POWER AND DATA OVER FIBER FOR SEA-FLOOR OBSERVATORIES

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Abstract: For the last decades, transmission of data and power over one single fiber has been investigated in different configurations for seafloor observatories. Recently, this technology was studied for long links up to 10 km. This quasi-all-optical link was demonstrated capable of transmitting data at 5 Mbits/s while providing an electrical power of 120 mW to the sensor. In this presentation, we will first present the developed technology and how the different parts of this link were optimized. Then we will expose its use for acoustic applications.

1. INTRODUCTION

The study of the sea floor is the cornerstone of many scientific problematic in geophysics, geochemistry, physical oceanography or biology. In addition to several fundamental scientific questions that are addressed, the monitoring of the seabed activities has become a strong necessity for assessing geo-hazard risks and preventing damages. Therefore, since the first seabed observatory was deployed by Japan in 1978, several systems have been developed and deployed in many locations. For instance, the European countries are currently operating observatories in the Azores archipelago, the Mediterranean Sea, the Iroise Sea, the Black Sea, the Ligurian Sea ... Canada is operating NEPTUNE in the Juan de Fuca gulf.

To be able to provide the scientist with such research infra-structures capable of performing long-term monitoring in real-time many technological breakthroughs had to be achieved. As the technologies and scientific approaches progress continuously, the seabed observatories are expected to evolve and be extended. In this work, we aim to develop a new technology for easy and cost effective extension of cabled observatories. The aim is to change heavy and expensive subsea cables by light and easy-to-deploy optical fiber links.

For the last decades, different technical solutions have been investigated to transmit power and data over fiber. In 2012, Lau et al reported the development of an extension for a seafloor observatory using this technology [1]. However, the system was only dedicated to an extension of few hundreds of meters from the junction box, which is too limiting for many scientific applications of cabled sea-floor observatories.

Cabled observatories are commonly composed of junction boxes connected to each other by optical fiber to transmit data and electric cables to get power. One of the junction box is connected to the shore.

We propose an extension of seafloor observatories by using the power-over-fiber technology will enable the easy deployment of sensors up to 10 km from a junction box. This system is also expected to transmit data in real time and at high speed.

The sensor interface, in our device, was developed for communicating with analogical sensors, in particular hydrophones. This kind of sensor could require a high sampling frequency (up to 100 kHz for some applications), high transmitted bit rate and continuous

measurement. For instance for a 16 bits sampling, the transmission rate has to be at minimum 3.2 Mbits/s.
To fulfil these technological requirements for a long distance, only low loss optical link can be used. Moreover, unlike most of the power-over-fiber systems reported in the literature [2], our quasi-all optical extension [3, 4] permits to increase the electrical power delivered to the sensor thanks to the transmission of a high power laser beam into the low attenuation spectral range of a monomode fiber.

2. OPTICAL SETUP

The whole system consisted in two parts (Figure 1). The first one is directly connected to the observatory junction box that provides power and communicates with it. It emits light for power and communication through the optical fiber that can be as long as 10km. It contains a High Power Laser Source (HPLS) emitting up to 36 dBm at 1.48 µm that is multiplexed with the down-stream data laser emitting at $\lambda_{down} = 1.55$ µm. These two laser sources then propagates along the optical fiber link. A microcontroller board communicates with the junction box and drives the two lasers. In addition, it receives the data from the up-stream data photodiode and transmits them to the junction box.
At the other side of the cable, is the terminal part. It converts the high power laser light into electrical power for the sensor. As the photovoltaic cell cannot convert power larger than few hundreds of mW, the 1.48 µm laser light is split to illuminate four cells. The down-stream data laser light is converted to drive the sensor interface board. This electronics converts the data out of the sensor and drives the up-stream laser that emitted the light back to the optical fiber cable at λ_{up} in C-band.

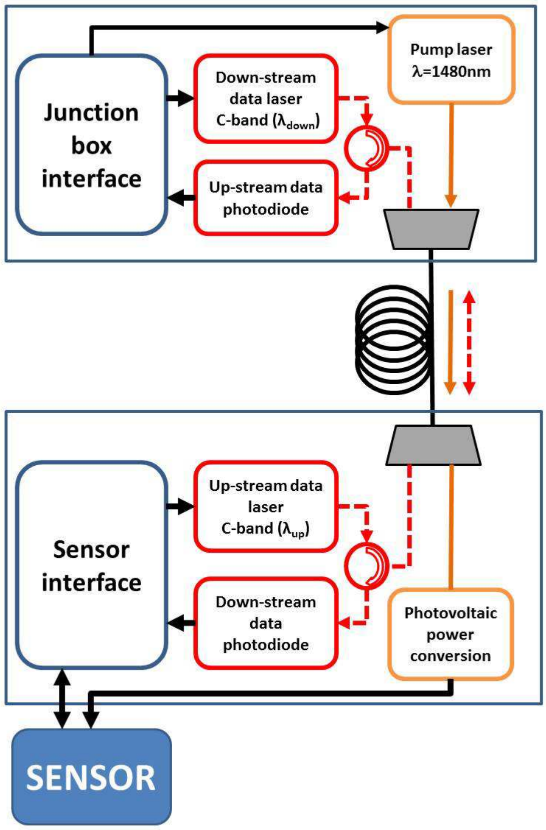

Figure 1: Architecture of the power-on-fiber. The red lines correspond to the data laser while the orange ones to the power laser path.

In this configuration, when the HPLS emits 33 dBm the sensor gets up to 180 mW electrical power at the end of a 10 km-long cable. The main losses come from the propagation through the fiber (2 dB) and the optics-to-electronics (O/E) conversion by the photovoltaic cells (6 dB). At 1.48 µm, the detector is made of InGaAs whose conversion yield is of about 25% (JDSU, PPC-9LW).
The data transmission is mainly affected by Raman scattering which generates a Stokes shift around 13.2 THz in a SMF-28. It should be noted the Brillouin scattering does not disturb the data transmission in our configuration.

In our experimental configuration, the HPLS optical wave propagates simultaneously with the data signals (wavelength in C-band). Stimulated Raman scattering phenomenon then amplifies both up and down stream data. On the other hand, it also contributes to amplify photon noise generated by spontaneous emission. The transmission error rate of the data is then a balance between amplified data and noise.

The Table 1 shows the attenuation of up-stream and down-stream data with regards to the power emitted by the HPLS, noted P_{HPLS} hereafter. The wavelength were chosen λ_{down} = 1550 nm and λ_{up} = 1551 nm At 33 dBm, the Raman amplification of data almost balances the attenuation along the 10 km-propagation in the optical fiber.

The BER (Bit Error Rate) of the up-stream and the down-stream data transmission was also measured as the HPLS power increases (Table 1). The BER increases with P_{HPLS}. It is always much smaller for up-stream than down-stream transmission. Indeed, when the data are transmitted in the same direction as the pump laser (HPLS), the ASE (Amplified Spontaneous Emission) becomes much stronger.

P_{HPLS} between 30 and 33 dBm will enable us to work with low BER. However, depending of the sensor power requirement, it might be necessary to increase P_{HPLS}.

Table 1: Data power attenuation and electric power available at the end regards to the HPLS emitting power

P_{HPLS} (dBm)	Down-stream data attenuation (dB)	Up-stream data attenuation (dB)	Electric power (mW)
30	-5.2	-5.2	80
33	-0.2	-0.2	180
36	-2	-2	220

Table 2: BER of up-stream and down-stream data transmission with regards to the HPLS emitting power. Signal bit rate : 150 Mbit/s

P_{HPLS}	BER down-stream data	BER up-stream data
0 mW	$<10^{-12}$	$<10^{-12}$
30 dBm	$8\ 10^{-12}$	$<10^{-12}$
33 dBm	$2.5\ 10^{-6}$	$<10^{-12}$
36 dBm	10^{-1}	10^{-8}

The best compromise for the HPLS power is then 33 dBm. This configuration leads to obtain an electrical power of 180 mW; and acceptable BER for the down-stream data.

3. COMMUNICATION:

As previously said our optical extension is dedicated for low-power submarine sensors. The electronics was developed to minimize the power consumption of the sensor interface by using low-power circuits (E.g. MSP430 microcontroller). Then, among possible protocols, we selected the SPI (Serial Peripheral Interface) protocol. Firstly it is compatible with sensors commonly used in the oceanic field, it is easy to implement, and it can transmit data at a rate suited to our needs (several Mbits/s). Secondly, it is a synchronous protocol with a master circuit, which provides the clock signal, and slave circuits. The junction box interface is the master one as the consumption requirements are much less drastic. Our first prototype was designed to drive a hydrophone without any control signal. This permits the use of a three wires SPI protocol. Nevertheless, only two optical data channels are available in our optical architecture. To address this issue, we proposed a solution which consists in using only two SPI signals, the clock and data coming from the slave, and creating the last signal (chip select) from the clock signal at the sensor interface. Then only two signals are transmitted through the optical link: the clock that goes downward,

and the data from the hydrophone that go upward.
Concerning the data transmission, NRZ coded optical data in C-band is used.

4. SYSTEM INTEGRATION:

When transmitting high power on optical fiber, fiber fuse may happen. The optical fiber is then generally damage and has to be changed. This phenomenon is difficult to cope with as it can be generated by random contamination, heat or contact. Then, from the HPLS to the photovoltaic cells, the fiber is continuous. The different patches are then spliced by fusion.
To get out of the marine container, commercial feedthroughs (SEDI Fibres Company) were integrated. They were qualified by measuring injection losses with regards to the hydrostatic pressure from 1 to 600 bars at three pump laser powers (27, 30 and 33 dBm). The insertion losses remain constant as the pressure increased whatever the P_{HPLS} is (figure 2). Strikingly, the injection losses decrease as the P_{HPLS} increases. This phenomenon is not well understood up to now [5].
These results show that the propagation of a high power laser beam combined to high hydrostatic pressure does not affect drastically the attenuation of the quasi-all optical link.

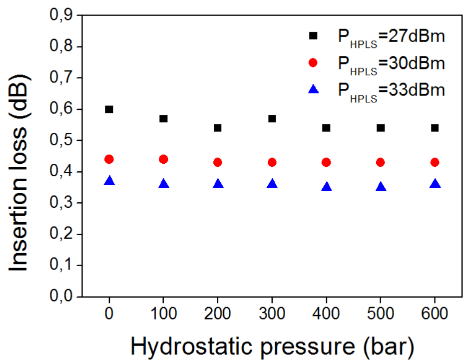

Figure 2: Insertion loss with regards to the hydrostatic pressure for three pump laser power (27, 30 and 33 dBm)

5. DEMONSTRATION:

A prototype was developed in order to demonstrate the capabilities of the optical-powering of the hydrophone. The current design of the electrical-optical converter for upstream data is based on a VSCEL (Vertical Cavity Surface Emitting Laser) with a lasing wavelength λ_{down} around 1537 nm and power intensity about -3.2 dBm. In our experimental conditions, this source offers better conversion efficiency than DFB (Distributed Feedback Laser diode) currently used for the first characterization. Furthermore VSCEL can be easily driven, which is a major advantage in a low consumption application. The O/E module is based on a standard PIN photodiode with a transimpedance amplifier.
After minimizing the different component consumptions, the sensor interface needs about 60 mW to transmit data at a 5 Mbits/s rate. Consequently, our system can provide 120mW to the sensor.

For the demonstration an acoustic source and the hydrophone were plunged into a seawater tank (Figure 2a). A 5 km optical fiber link was used for this experiment. A laptop drove the junction box terminal and got the data from it.
The acoustic source was set to emit a sinusoidal signal at 11 kHz. The signal that was measured by the quasi-all-optical link is shown of figure 3. As expected, the signal was a sinusoid. Its frequency was 11 kH

6. CONCLUSIONS:

The ability of powering sensor and transmitting data with only one fiber would provide scientists with an interesting approach to extend seafloor observatories.
The system can provide up to 180 mW at the end of a 10 km-long monomode optical fiber, 120 mW of which for the sensor. It

uses a high power laser source emitting at 1.48 µm and VCSEL laser diode emitting at 1.537 µm to transmit data.

A hydrophone can be powered by our system to measure in real time acoustic signals. Data are transmitted back to the junction box with a rate of 5 Mbits/s. Signal of frequency as large as 100 kHz can then be register continuously and in real time.

7. REFERENCES

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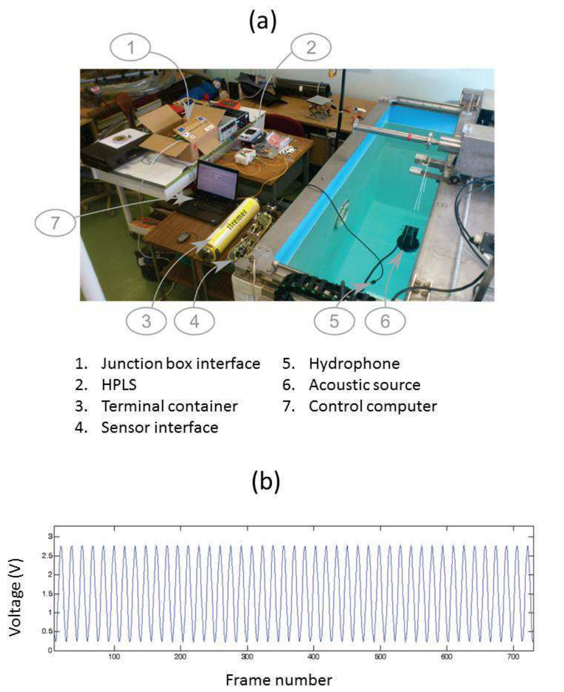

Figure 3: Picture of setup of the optical powered hydrophone experiment (a) and a typical signal obtained at the junction box end.