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Submarine fiber cable network systems cost planning considerations with achieved high transmission capacity and signal quality enhancement

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ABSTRACT

This paper has presented theoretically the comparison between three types of fibers which are investigated extensively: plastic clad silica (PCS), polystyrene (PS) and perfluorinated graded index polymer optical fibers (PF GI-POF) for high speed undersea cable systems. Based on experimental data, both the deep ocean water temperature and pressure are tailored as functions of the water depth. It is taken into account the estimation of the total cost of the submarine fiber cable system for transmission techniques under study. The system capacity as well as the spectral losses, and the dispersion effects are parametrically investigated over wide range ranges of the set of affecting parameters {wavelength, ocean depth (and consequently the ocean pressure and temperature), and the chemical structure}. The results show that PCS has the optimum performance in compared with other fibers. Therefore PCS fiber is the most appropriate candidate among all types of fibers for high speed local submarine communication systems.

1. Introduction

As information technology progresses, available network bandwidth for end-users increases, and the demand for high bandwidth in data communications and multimedia applications is growing stronger. Silica based optical fibers are widely utilized in backbone networks and are now found even in premise and access areas. Particularly in such local area networks (LANs), many fiber bendings and junctions are inevitable. A high-bandwidth graded-index plastic optical fiber (GI POF) is expected to be a medium for high-speed LANs because its excellent flexibility and large core allow for a low cost and user friendly installation [1]. Optical fibers composed of plastic have been in use longer than glass fibers. Types of standard fibers using plastics include multimode step index and graded-index fibers [2]. Multimode step index and graded-index plastic clad silica (PCS) fibers exist. PCS fibers have a silica glass core and a plastic cladding. Normally, PCS fibers are cheaper than all-glass fibers but have limited performance characteristics. PCS fibers lose more light through a plastic cladding than a glass cladding. All-plastic fibers have a higher numerical aperture (NA), a larger core size, and cost less to manufacture. However, all-plastic fibers exhibit high loss in the thousands of decibels per kilometer. This high loss is caused by impurities and intrinsic absorption. PCS and all plastic fibers are used in applications typically characterized by one or all of the following: high NA, low bandwidth, low loss in local data communications, tight bend radius, and low cost. Improved fabrication techniques provide the opportunity to experiment with material composition in both multimode and single mode fibers [2,3]. Fiber manufacturers fabricate optical fibers using glass material whose characteristics improve system performance in the far infrared region [4–7].

From the planning stage to the deployment of an undersea fiber-optic cable, a considerable amount of time, money and resources are invested to ensure the success of a submarine network. Yet one point that is often overlooked during this process, and which can lead to unfortunate delays [5], is the final acceptance test of the fiber simply put, this comes down to making sure that the fiber can deliver on the promised and expected bandwidth. This final acceptance test is often ignored since legacy data rates are considered as being extremely challenging to transmit. Yet with the deployment of 40 G [6], newer and more serious challenges are at hand, and in order to face them, they must be understood and properly prepared for. To do so, some critical physical-layer tests must be performed, including dispersion testing, such as chromatic dispersion (CD) and polarization mode dispersion (PMD). Tests that were considered as being of mild importance at 10 G, have become critical at 40 G transmissions. Once these parameters have been fully qualified and optimized [7], the system turn-up tests must then be performed; this includes signal power level and optical signal to noise ratio

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(OSNR) measurements, which are important in both repeated transoceanic or festoon links [8,9].

The paper is organized in the following sections. Section 2 has been discussed under water optical communications using submarine cable in more detail. Section 3 has explained and analyzed the mathematical model equations. Section 4 has presented the simulation results and performance evaluation of types of plastic fibers for high speed local submarine communication systems. Finally, Section 5 has presented the summary of PCS which has the optimum performance in compared with other plastic fibers and assured that PCS fiber is the most appropriate candidate among all types of fibers under the same operating conditions.

2. Under water optical communications using submarine cable

Fig. 1 shows the schematic view of under water optical communications with using submarine cable. Light propagation in seawater is highly wavelength sensitive, with transmittance falling from near 100% over several meters in clear ocean water for light of wavelengths 400–500 nm to near zero for turbid waters and wavelengths below 300 nm and above 700 nm [10].

Most of the current optical submarine cable systems employ WDM signals with a bit rate of 10 Gb/s. Very large capacity transmission of over 1 Tb/s per one fiber-pair is available for commercial systems, thanks to the significant advancements in the fields of optical transceivers, wavelength division multiplexing, optical amplification and optical fiber technologies. The main factors restricting the transmission distances and capacities of optical submarine systems include the degradation of optical signal waveforms due to the wavelength dispersion and nonlinear optical effects, both of which occur in the optical fibers. Also of concern is the signal to noise ratio degradation due to the accumulation of amplified spontaneous emission (ASE) noise emitted by the optical amplifiers incorporated in the submarine repeaters [11].

3. Submarine system model analysis

The pressure dependent Sellemeier coefficients and material dispersions for PCS, PS and PF GI-POF will be cast under the form [12]:

$$n^2(\lambda, T, P) = n^2(\lambda, T) f(P, \lambda) \tag{1}$$

where n is the refractive index, λ is the operating optical signal wavelength, T is the ambient temperature in K, P is the pressure in MN/m^2. Where $f(P,\lambda)$ is found to possess the form:

$$f(P, \lambda) = 1 + R(P, \lambda) \tag{2}$$

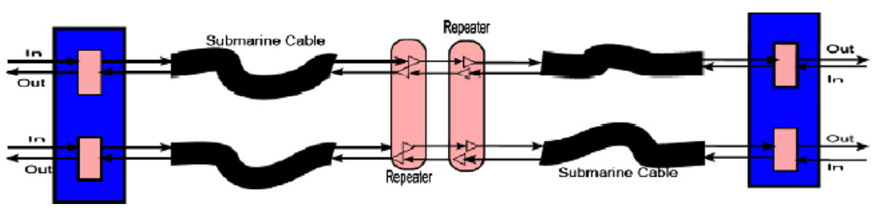

Fig. 1. Under water optical communications with using submarine cable.

Table 1
Coefficients for different materials based submarine transmission links [1–5,7,8].

Coefficients	Materials based submarine system		
	PCS [1,3,5,8]	PS [2,4,7,8]	PF GI-POF [1,2,5,7]
A_1	$1.54\times10^{-2}+5.65\times10^{-4}P+3.43\times10^{-7}P^2$	$2.543\times10^{-2}+0.03\times10^{-4}P-3\times10^{-7}P^2$	$0.45\times10^{-2}+2\times10^{-4}P-7.54\times10^{-7}P^2$
A_2	$0.54\times10^{-2}-6.5\times10^{-4}P-5.3\times10^{-7}P^2$	$2.34\times10^{-3}-5.23\times10^{-5}P+0.23\times10^{-9}P^2$	$4.76\times10^{-4}-0.65\times10^{-5}P-2.89\times10^{-9}P^2$
A_3	$7.8\times10^{-3}+0.05\times10^{-6}P+3.3\times10^{-9}P^2$	$4.78\times10^{-3}+.025\times10^{-7}P-0.13\times10^{-9}P^2$	$0.03\times10^{-4}-2.54\times10^{-6}P+2.98\times10^{-9}P^2$
B_1	0.4023	0.2123	0.00987
C_1	0.3456 (T/T_0)	65.2387 (T/T_0)	0.04353 (T/T_0)
B_2	2.5466	1.07653	1.435
C_2	3.5438 (T/T_0)	0.0345 (T/T_0)	2.8765 (T/T_0)
B_3	10.6543	0.055876	0.05234
C_3	0.2732 (T/T_0)	1.052 (T/T_0)	29.5432 (T/T_0)
G_1	2.65	4.65	2.876
G_2	−0.324	0.564	0.243
G_3	0.143	0.265	0.176
G_4	3.32	5.65	3.65
G_5	−0.453	0.765	0.432
G_6	0.324	0.456	0.765
G_7	3.87	6.87	4.21
G_8	−0.976	0.43	0.121
G_9	0.843	0.654	0.965
H_1	0.7	0.454	0.654
H_2	0.0453	−0.0123	−0.0053
H_3	0.00654	−0.00212	−0.00064
H_4	0.788	0.412	0.599
H_5	0.053	−0.0226	−0.0068
H_6	0.00754	−0.00345	−0.00078
H_7	0.854	0.378	0.512
H_8	0.065	−0.0456	−0.0079
H_9	0.00896	−0.00678	−0.00089