), such as a smartphone, the fiber monitor antenna will feed the circuit and sequentially read the status of the 24 channels (12 channels in both directions) that are sent by NFC.

# IV. MEASUREMENTS

## *A. Methodology*

After studying the macro bending problem theoretical model, the mitigation measures caused by macro bending were performed, which followed the following methodology:

- In order to exclude physical differences, measurements were made on optical fibers with the same characteristics that are used in the real network G.652 [10].
- A set of different radius was built (in the pre-established region of interest between 6 and 15 mm).
- A signal at 1550 nm was injected into the fiber at one end, and the same was measured after undergoing different curves with different radius.
- Attenuation measures (by macro bending insertion) were compared with the theoretical values.

## *B. Results*

A set of initial theoretical and practical insertion loss values were obtained to assess the differences and required margins for the network operation considering the losses caused by macro bending. Fig. 9 presents theoretical results and observed measurements.

TABLE I. TEST RESULTS USING THE SETUP DESCRIBED IN FIGURE 8.

| $P_i$ [dBm] | $P_o$ [dBm] | IL [dB] | Signal Detected |
|---|---|---|---|
| -6.77 | -7.62 | 0.85 | Yes |
| -28.34 | -29.23 | 0.89 | Yes |
| <-30 | - | - | No |

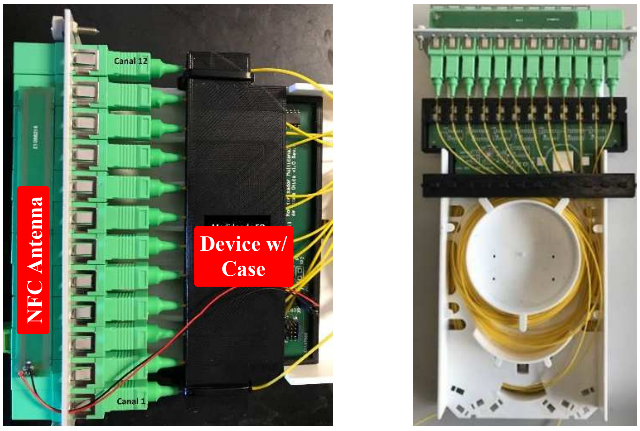


Fig. 6. Photograph of the device installed in an optical card, with case covering the electronics (left) and without the enclosure (right).

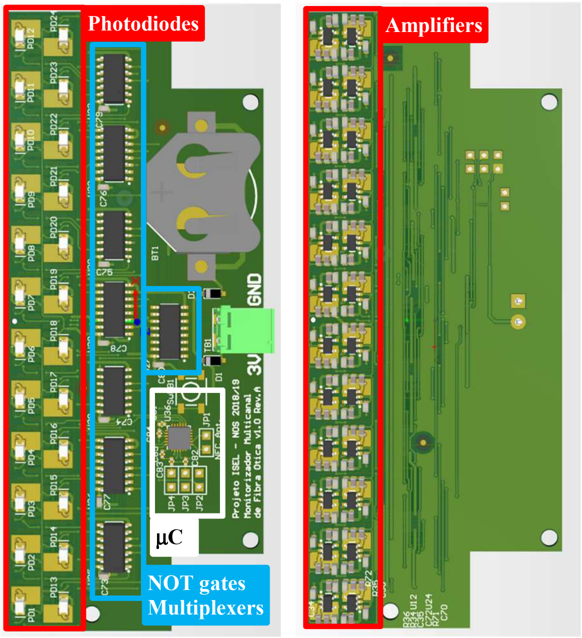


Fig. 7. The 3D rendering of the Printed Circuit Board (PCB) of the developed prototype top view (left) and bottom view (right), On the left two photodiodes per optical channel and multiplexers for channel selection and microcontroller. On the right the channels amplifiers.

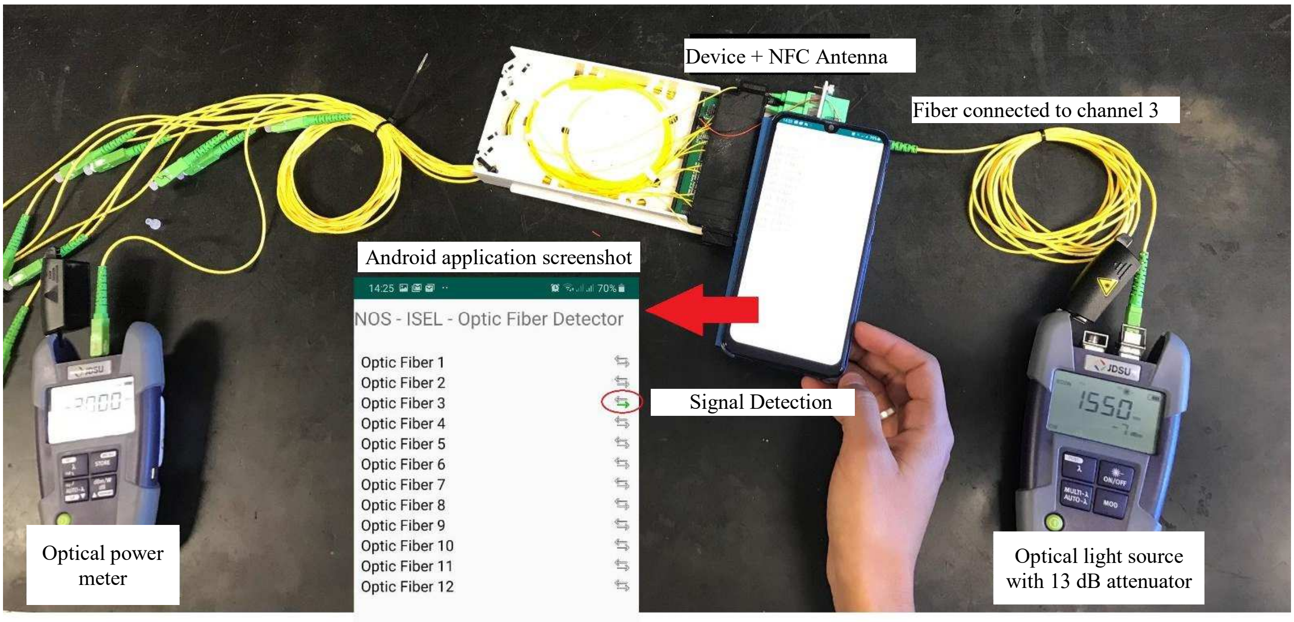


Fig. 8. Measurement setup (optical transmitter and receiver [11] with the developed measurement sensor apparatus).

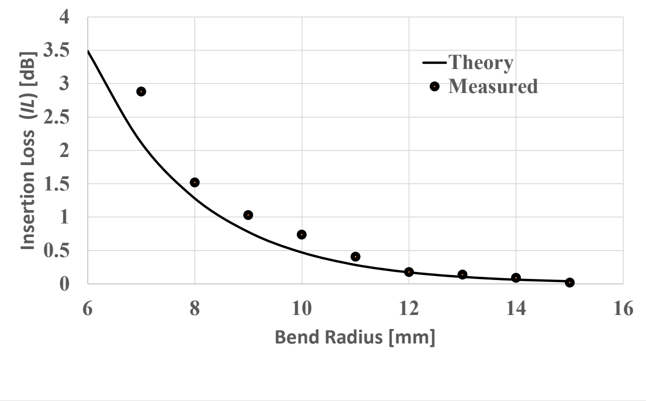


Fig. 9. Theoretical and measurement results of the G.652 fiber [5] in accordance with IEC 60793-1-47 [12].

Through Fig. 9, it is possible to notice the difference between the theory and the measurements is not significant, with only greater differences for smaller radius of curvature. However, this divergence is outside the project area of interest (below 1 dB), therefore, this is not a practical problem and was not addressed. From the results obtain in a macro bending with a radius of 10 mm was implemented with the mechanical parts.

The final test was conducted with the setup shown in Fig. 8. Using the OLS-35 [11] light source, an optical signal was injected into channel 3 and measured with the OLP-35 optical power meter on the other end. Upon removing the attenuation of splices and connectors, we detected signals down to -28.3 dBm when the IL was less than 1 dB. See Table I for results.

## V. CONCLUSIONS

We developed a prototype for simultaneous monitoring of up to 12 optical channels in both directions using macro bending. Communication and power are provided by NFC fields and a smartphone application displays the gathered data. In this study, we demonstrate the feasibility of non-intrusive monitoring of multiple optical channels with a battery-free device. By using low power electronics and an antenna with 47x32 mm, it was possible to power the device, measure the signal, and transmit the data back to a Smartphone.

Rather than using fast electronics to measure the optical power of GHz signals, a novel method is used to accumulate the and average the output signal from optical signals, using the parasitic capacitance of the photodiode. Additionally, this solution requires the NFC field to be present for at least one second to complete measurement.

Using macro bending, optical signals can be detected at -30 dBm power with an insertion loss below 1 dB. These detection levels were obtained with the PIN photodiode and without any change in the fiber. The measurement minimum time, however, is inversely proportional to the optical power and for a -30 dBm power, this is one second. Additionally, a variety of mechanical components were constructed with a 3D printer, including parts for bending the fibers, isolating optical signals between each channel, and minimizing ambient light interference.

## REFERENCES

[1] Live fiber detector, LFD-200, EXFO Inc, 2021. [Online]. Available: https://www.exfo.com/umbraco/surface/file/download/?ni=10961&cn=en-US&pi=5616

[2] Y. Takeuchi, K. Mabuchi, J. Iwasaki and K. Sakuraba, "Highly sensitive optical line checker with a leaking component embedded on an optical fiber cord," 2011 Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference, 2011, pp. 1-3.

[3] Govind P. Agrawal, Fiber-Optic Communication Systems, 3rd Ed. John Wiley & Sons, 2002.

[4] I. Kimukin, N. Biyikli, B. Butun, O. Aytur, S. M. Unlu and E. Ozbay, "InGaAs-based high-performance p-i-n photodiodes," in IEEE Photonics Technology Letters, vol. 14, no. 3, pp. 366-368, March 2002.

[5] *Surface-Mount InGaAs Photodetector*, SD003-151-001, REV 11-24-14, Advanced Photonix, Inc, 2022. [Online]. Available: https://media.digikey.com/pdf/Data%20Sheets/Photonic%20Detetectors%20Inc%20PDFs/SD003-151-001.pdf

[6] ITU-T Rec. G.984.2 Gigabit-capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) layer specification

[7] Telcordia GR-253, “SONET Transport Systems: Common Criteria”, Set. 2000.

[8] *Single Micropower, 1.6V, Precision Operational Amplifier with CMOS Inputs,* LMP2231, REVISED MARCH 2013, Texas Instruments, [Online].Available:https://www.ti.com/lit/ds/symlink/lmp2231.pdf?ts=1646082352163&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLMP2231

[9] *32-bit ARM Cortex®-M0+ microcontroller*, LPC8N04, Rev. 1.4 — 8 June 2018, NXP Semiconductors, [Online]. Available: https://www.nxp.com/docs/en/data-sheet/LPC8N04.pdf

[10] ITU standard G.652 (11/2009), “Characteristics of a single-mode optical fibre and cable”, International Telecommunication Union (2009)

[11] JDSU, SmartPocket™ Optical Light Source OLS-34/35/36, JDS Uniphase Corporation, 2009.

[12] International Standard, “Optical fibres - Part 1-47: Measurement methods and test procedures - Macrobending loss,” IEC 60793-1-47:2007.