ELSEVIER

Developments for a passive optical node network for deployment in deep sea enabling time synchronous data readout.

Eric Heine,[a] Mar van der Hoek,[a] Jelle Hogenbirk,[a*] Peter Jansweijer,[a] Sander Mos,[a] Henk Peek,[a]

[a]*Nikhef, Kruislaan 409, 1098 SJ Amsterdam, Netherlands*

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

An overview of an optical network design for a VLVnT (Very Large Volume neutrino Telescope) [1] residing on the seabed is presented. The passive optical network transports all data to shore in a synchronous way without data congestion. Due to fixed propagation delay and low jitter over the fiber network an accurate event time stamp can be generated onshore. The determined signal propagation can also serve for detector calibration. The results of a proto type vertical cable test are presented.

. © 2008 Elsevier Science. All rights reserved

PACS: 95.55.Vj, 42.81.Uv, 42.79.Hp, *43.60.Fg

VLVnT; Underwater neutrino telescope, readout system, Passive Optical Network (PON), reflective electro absorption modulator (REAM) ;

* Corresponding author. Tel.+31(0)20 592 2051; e-mail:jelle@nikhef.nl

1. Introduction

Developments in photonic technology in the last few years are overwhelming. The developments in optical data communication caused a real boost in deploying long haul networks including fiber to the home (FTTH). Today, 150 separate optical channels, carrying each 10 Gbps over a single fiber is considered as standard. An optical amplifier compensates for the optical losses of all those optical channels over distances up to 100 km. Long haul standard fiber in combination with optical amplifiers and sections of dispersion compensating fiber can almost span every distance on earth. The completely passive behaviour of optical channels shows very stable constant signal propagation with negligible time jitter. Because of these characteristics, using photonic technology is ultimately suitable for data transfer in timing critical applications. The bandwidth of such a fiber network enables synchronous readout without data congestion and reduces electronics on the seabed. As a consequence there is less power dissipation on the seabed.

1.1. General

The basic architecture of an optical dense wavelength divisional multiplexing (DWDM) network for a Very Large Volume neutrino Telescope (VLVnT) is divided in an onshore part and a counterpart on the seabed. Figure 1 shows the basic architecture.

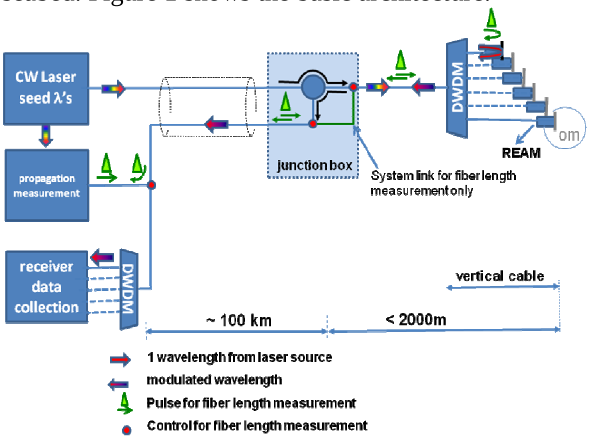

Fig. 1: Basic optical architecture

An on shore laser farm, produces continuous wave (CW) optical channels. These channels are sent over a long distance optical fiber to the junction box. Here those channels are forwarded via a circulator to a DWDM multiplexer in the base of a detector unit at the seabed (generally the base of a vertical string). From there, the CW signal is routed to a reflective electro absorption modulator (REAM) in an optical module (OM). The CW laser light is modulated by the REAM with the data generated by the OM and reflected back to the circulator in the junction box. The maximum length of such a bidirectional optical channel using the same wavelength in both directions is limited to approximated 2 km mainly due to Rayleigh backscattering. The optical circulator in the junction box routes the modulated signal via a return fiber to the shore station. The feature of this type of passive optical network (PON) is that the signal propagation delay is constant and that there is no significant time jitter, due to the absence of active routers or switches. Therefore a trigger signal from shore to a detector sub circuitry is very well defined in time as well.

A propagation measurement can be started over a return fiber by interrupting the synchronous data collection. The circulator in the junction box must be bypassed by a time calibrated bypass fiber. The measurement uses a pulse signal that is sent from shore via the return fiber to the REAM in the OM where it is reflected and sent back over the same fiber route. Propagation differences depend on fiber lengths, fiber chromatic dispersion, temperature and the central wavelength of the optical channel. The event time stamp on shore can be corrected with the measured signal propagation.

1.2. Laser farm

The accuracy of the central wavelength of the different CW laser 'seed' wavelengths depends, like every individually laser for DWDM applications, on precise tuning and monitoring. The foreseen optical channel spacing of 50 GHz demands that the laser temperature is controlled within 0.1 °C. The onshore location of the laser farm and the fact that there are no sub-marine DWDM lasers enables instantaneous access for maintenance and management of the PON.

1.3. Multiplicity

The number of optical DWDM channels per fiber exceeds the number of foreseen OMs per vertical string. Therefore several vertical strings can be connected to a single return fiber running from Junction box to shore. This is done by using DWDM bidirectional multiplexers at the foot of the strings. Each of these DWDM multiplexers carries the selected number of CW channels forward and the reflected data-modulated light backward. The current timing accuracy for a 3 inch photomultiplier signal is 1 ns. For synchronous read out of a group of 10 photomultipliers for "all data to shore" transmission gives a bit rate equivalent translation of 10Gbs per optical channel. A proof of principle will be available in September 2008. It will demonstrate data communication and timing accuracy over a span of 100 km with a bandwidth of 10 Gbps per optical channel.

2. Optical budget of a reflected optical signal

A passive configuration for a VLVnT architecture, using only lasers on shore and sub-marine electro-optical modulators, was originally proposed at the VLVnT2003 [2]. In order to test various aspects of such a passive configuration, some tests were done at the Technical University Eindhoven, the Netherlands. For the experiments, a single bidirectional fiber setup was made (see figure 2) to investigate the effects of accumulated Rayleigh backscatter and the threshold level for Brillouin scattering. According to literature, accumulated Rayleigh backscatter increases with fiber length but for fiber lengths in excess to 10 Km at 1550 nm it is limited to a level of -32 dB [3].

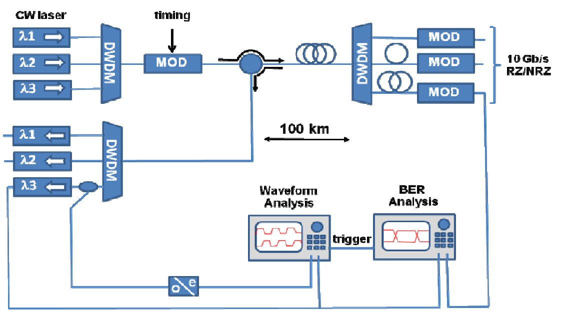

Fig. 2: Reflected light measurement setup due to light scattering in a fiber

For bidirectional fiber transmission over 100 km, the experiments revealed that due to the level of accumulated Rayleigh scatter, the signal to noise ratio as received by the detector is too low. The limit for 10 Gbps bidirectional fiber transmission is 2 km. This limit has led to the configuration as already shown in figure 1 [2].

3. Vertical cable assembly

3.1. Description

Vertical cables for the connection of 25 stories with OMs have been successfully used for the ANTARES detector.

A new design for a VLVnT vertical cable has been built by Seacon Europe Ltd, (UK) and is shown in figure 3. This type of cable structure has been successfully deployed by the British Navy. The vertical cable assembly has breakouts with a connector for quick and reliable connection to each OM.

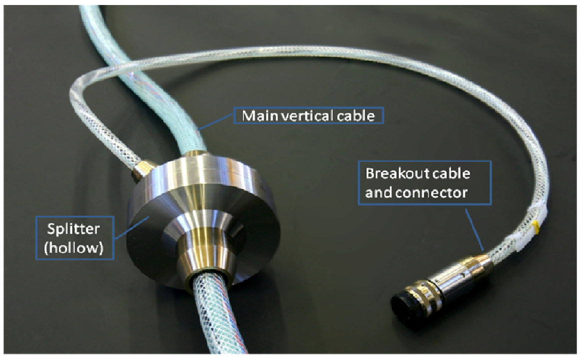

Fig. 3: Part of the vertical cable.

The cable harness consists of a Polyurethane hose, resulting in a free path for fibers and electrical wiring through the hoses. The hose system is filled with silicon oil to achieve an equal pressure system. The connectors are constructed to block the pressure difference between the almost atmospheric pressure inside the OMs and the pressure at the seabed. A DWDM unit is foreseen to be mounted in the base of each vertical string; therefore only one single fiber contact is required to connect the string. Powering requires 2 electrical connections.

3.2. Proto type vertical test cable

Seacon has built a 100 meter proto type cable with a breakout at every 25 meters. The top and bottom bulkhead connectors have 40 optical contacts and 4 electrical contacts. The cable is designed to withstand 60 MPa.

3.2.1. Electrical transmission tests

Besides power transport, the unshielded twisted pair (UTP)[1] in this cable assembly can be used for data transmission. The electrical loss in the proto type cable is significantly higher than expected due to the dielectric loss of the applied silicon oil[2]. The measured attenuation of 100 m UTP is 35 dB at 30 MHz and 49 dB at 50 MHz. It is expected that the low dielectric loss of silicon transformer liquid will result in a much lower attenuation.

No changes in electrical properties were observed while measuring over the range from atmospheric pressure up to 20 MPa.

3.2.2. Optical fiber tests

The test cable construction allows daisy chaining of 36 pressure resistant fibers[3] of 100 meters. This daisy chain uses 35 optical connector pairs and 2 connector pairs in the flying leads to the instruments. The total fiber length, including the flying leads, is 3750 meters.

At atmospheric pressure the total optical loss is 37.10 dB at 1550 nm. Due the short flying leads it was not possible to resolve the individual daisy chained bulkhead connector pairs with an optical time domain reflectometer (OTDR). The measured attenuation is linearly distributed. Therefore the total optical attenuation is assumed to be distributed evenly over the total number of 108 connector pairs. The attenuation per connector pair is 0.35 dB.

For comparison, the OTDR measurements did not deviate significantly from the expected values for a set of bulkhead- and flying lead connectors. The absolute polarization mode dispersion (PMD) measured on the series assembly of 3750 m length is 40 fs, resulting in an PMD coefficient of 21 fs/km^{½}. The allowed PMD for 10 Gbps, accepted by the telecommunications industry[4], is 10% of the bit time (10 ps). This limits the PMD coefficient for a link length of 100 km to a maximum of 1 ps/km^{½}.

Increasing the pressure on the cable assembly to 20 MPa resulted in an unexpected high optical loss which was due to mechanical failure. Measuring the PMD over a single fiber section of 100 m at a pressure of 20 MPa resulted in an absolute PMD value of 26 fs, being equivalent to a PMD coefficient of 82 fs/km½ . The increase in PMD at 20 MPa can be introduced by e.g. the additional coating that has been applied to the fiber for increased resistance to pressure. At present, the results for PMD over 100 km indicate this type of fiber to be suitable for 10 Gbps transmission over 100 km without the need for PMD correction. Still, PMD effects need to be investigated for higher pressures and series configuration of all fibers.

As the refractive index of quartz under pressure is well known and shows negligible pressure sensitivity, no measurements for chromatic dispersion are carried out.

Acknowledgments

This work is part of the research program of the 'Stichting voor Fundamenteel Onderzoek der Materie (FOM)', which is financially supported by the 'Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)'.

The authors like to thank the photonic laboratory of the Technical University of Eindhoven, The Netherlands, for facilitating measurements.

CIP Technologies (UK) and Seacon Ltd (UK) take part in this research program for respectively the optical structure and design of the 'hose'-cable.

References

[1] Proceedings of The workshop on Technical aspects of a VLVnT in the Mediterranean Sea ISBN90-6488-026-3

[2] M. van der Hoek, Data Transmission, VLVnT 2003 (http://www.vlvnt.nl/talks/P3/)

[3] M. Oskar van Deventer, Kluwer Academic Publisher, Fundamentals of Bidirectional Transmission over a single fibre. ISBN 0-7923-3613-

---

[1] UTP properties: Wire type: 20 AWG

2 Dow Corning 200 fluid 100 CST

3 Draka Comteq SMF28

4 Complies with IEC 60794-3:2001.Section 5.5