Design of an Optical Submarine Network With Longer Range And Higher Bandwidth

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Abstract - The modern age, sometimes also referred to as the information age is built upon a vast, globally interconnected communication network. The core component of this network has been the use of optical fiber networks. An optical fiber network, commonly referred to as an optical network is a telecommunications network with optical fiber as the primary transmission medium which is designed in such a way that it makes full use of the unique attributes of optical fibers. Over the last three decades, optical fiber communication has become the preferred medium for provision of the major infrastructure for voice, video and data transmission, because it offers far greater bandwidth and is less bulky than copper cables. Due to the rapid growth of the Internet and the World Wide Web, there was pressing need to develop fast reliable communication between different continents. This challenge was overcome by optical submarine networks which were essentially optical fibers laid over or under the ocean bed.

I. Introduction

By sending the pluses of light via an optical fiber cable on can communicated from one place to other. This mode of communication is known as Optical communication. An electromagnetic wave (i.e. – light) is generated and modulated as per our requirement. Now this modulated wave is then placed into in optical fiber cable for transmission. Electrical cables are generally not preferred for any long distance or high bandwidth communication system. In this case, Optical fiber cables are preferred. There are so many applications of this kind of systems. Internet is the best example which can signify the communication between two large continents. The data here is transmitted through using light, hence it is faster and more reliable than any other communication systems. An optical fiber communication system consists of a transmitter which converts the electrical signals to optical and place it on the optical fiber cable for transmission, a bundle of optical fiber cables packed into one large cable is used as the medium for light to travel, several amplifiers and to convert back the optical signal to electrical signal, an optical receiver is also used.

As we have our fastest mode of communication for large distances, we use it for the communication between two continents via the sea route. This kind of network is known as the submarine network. Here, on the sea bed, a cable is laid between the two stations. Nowadays, these cables are generally used to carry the data which is digitally modulated. As the distance between the two components is significantly large, even though we are using optical fiber communication, repeaters and amplifiers has to be used. The repeater contains several equipment for the applications such as error measurement and its control and signal reforming. In the case of repeaters, a solid state laser is used to again place the signal into the fiber. This laser acts as an amplifier because when it starts the emission, a short length of the doped fiber also gets excited. Now this excited part of the fiber also acts as a laser and in result, amplifies the signal. We can use the concept of DWDM with optical communication to make it even better and efficient. A constant current is passed through the center of the cable which powers up the repeaters. Hence we can say that all the repeaters attach to any system are in series with each other. A positive voltage is applied from one end of the cable and a negative voltage from the other. A virtual ground point exists roughly halfway through the cable. We use optical fiber for long distance communications from under the sea because of its extraordinary efficiency and the permissibility to transmit for over 100s of kilometers without any repeater or amplifier in between. Some distortion gets added on inserting any amplifier of repeater in between the optical fiber link. Hence we have to minimize the use of amplifiers or repeaters for this kind of transmissions.

In this project we are going to stimulate and maximize the distance for a section of submarine optical network between two repeaters or between two amplifiers for which the least error or BER is observed.

II. Optical Submarine Networks

Optical submarine networks are actually a part of a larger optical communication network that is deployed into the ocean. The typical characteristics are as follows,

1. The ranges of the transmission distances for these systems are,
   - **Long-haul** optical fiber networks from 600 to 1000 km;
   - **Extended-long-haul (ELH)** from 1000 to 2000 km;
   - **Ultra-long-haul (ULH)** above 2000 km.
2. The cables are difficult to access. Hence, maintenance requirements must be very low.
3. System lifetime should be very high as the process of laying submarine cables is very expensive.

4. The cables are usually capable of supporting large data rates and multiple services.
5. The above is usually accomplished by employing Dense Wavelength Division Multiplexing (DWDM).
6. The distance between in line amplifiers or repeaters should be large.

III. Major system parameters

The table below show some major system parameters that are used during the experiment.

TOTAL CAPACITY	80Gbps
BIT RATEPER CHANNEL	10Gbps
MODULATION SCHEME	NRZ
SIGNAL WAVELENGTH	1552.42 to 1558.12nm
CHANNEL SPACING	100Ghz or 0.8nm
MAXIMUM SYSTEM LENGTH	840Km
REPEATER SPAN	56Km
BIT RATE ERROR	Less than 10^{-9} [Without error control coding]
OPTICAL FIBER	Corning submarine SMFL
INPUT POWER	1dBm

IV. Block Diagrams

Figure 1 illustrates the block diagram of the communication system using optical fiber links to communicate between the stations.

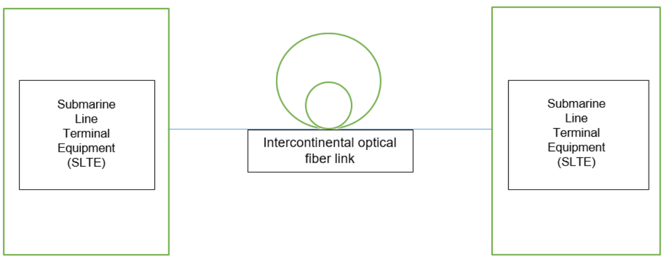


Fig. 1 – Overall optical communication system

Figure 2 illustrates the block diagram of transmitter section of Submarine Line Terminal Equipment (SLTE). Here, 8 channels are used for communication purposes. These 8 channels are passed to an 8×1 multiplexer which mixes the 8 signals into one using Dense WDM concept.

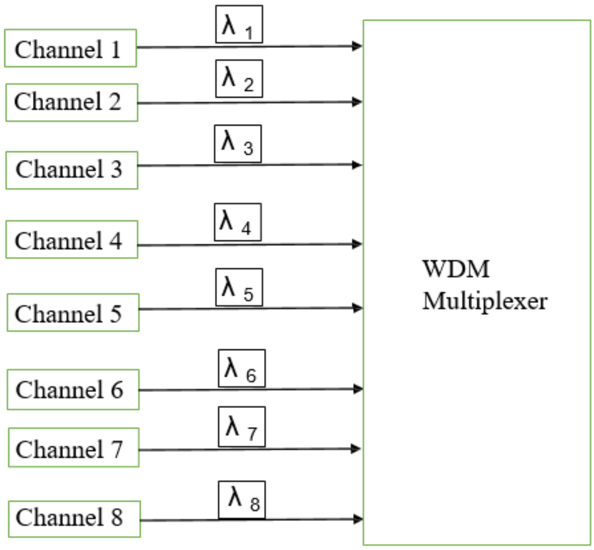


Fig. 2 – Submarine Line Terminal Equipment (SLTE) – Transmitter Section

Figure 3 illustrates the block diagram of receiver section of Submarine Line Terminal Equipment (SLTE). Here, the incoming signal from the optical fiber link is passed through an 8×1 de-multiplexer which separates the dense wavelength division multiplexed 8 signals and give 8 signals as the output.

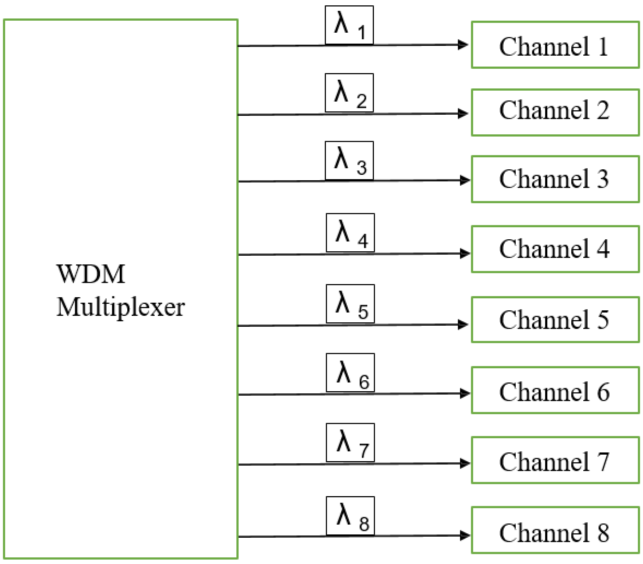


Fig. 3 – Submarine Line Terminal Equipment (SLTE) – Receiver Section

On the transmitter side, the signal is generated using the network shown in figure 4. On the receiver side, the incoming signal is extracted using the following network shown in figure 5. And the network used as the link between receiver and transmitter is illustrated in figure 6 below.

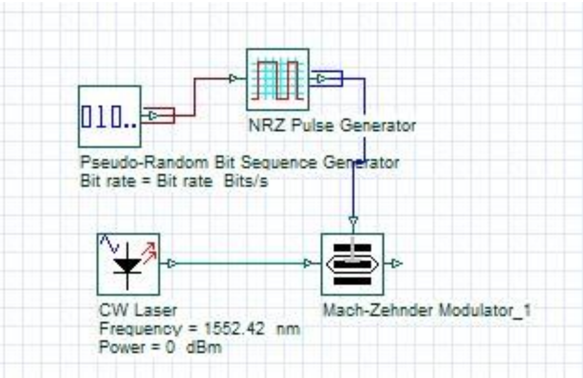


Fig. 4 – The network used at the transmitter side

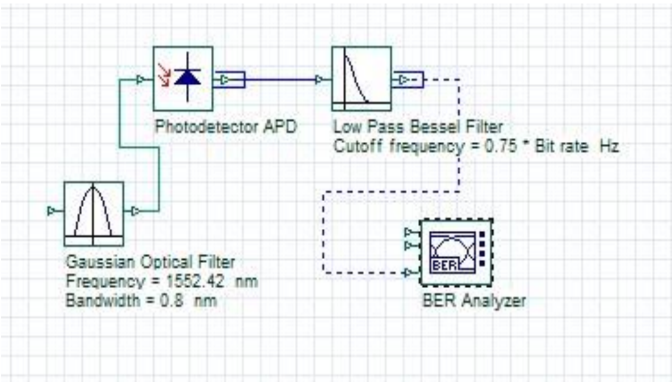


Fig. 5 – The network used at the receiver side

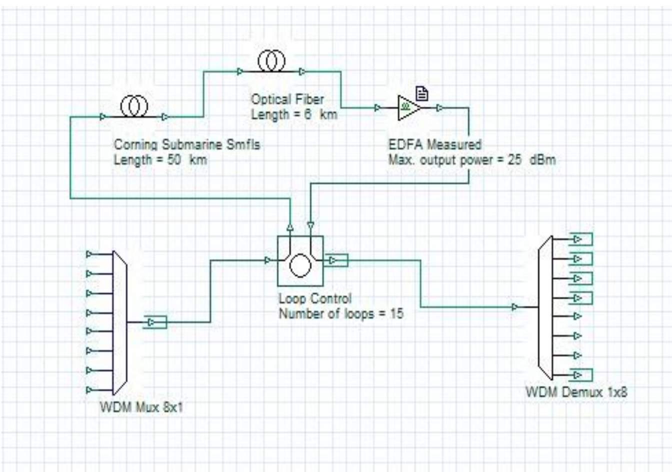


Fig. 6 – The intermediate network used between transmitter and receiver

V. Components Description

A. On the transmitter side, the components used are:

1. A pseudo random bit sequence generator having a generation rate of 10Gbps
2. A pulse generator generating pulses with NRZ encoding technique.
3. A CW Laser acting as a source of light generating the light of frequency 193 THz.
4. A Mach Zehnder modulator is attached at the end

B. On the transmitter side, the components used are:

1. A Gaussian optical filter to separate the incoming channels based on their respective wavelengths. For each wave, individual Gaussian optical filters are used. The center frequency is tuned to the frequency of corresponding channel. The bandwidth factor in the filter is set equal to the channel spacing.
2. An avalanche photodetector is used to detect the incoming optical signal.
3. A low pass Bessel filter with the cut-off frequency of 7.5Gbps is used to eliminate high frequency noise.

C. In between transmitter and reciever, the components used are:

1. **Corning submarine (SMFL) is used as the link from transmitter to the standard single mode fiber (SSMF) with,**
   - **Dispersion factor as -2ps/nm/km**
   - **Attenuation factor as 0.2 dB/km**
2. **Standard single mode fiber (SSMF) is used as a link from Corning submarine (SMFL) to the reciever with,**
   - Dispersion factor as 16.75ps/nm/km
   - Attenuation factor as 0.2 dB/km
3. An erbium doped fiber amplifier (EDFA) is also used with the gain of 10 dB.

VI. Design and Analysis

A. Calculation of fiber lengths and amplifier gains

1. Length of Corning Fiber (Lp) = Optimum length (in this case it is taken as 50 km which is typical in case of submarine systems)
2. Length of SSMF (Ls) is given by : LpDp + Ls Ds = 0
3. Calculation of EDFA gain (G) is given by : $(Attenuation/_{km}) \times (Ls + Lp)$ = G

B. Determination maximum system length

1. The length of the fiber was increased until the BER reduced to the maximum BER allowed by ITU standards ($< 10^{-12}$ with error control coding).

Note: In this project, no error control coding was used and yet the above mentioned standards were met

2. Number of loops = 15
3. Length of the fiber in each loop is 56 km
4. Hence total length = (Length of fiber in each loop) × (Number of loops) = 840 km

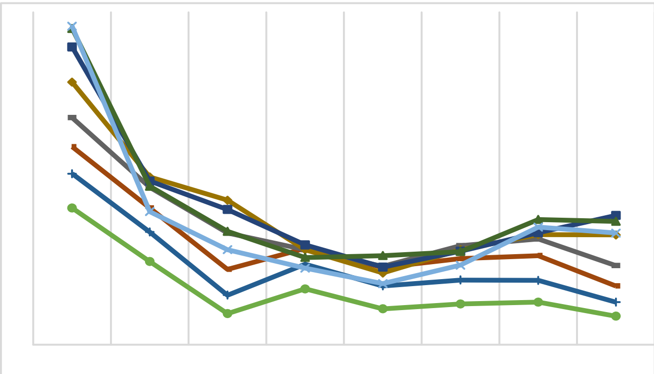


Fig. 7 – The quality factor ration for each wavelength

C. Determination of optimum power

The system was kept at its maximum length and hence, for different values of input power, the quality factor for each channel was analyzed. At low input powers, for all the channels, the quality factor increases when input power increases. However, beyond 1 to 2 dBm, it was observed that as the input power increased, the quality factor of outer channels (at the edges of the spectrum) tends to increase more than of the inner channels. For channels 1554.92 nm and 1556.52 nm, there was no significant improvement in the quality factor for powers greater than 1 dBm. Hence the input power for the system was selected as **1 dBm**. The following graph below (figure 7) shows a plot of the quality factor,

1552.52 1553.32 1554.12 1554.92 1555.72 1556.52 1557.32 1558.12
WAVELENGTH (nm) →

VII. Simulation and Results

On simulating the above discussed network in optisystem, some promising results were obtained. Figure 8 shows optical spectrum of the signal obtained after multiplexing and figure 9 shows the plot between the square of its amplitude and time. The output that we are getting in figure 8 is taken from Optical Spectrum analyzer and the output that we are getting in figure 9 is taken from the Optical Tim Domain Visualizer.

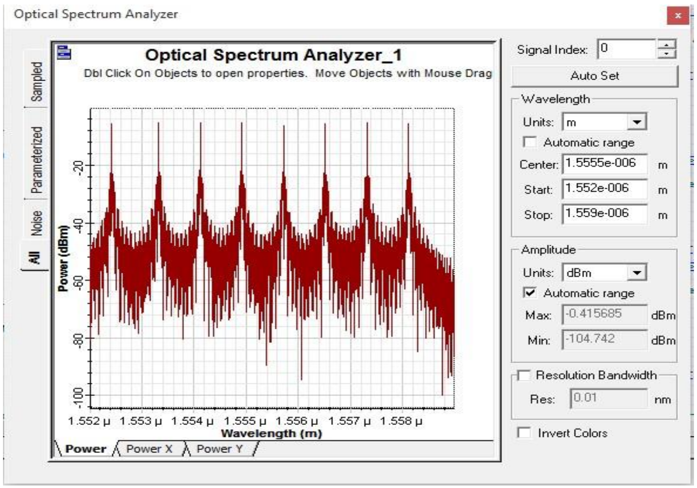


Fig. 8 – Optical Spectrum of multiplexed signal

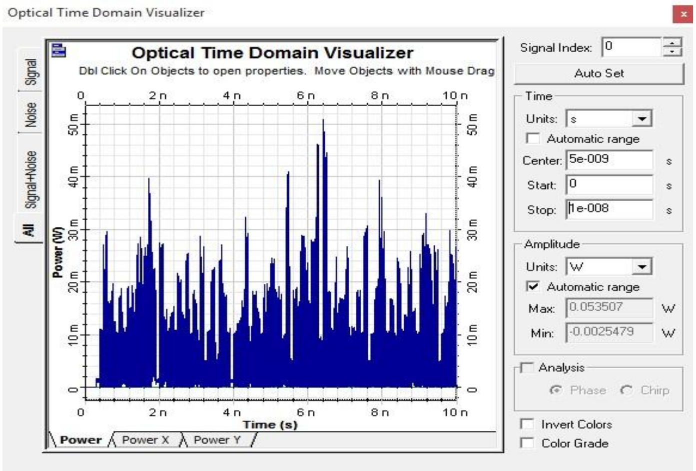


Fig. 9 – Plot $(Amplitude^2)$ vs Time of multiplexed signal

Figure below (figure 10) shows the spectrum obtained from different wavelengths after de-multiplexing. It is clearly visible that the signals are getting detected with reasonable power. Hence the signals are detectable and usable as the receiver's end.

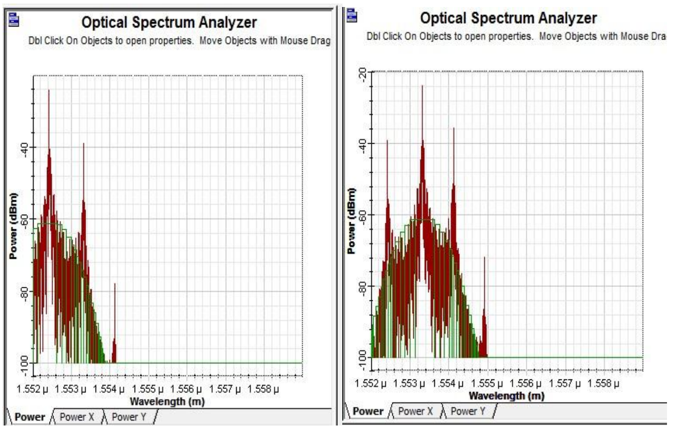


Fig. 10.a – Optical spectrum for 1552.52nm and 1553.32nm

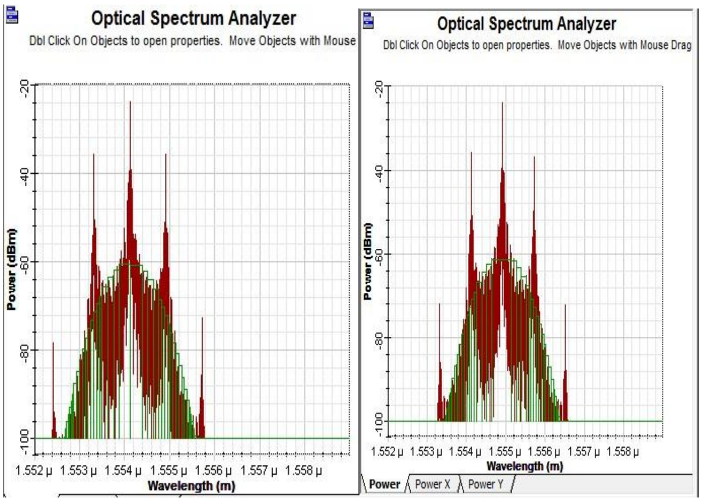


Fig. 10.b – Optical spectrum for 1554.12nm and 1554.92nm

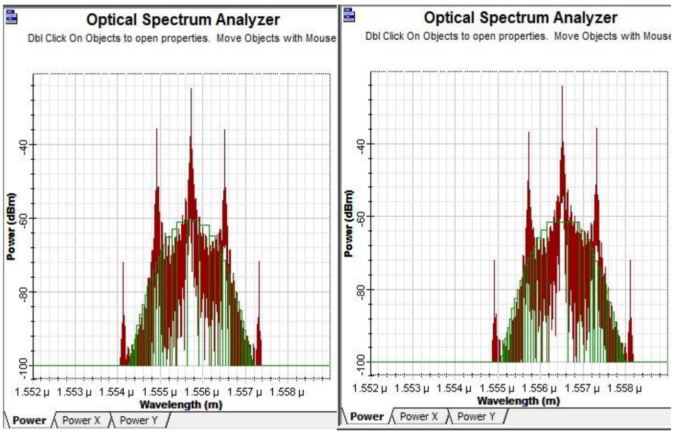


Fig. 10.c – Optical spectrum for 1555.72nm and 1556.52nm

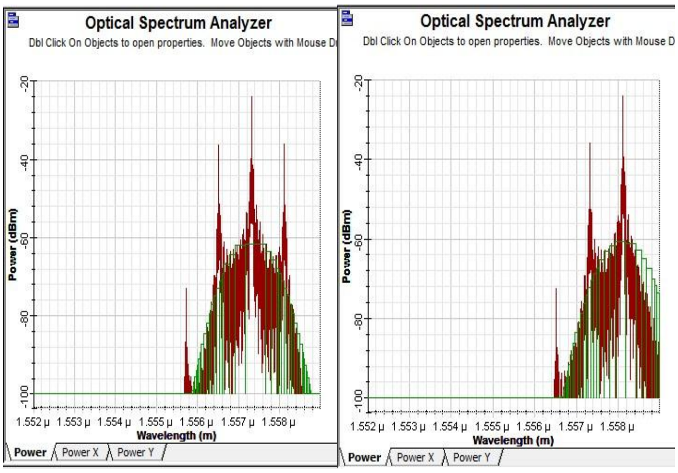
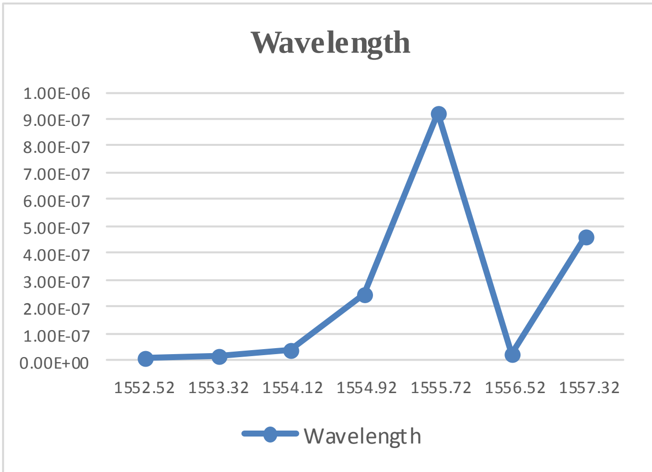


Fig. 10.d – Optical spectrum for 1557.32nm and 1558.12nm

VIII. Conclusion

An optical fiber submarine network for long haul applications was designed and implemented using software simulations in Optisystem. The various system parameters were determined and calculated by rigorous analysis with the aim of optimizing performance such that the transmission range is as long as possible. The final design achieves reliable communication over a distance of **840 km** with a maximum BER 10^{-7} for all the channels. Figure below shows the BER values obtained for different frequencies at receiver side after the communication.



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