Comparing ITU-T G.652,653 and 655 fibers for RZ modulation

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ABSTRACT: The study of advanced modulation formats for high speed internet services using potentially the bandwidth of single mode embedded fiber is very important. An investigation is done on ITU-T G 6.652 (single mode fiber) 6.653 and 6.655 transmission fibers for RZ pulse with different duty cycle. The variation of Q-value and BER versus distance for different duty cycle for different fibers is compare on single channel signal transmission for 10 Gbit/sec system.

Keywords: Fiber optic; Modulation; Communications

1. Introduction

The choice of fiber infrastructure is an important issue in the design of high capacity optical networks. DSF have been extensively studied at 10 Gbits per sec transmission rate [1], but its application is limited when high input power and low channel spacing are involved.

The dependence of the 10-Gb/s/ch long distance transmission performance on the signal pulse duty factor is studied by numerical calculation and experiments. The duty factor of the signal pulse is defined as the ratio of the signal pulse width to the bit duration time (100 ps) [2]. It is clarified that the optimum duty factor depends on GVD compensation interval for single-channel transmission. Reducing the duty factor was effective in suppressing XPM induced waveform distortion in WDM transmission. Analysis of both single-channel and WDM transmission showed that duty factors 0.5 were suitable for a dispersion managed system with GVD compensation interval of 500 km and a fiber dispersion parameter of 1 ps/nm/km [2].

Going through the literature, a need was felt to have a performance details of optical RZ pulse in other fiber types especially dispersion shifted fibers (DSF) of optical communication systems [7-14]. Most optical communication systems have adopted the non return to zero (NRZ) signal pulse format for data rates of up to 10 Gb/s/ch [6, 15-19] however some experiments over 100 Gb/s with dispersion management and WDM technology have used return to zero signal pulse formats at data rates of 5-10 Gb/s/ch [3-5]. This is because the RZ signal pulse format has several potential advantages over the NRZ signal pulse format including suppression of interchannel interaction caused by the fiber nonlinearity, such as cross-phase nonlinearity (XPM) and Four Wave Mixing (FWM).
and increase in signal-to-noise Ratio’s (SNR’s) for constant average optical powers. The issue is which duty cycle is better for RZ pulse for single channel 10 Gbps optical communication system using the SSMF which is extended to the dispersion shifted regime [20]. The results for variable duty cycle fraction for G.652, 653 and 655 are not available in the literature, thus explored.

2. Performance measures
The right choice of the performance evaluation criteria for the characterization of optical transmission links represents one of the key issues for an effective design of future long-haul optical systems. Long-haul transmission links experience performance degradation due to ASE-noise from optical amplifiers along the line. The most widely used performance measures for performance evaluation are Q-factor, BER and eye diagram.

2.1. Q-factor
Q-factor measures the quality of an analog transmission signal in terms of its signal-to-noise ratio (SNR). As such, it takes into account physical impairments to the signal viz. noise, chromatic dispersion and any polarization or non-linear effects which can degrade the signal and ultimately cause bit errors. In other words, higher the value of Q-factor the better the SNR and therefore the lower the probability of bit errors.

2.2. BER
The BER can be estimated from eq.(1), [21] and requires Q>6 for the BER of $10^{-9}$. This BER gives the upper limit for the signal because some degradation occurs at the receiver end.

BER = ... (1)

Optical communication systems use a BER to specify the performance requirements for a particular transmission link application. For example SONET/SDH networks specify that the BER must be $10^{-10}$ or lower, whereas gigabit Ethernet & fiber channel requires a BER of no more than $10^{-12}$.

2.3. EYE DIAGRAM
The eye diagram is powerful measurement tool for assessing the data-handling ability of a digital transmission system. The eye-pattern measurements are made in the time domain and allow the effects of waveform distortion to be shown immediately on the display screen. The basic upper and lower bounds are determined by the logic one and zero levels.

The width of the eye opening defines the time interval over which the received signal can be sampled without error due to interference from adjacent pulses (known as intersymbol interference). The vertical distance between the top of the eye opening and the maximum signal level gives the degree of distortion. The more eye closes, the more difficult it is to distinguish between ones and zeroes in the signal.

3. System modeling for transmission performance evaluation
Fig. 1 Optical communication link

The simulated diagram of optical communication system considered is given in Fig. 1 to examine the performance of RZ modulated signals on different fibers for different duty cycle. The simulation has been carried out using a commercial package OptSim™. The data is pseudo random having bit rate 10 Gbits/s with 16 samples per bit using polynomial of degree 7. The adjustable duty cycle RZ driver converts input to electrical outputs -2.5 low level to 2.5 high level. The numbers of poles in low pass Bessel filter has been kept to 1 and uses the -3dB cutoff frequency 9.953 GHz. The Modulator is a single arm mach-zehnder amplitude modulator with \( \sin^2 \) electrical shaped input-output (P-V) characteristics. Typical transfer function is taken for a mach-zehnder external modulator based on the eletro-optic effects in the LiNbO\(_3\) devices. The level of extinction ratio (corresponding to the ratio between the maximum and minimum values of the input-output transmission characteristics) is kept ideal. Fixed output power optical amplifier is used which sets the amplifier gain so as to have a total output power equal to a 5 dBm, flat gain shape and noise figure value 4.5.

The fiber length is varied up to 180 km in presence of fiber nonlinearity and polarization mode dispersion but without Raman cross talk to analyze the variation of various factors with respect to distance.

At the receiver, optical signal is passed through band pass raised cosine optical filter for centre wavelength 1552 nm. The detection is done with the use of pin Photodiode at 1552 nm wavelength with quantum efficiency of 0.75 and 0.939 A/W responsitivity. Electrical filter of low pass Bessel types with 5 poles & -3dB BW gives the electrical signal which is subsequently measured for Q values, BER and eye diagram.

<table>
<thead>
<tr>
<th>S. No</th>
<th>ITU-T Standard</th>
<th>G.652 Parameter</th>
<th>SMF</th>
<th>DSF</th>
<th>Corning LEA F</th>
<th>Lucent True Wav e</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Core effective area ((m^2))</td>
<td>(80 \times 10^{-12})</td>
<td>(55 \times 10^{-12})</td>
<td>(72 \times 10^{-12})</td>
<td>(55 \times 10^{-12})</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Loss at 1550 nm (\text{in dB})</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Zero dispersion wavelength ((\text{nm}))</td>
<td>139</td>
<td>158</td>
<td>151</td>
<td>146</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Fiber nonlinearity ((1/W/\text{km}))</td>
<td>1.27</td>
<td>1.84</td>
<td>1.40</td>
<td>1.84</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>First order dispersion (D (ps/nm-km))</td>
<td>16</td>
<td>-2</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Second order dispersion</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of fibers used in set up.
4. Results and Discussion

The investigation has been carried out at a bit rate of 10Gb/s for variable length link to yield a performance analysis of RZ data format for different duty cycle under different ITU-T recommended fibers.

To optimize the amplifier spacing it is important to investigate the performance of different fibers listed in Table 1 for variable length. Fig.(2)-(3) represents the variation of Q-value and BER with duty-cycle respectively for different fibers. Fig.4. represents the comparison of eye diagram for different fibers for fixed length (i.e. 100km) & duty cycle 0.8.
SONET/SDH networks specify that BER must be $10^{-10}$ or less. The maximum length range attainable with duty cycle variation from 0.2 to 0.8 is listed in Table 2 (Fig 3). Thus, amplifier distance can be increased up to 30 km for SSMF with duty cycle selection from 0.2 – 0.8. The amplifier distance can be increased only 10 km for DSF whereas this value is very low for LEAF and TW fibers.

From fig 2.3 and 2.4 it is clear that LEAF and TW fiber are showing similar trend, the Q-value variation with duty cycle is observed only for 40 – 120 km length of fiber. On comparing these 4 fibers for fixed length (100 km) of fiber & fixed duty cycle (0.8) then the eye diagram is shown in fig.4.

### Table 2. Fiber length range for duty cycle variation from 0.2 - 0.8, for BER=$10^{-10}$

<table>
<thead>
<tr>
<th>ITU-T</th>
<th>Fiber used</th>
<th>Fiber span length (kms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G65 2</td>
<td>SSMF</td>
<td>60-90</td>
</tr>
<tr>
<td>G65 5</td>
<td>DSF</td>
<td>150-160</td>
</tr>
<tr>
<td>G65 5</td>
<td>Lucent TW</td>
<td>150-160</td>
</tr>
<tr>
<td>G65 5</td>
<td>Corning LEAF</td>
<td>155-157</td>
</tr>
</tbody>
</table>
Fig 3. BER vs fiber length for different ITU-T transmission fibers for variable duty cycle 0.2, 0.4, 0.6, 0.8 of RZ pulse.

Fig 3 shows the variation of BER with fiber length for different ITU-T standard fibers for different duty cycle. Fig 4 shows the eye diagram for different fibers at span length of 100 kms and fixed duty cycle value of 0.8. On comparing Fig 4.1, 4.2, 4.3 and 4.4 it is clear that DSF gives the best results in the optical communication link of 100 kms at 10 Gb/s/ch with duty cycle 0.8 of RZ pulse.
The Q-value for 100 km fiber length & 0.8 duty cycle is listed in Table.3. The higher duty cycles gives higher Q values in SSMF, while it is least effected in DSF. The Lucent TW and Corning LEAF shows exactly reverse trend i.e. the Q-value decreases at higher duty cycles.

### Table 3 .Q-value for 100 km fixed fiber length

<table>
<thead>
<tr>
<th>ITU-T Fiber used</th>
<th>Q-Value for different duty cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty cycle</td>
<td>0.2</td>
</tr>
<tr>
<td>G65 SSMF</td>
<td>6.02</td>
</tr>
<tr>
<td>G65 DSF</td>
<td>34.0</td>
</tr>
<tr>
<td>G65 Lucent TW</td>
<td>36.2</td>
</tr>
<tr>
<td>G65 Corning LEAF</td>
<td>35.8</td>
</tr>
</tbody>
</table>

### 5. Conclusion

The ITU-T recommended fibers are compared for RZ modulation by varying the span length to 180 km without post compensation for different duty cycle at 10 Gb/s/ch optical communication system. For SSMF, the variation of duty cycle help to increase the amplifier distance from 60 to 90 km. Whereas DSF fiber shows negligible change with duty cycle but the maximum span length travelled is about 150 km which is better than SSMF. Corning and Lucent fiber are showing similar trends i.e span length travelled increases upto 120 kms on increasing duty cycle value and the Q-value decreases with the increase in duty cycle value

### 6. References


O. Sinkin, J. Zweck, C. Menyuk, Effects of nonlinearity-induced timing and amplitude jitter on the performance of different modulation formats in WDM optical fiber communications systems, OFC2003.

