Submarine optical fiber communication provides an unrealized deep-sea observation network: Supplementary material

Yujian Guo[1], Juan M. Marin[1], Islam Ashry[1,+], Abderrahmen Trichili[1], Michelle-Nicole Havlik[2], Tien Khee Ng[1], Carlos M. Duarte[2,*], and Boon S. Ooi[1,]**

[1]Computer, Electrical and Mathematical Sciences & Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.
[2]Red Sea Research Center and Computational Biosciences Research Center, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.
[+]islam.ashry@kaust.edu.sa
[*]carlos.duarte@kaust.edu.sa
[**]boon.ooi@kaust.edu.sa

Experimental Methodology

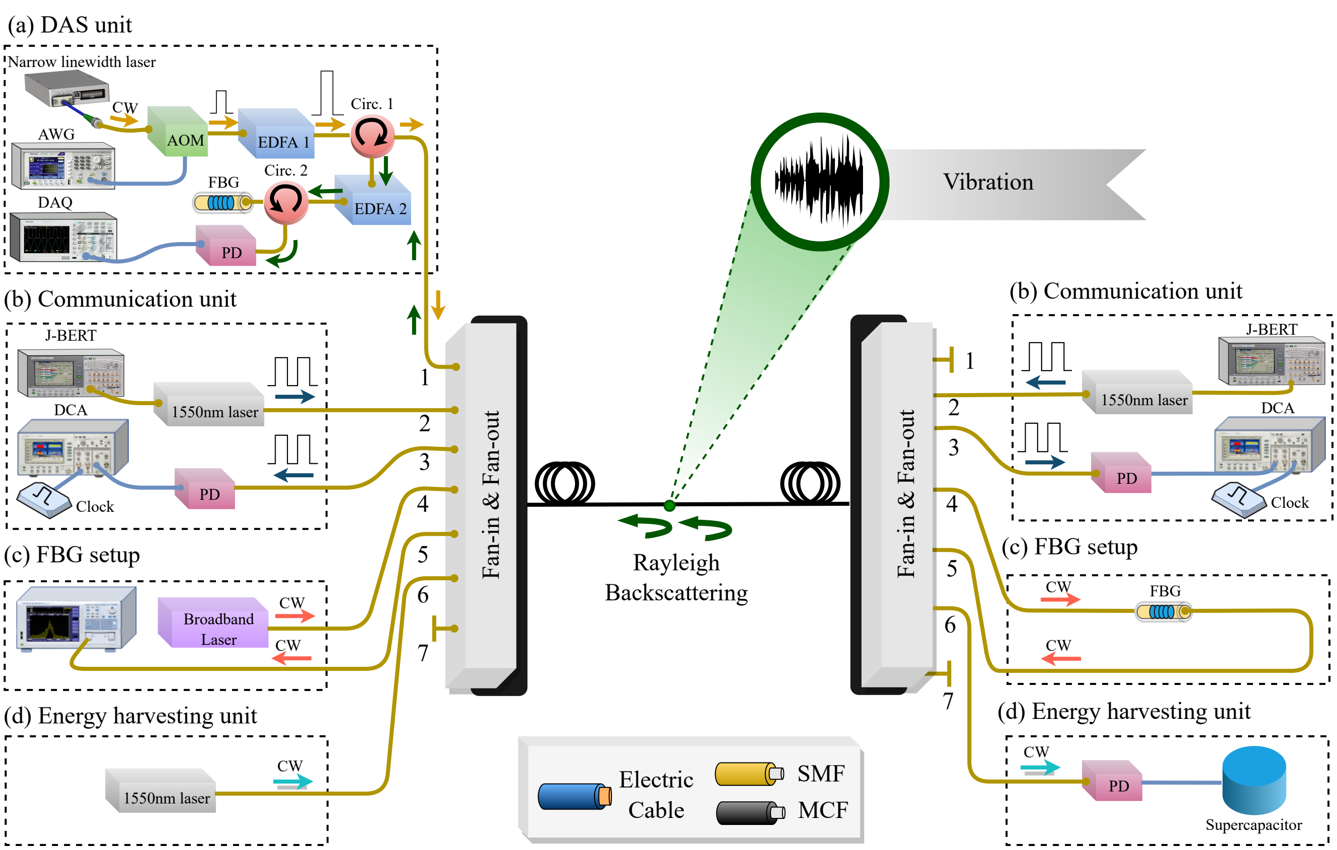

Figure 1. Experimental setup of the hybrid submarine fiber communication, sensing, and energy harvesting system: (a) DAS unit, (b) communication unit, (c) FBG-based temperature sensing setup, and (d) energy harvesting unit.

The detailed experimental setup for the hybrid system is shown in Fig. 1. The DAS unit comprises a collection of back-scattered Rayleigh traces created by a train of pulses launched from a narrow linewidth 1550-nm laser connected to an acousto-optic modulator (AOM). A 5-kHz pulse repetition rate and a 50-ns pulse period are used in the DAS unit, offering a 5-m spatial resolution. The optical pulses are then amplified by an erbium-doped fiber amplifier (EDFA1) and injected into a core of the MCF throughout a circulator and a fan-in/out multiplexer/demultiplexer (MUX/DEMUX). The back-scattered Rayleigh traces from the MCF are circulated to another EDFA (EDFA2), which amplified spontaneous emission (ASE) noise is filtered out using a fiber Bragg grating (FBG). The filtered Rayleigh signals are detected by a photodetector (PD) and sampled using a data acquisition device (DAQ).

In the FD communication system, each communication unit comprises a high–performance serial bit error rate tester (BERT) connected to a 1550-nm fiber-pigtailed laser. Upon propagation, the signals are received by a balanced PD and demodulated using a digital communication analyzer (DCA). Besides, the FBG-based temperature sensing setup contains a broadband laser generating a continuous wave (CW) light and an optical spectrum analyzer (OSA) on one side of the MCF. On the other fiber side, an FBG is connected to two cores to have a U-turn shape that transmits the broadband optical light back to the OSA. Monitoring the Bragg wavelength shifts on the OSA measurements provides the temperature values at the FBG location. In parallel, the energy harvesting unit comprises a 1550-nm laser generating a CW signal that is received by an Indium Gallium Arsenide (InGaAs) photodetector, which charges a supercapacitor.

Characterization of the FD Communication System

We measured the eye diagrams of the 3.2 Gbps OOK-modulated signals for the FD communication system (Fig. 2), when all other systems run in parallel. The open eyes in Fig. 2 indicate good received signal quality on both fiber cores.

Calibration of the DAS system

The DAS system is pre-calibrated before the testing by using a speaker submerged in the water, as seen in Fig. 3(a). The speaker generates a predetermined sound of a 1000-Hz single-frequency. As Fig. 3(b) shows, the DAS unit perfectly locates the speaker position and determines the sound frequency.

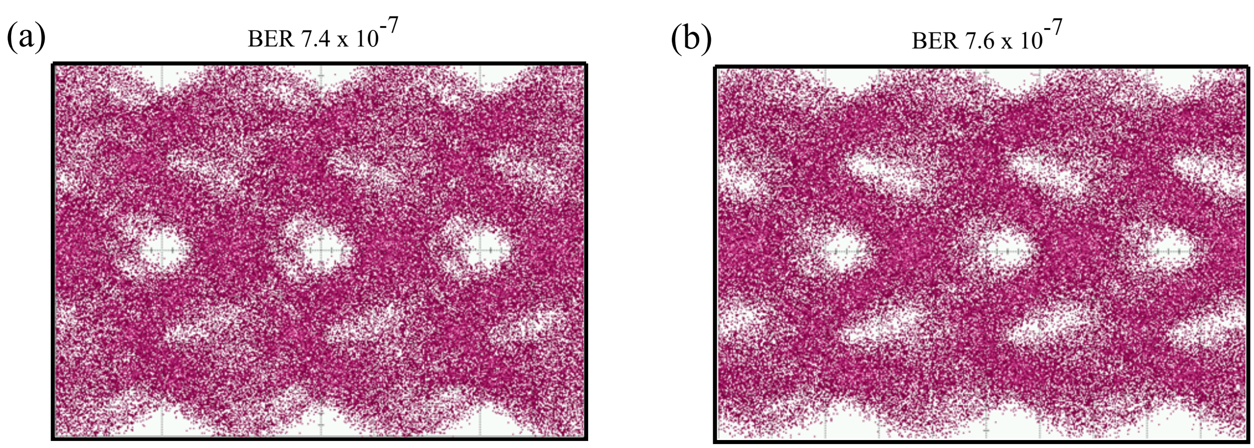

Figure 2. Eye diagrams of the OOK signals in the FD communication links.

Supercapacitor Charging

The equivalent charging circuit of the supercapacitor is shown in Fig. 4. I_{PD} is the photocurrent from the InGaAs PD working in a photovoltaic (PV) mode, and is proportional to the incident light power from the far end of fiber core. R is the equivalent resistor in the circuit from supercapacitor and electrical cable. C represents the capacitance of the supercapacitor serving as an energy storage/buffer unit, while I_{out} is the current that feeds the supercacitor.

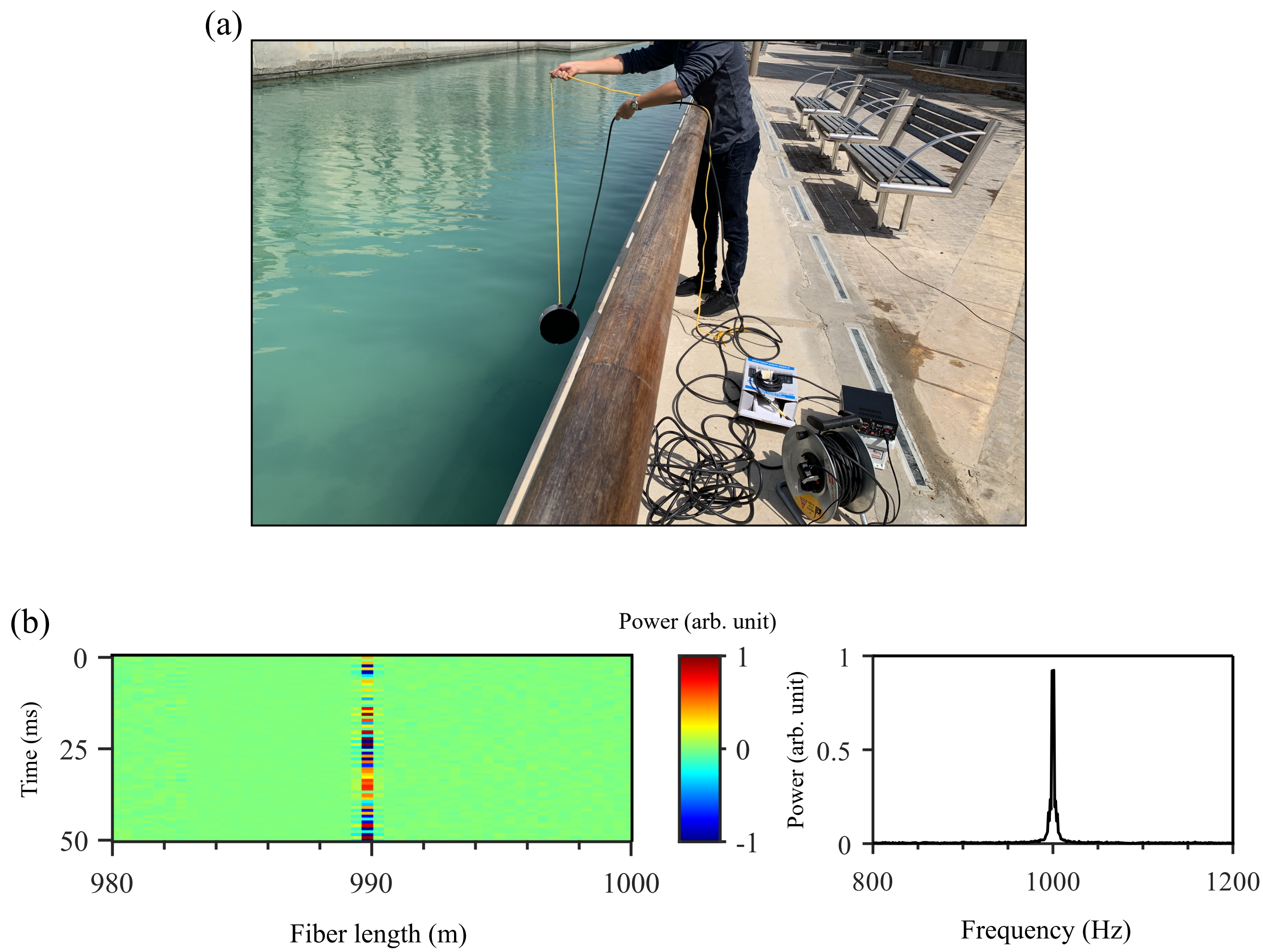

Figure 3. (a) Immersion of the speaker in the water at the fiber deployment location. (b) DAS calibration for sensing a predetermined acoustic event.

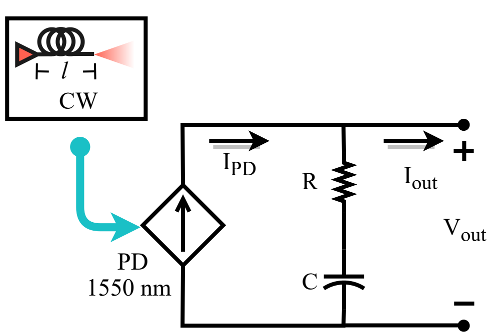

Figure 4. Equivalent charging circuit of the energy harvesting unit.