All Optical Power Supply and Data Transmission System for Submarine Instruments

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***Abstract*-The observation and the understanding of ocean depth behaviours require the development of sea floor observatories, well equipped with real time instrumentation. However, a large-scale deployment of such a network is expensive and needs a complex infrastructure with power supply and data exchange issues. The main objective of this study is to develop a flexible and low cost extension for existing observatory networks. The proposed and investigated solution is a quasi-all-optical extension, which consists in deploying a fibre optic devoted to transport both the energy required to supply the instrument and the up/down-stream transmitted data. In this paper, we present the architecture of this quasi-all-optical extension and we discuss about its feasibility thanks to experimental results.**

I. Introduction

Important projects concerning the development of sea floor observatories have recently been undertaken in various areas (Canada, USA, Europe and Japan) [1]. There are multiple objectives, such as to provide strategic long term monitoring capabilities in geophysics, chemistry, biochemistry, oceanography or biology.

It is well-known that these observatories require complex substructures, expensive equipments and important means for the data exchange and the power supply: for example the renting of cable maintenance vessels. Today, one of the main issues is to reduce the cost and the complexity of these sea floor observatory networks to explore with more flexibility some specific and geographically extended areas.

The use of fibre optic technology with a quasi-all-optical architecture for energy and data transmission to pilot sensor instrumentation seems to be an attractive solution. This optical solution can be used for extending current networks, and can result in a large-scale deployment of observatory stations without requiring a complex infrastructure, costly means and frameworks.

The main goal of this work is to demonstrate that power and data transportation on a fibre optic cable could be an interesting solution. We discuss here about its feasibility thanks to experimental results.

This study is part of the ESONET framework "implementation and development of cabled networks for sea floor observatories" which implicates different international research institutes [1].

In section II we describe more precisely the context and the main objective of this study. In the following section, we present the optical network architecture. Then, in section IV, some experimental characterisations are presented. This allows us to discuss about the superimposition of data and energy in the same fibre optic.

II. Main objective

Figures 1a and 1b show a schematic of typical sea floor observatory network architecture. A terrestrial station supplies the power in the electric form and manages the data transmission in the optical form towards a junction box. Mostly, the sensor is plugged in the junction box by an electrical link.

Sometimes, it could be interesting to extend the observatory network in order to expand, for occasional reasons, the measurements over a few kilometres far from the existing infrastructure. We suggest in our work to extend the network from one junction box (Figure 1b: *"optical extension"*) and to take advantage of a quasi-all-optical architecture. Our investigated solution consists in deploying a single fibre optic, which transports both the energy to supply the instrument and the up/down-stream transmitted data.

This quasi-all-optical extension will be directly linked up to a junction box. A power laser placed inside the junction box converts the electrical energy into optical energy. Then the power supply and the data are both transmitted in the optical form thanks to one fibre optic. The sensor receives them in the electrical form after O/E conversion. As it is a bi-directional transmission, the sensor has to be equipped with a laser to communicate up-stream data towards the terrestrial station.

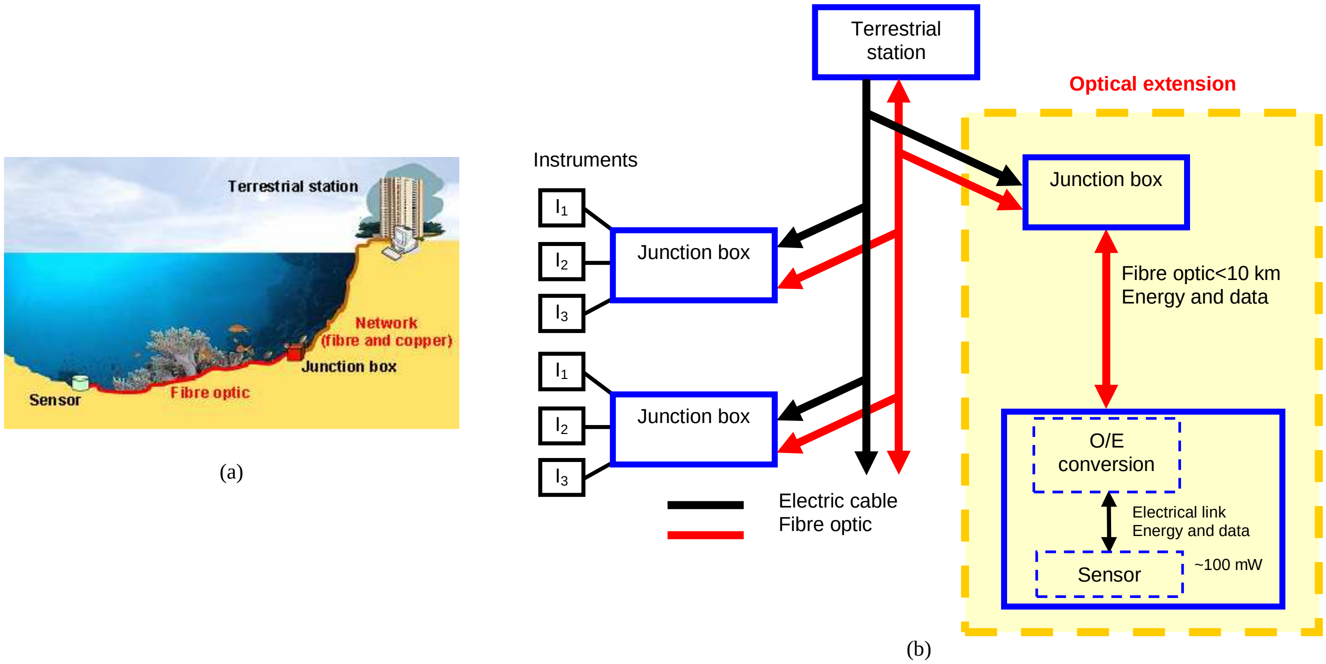

Figure 1. Architecture of a typical sea floor observatory network extended thanks to our quasi-all-optical solution.

The power requirement is approximately some hundreds of electric mW to supply an instrument located at about ten kilometres from the junction box.

However, considering the limited energy efficiency of the various optoelectronic components presently available on the market and the high optical power needed, some critical points need to be addressed prior to launch into the prototyping phase, i.e.:

- Energy efficiency: currently available optical components are not appropriate for this type of application. It is thus necessary to study solutions to improve their performances (efficiency of laser sources and photovoltaic cells used to supply the energy, management of the electrical impedance, …)
- Submarine connection assembly: to limit high cost and complexity, the transport of both energy and data on the same fibre has been preferred, thus exposing the optical signal to unwanted non-linear effects (Raman, Brillouin).
- Optical up-stream data generation and transmission from the sensor instrumentation: considering the small electrical energy level available at the sensor location, a "weak consumption" emission source must be selected and implemented within the most capable optical data generation system.

In this context, our work consists in evaluating the abilities, constraints and limitations of such a solution.

III. Quasi-all-optical Extension Architecture

In order to optimize the performances of the optical network (power efficiency, high quality data transmission,...) the optical wavelength and the power range should be carefully chosen. This has been done by taking into account the availability and the price of the needed components.

A. *Wavelength and power choices*

Two main types of fibre optic, multi-mode or single-mode fibre optic can be used to transport both the energy to supply the instrument and the up/down-stream transmitted data [2]. On the one hand, a multi-mode fibre optic has a larger core ($\geq 60\ \mu m$), allowing a greater density power transmission compared to single-mode fibre (core diameter $< 10\ \mu m$). On the other hand, a single-mode fibre allows much longer and higher-performance links (low attenuation, low wavelength dispersion...). That is the reason why single-mode fibres are currently used in optical telecommunication systems. Consequently, this type of fibre is cheaper. Furthermore, most of optical components are manufactured in order to operate with single mode fibres. Therefore, by taking into account those arguments, we have chosen a standard single mode fibre SMF-28 for our application.

The wavelength choice comes from a compromise between several parameters, i.e:

- the availability of continuous high-power fibre lasers (> 5 W),
- the optical attenuation in fibre optic,
- the photovoltaic power converter efficiency.

The optical energy to supply the sensor should be optimized for a maximum efficiency. Because common high-power fibre lasers emit infrared light either at $\lambda_1 = 0.98\ \mu m$ or at $\lambda_2 = 1.48\ \mu m$, we have evaluated the power efficiencies for these two wavelengths. This evaluation takes into account the optical attenuation of the fibre optic and the O/E conversion [2]. Figure 2 shows the calculated efficiency according to the fibre optic length, with photovoltaic power converter efficiencies set at their typical values (-3 dB at $\lambda_1 = 0.98\ \mu m$ and -6 dB at $\lambda_2 = 1.48\ \mu m$).

The presented curves in Figure 2 show that we must use the wavelength $\lambda_2 = 1.48\ \mu m$ when the fibre length is greater than 1 km. In our application, the distance between the junction box and the sensor is beyond 1 km and can reach up to 10 km, so we have chosen the 1.48 µm wavelength for the power supply transmission in our system.

Concerning the data wavelength, it is set in the C-band (1530 nm -1565 nm) in order to take advantage of the minimal attenuation range of the single mode fibre optic, and to benefit from a well-established technology in the telecommunication networks domain.

The electrical power requirement for the instrument is approximately evaluated to some hundreds of mW. So, by using the optical efficiency values presented in Figure 2, it is possible to estimate the necessary optical power that the power laser should deliver. We have found that we need a high-power fibre laser able to emit more than 8 W for an instrument located at 10 km from the junction box.

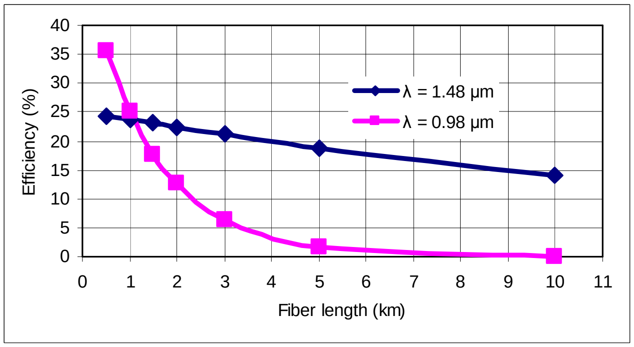

Figure 2: Efficiency of transmission (taking into account the fibre attenuation and the O/E conversion)

B. Quasi-all-optical extension architecture

Figure 3 shows a schematic of our proposed extension architecture. Its design enables both the energy and the data transport in the same fibre optic and permits a bidirectional communication between the sensor and the junction box.

The extension is made up of several optical components:

- a continuous high-power fibre laser (up to 10 W @ $\lambda = 1.48\ \mu m$) and a data laser (up to 10 mW @ $\lambda = 1.55\ \mu m$),
- two multiplexers/demultiplexers used either to combine or to separate the two different wavelengths (power supply and data),
- a 10 km fibre optic cable (standard single mode SMF-28),
- two optical circulators used to separate the down and up data stream (bidirectional transmission).
- a photovoltaic power converter for the power supply requirement of the sensor,
- two high-speed photodiodes for the data detection.

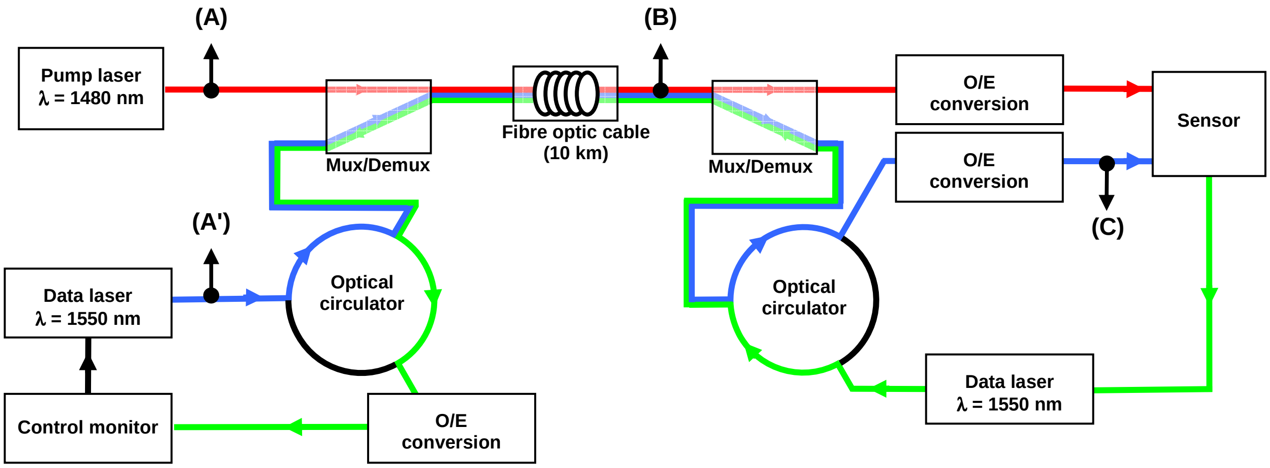

Figure 3: Architecture of our quasi-all-optical extension.

It is important to precise we have used only commercially available components to realise this quasi-all-optical extension. This was a fastidious work to do before to launch into the experimental tests, because there are, today, few optical components designed to withstand high power. For example, the necessity to find optoelectronic components with better energy efficiencies (pump laser, photovoltaic cells) or the necessity to develop a "weak consumption emission source" for the optical data generation localized nearby the sensor are essential.

We have also to mention that joining optic cables is more complex than joining electrical cable. The need to transmit high optical power has required the use of optical fusion splicing to establish the optical connection.

IV. Characterisations

In this section, some characterisations are presented with the aim to demonstrate the feasibility of our quasi-all-optical network extension concept. All these presented characterisations have been achieved without optical up-stream data.

First, we show the possibility to superimpose the data and the energy in the same fibre optic as depicted in Figure 4. The measured optical spectra are shown at three particular points along the fibre optic (written A, A' and B in Figure 3) when both power supply and data are transmitted. The power supply at λ = 1.48 µm is set at 30 dBm (1 W) and the data power is set at ~10 dBm (10 mW).

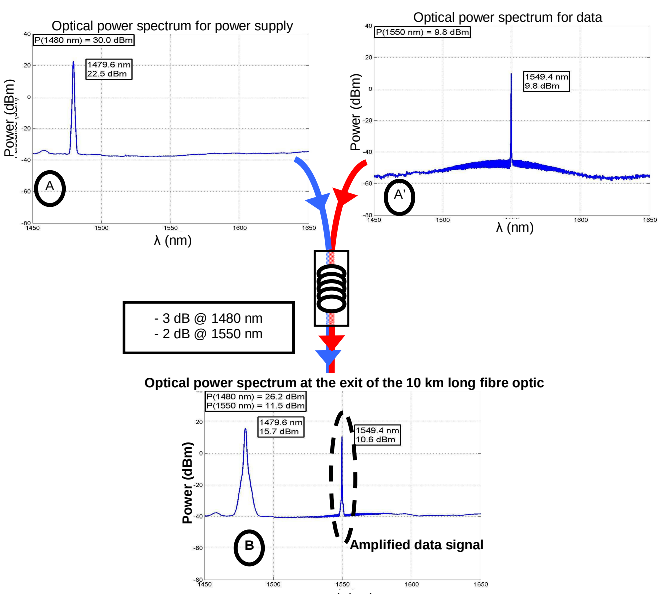

Figure 4: Optical spectra measured at three points along the fibre optic

At the end of the 10 km fibre optic (near the sensor), the high power fall down around 26 dBm (400 mW). The 4 dB losses come principally from the optical attenuation in the fibre optic and from the insertion losses in optical components. On the other hand, we can observe an increase of 1.7 dB in data power at the end of the fibre optic. This phenomenon, known as the stimulated Raman amplification, is a non-linear effect that can be useful to amplify the data power [2-4]. A great amplification with this process requires significant powers.

Measurements have also been performed in dynamic regime. We can assess the performances of the network by measuring data error transmission at the end of the optical cable. To do this, we had to work in dynamic regime. The measurement of the optical signal after 10 km in presence of significant optical power at λ = 1.48 µm give us some information about the Bit Error Rate (BER) and the noise level. Figure 5 shows samples of the observed data for several optical power supplies. Figure 5a presents for a non-return-to-zero (NRZ) modulated signal at a bit rate of 6 Mbits/s (data) emitted at λ = 1.55 µm by the data laser at the entrance of the optical extension (point A' in Figure 3). Figures 5b, 5c and 5d show the data observed at the instrument location after 10 km propagation along the fibre optic for several optical power supplies (point C in Figure 3).

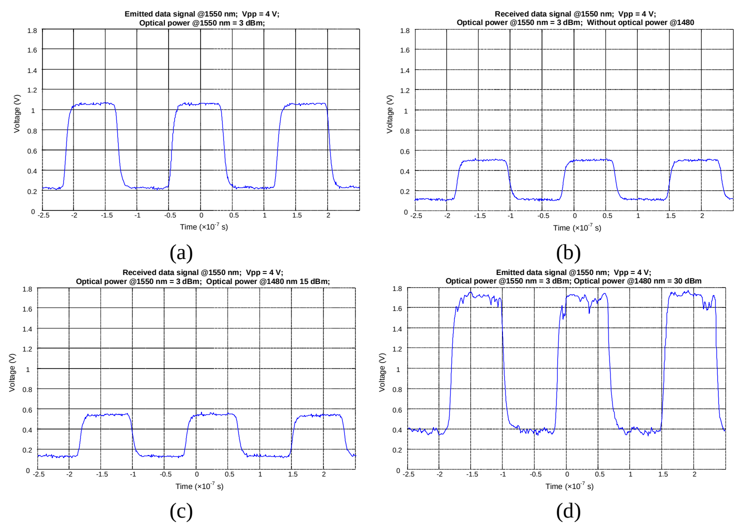

Figure 5: Example of data transmitted on the optical extension

(a): NRZ signal emitted by the data laser in the junction box,

(b): NRZ received data after O/E conversion without optical power supply,

(c) and (d): NRZ received data after O/E conversion with optical power supply respectively set at 15 dBm and 30 dBm.

We can remark that the measured signal shown in Figure 5b without optical power is not degraded compare to the signal shows in Figure 5a. The 3 dB decrease between them is due to the insertion loss components and the fibre optic attenuation. With a 15 dBm optical power supply, the signal shape is still well described (Figure 5c). We can see in Figure 5d, when the optical power is set at 30 dBm, that the signal is greatly intensified by Raman amplification. However small data fluctuation amplitudes are observed. These signal amplification and fluctuation amplitudes are caused by the non-linear effects (Raman, Kerr) [2-4].

V. CONCLUSION

Our works consist in the implementation and the tests of a quasi-all-optical extension dedicated to sea floor observatories. First experimental results have shown the feasibility of such a solution. In these first tests, we have observed two effects: the Raman amplification and the fibre fuse effect [5, 6]. The Raman amplification can be useful to increase the received optical data power. Moreover, we have noticed the emergence of the fibre fuse phenomenon with high optical intensities. This phenomenon can destroy the optical components. Therefore, this effect restricts the maximum optical power in the fibre.

We have also made some experiments in the dynamic regime. The first obtained results show that the interaction between the high optical power needed for the power supply and the low optical power used for data transmission don't affect so much the data transmission.

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