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Design of Low Loss Optical Link and Comprehensive Study of Optical Link Loss Budget

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Abstract: Photonic multi-protocol label switching (MPLS) technologies such as generalized MPLS, optical burst switching and optical packet switching have received considerable attention as promising solutions to cope with the growth of the internet and internet related services. Among them, OPS has the potential to maximize fiber capacity utilization due to time domain statistical multiplexing with packet –level data granularity. Furthermore OPS may be superior in terms flexibility of traffic engineering and network scalability. However OPS imposes a severe technical burden on forwarding functions such as label processing and content resolution because high speed, asynchronous, arbitrary-length ,burst optical packets, not stream data must be handled on a packet by packet basis. In this paper we discuss the various types of losses associated with an optical network and optical link loss budget by fiber optic simulation. The performance of an MZI switch has also been analyzed by incorporating it in the link, which is one of the most promising candidates for realization of highly scalable realistic switching fabrics. A comprehensive study has been made to optimize performance of the link by selecting the most suitable components at each point in the network. The bit error rate has also been measured and the Q factor has been determined for optimum performance. In this paper we also discuss the extraction of thermal noise parameter for a specific receiver sensitivity, receiver noise and receiver sensitivity and sensitivity degradation. All the simulations have been done using the optisystem module of optiwave.

Keywords: optical link, link loss budget, BER, optimization, MPLS, APD.

I. INTRODUCTION

A logical way to proceed with designing a fiber optic link involves analyzing the fiber optic link power budget, also called an optical link loss budget. A practical link must tolerate some range of optical loss. Ideally, but not always, it should work back-to-back (i.e., with the shortest possible fiber). And of course, it should work with some longer length of fiber. The designer can often adjust any or all of these variables to create a product that meets the needs for a given application.

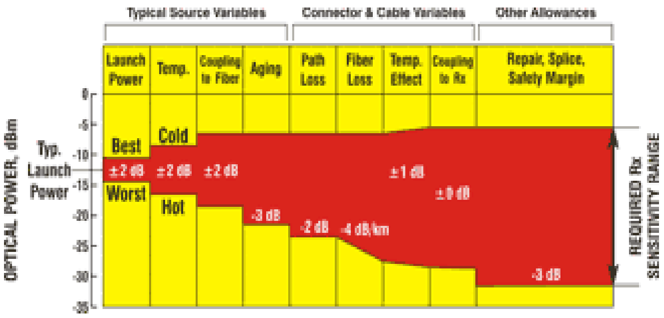

Fig. 1 Graph showing optical power and required sensitivity range

The graph shows a hypothetical link and its corresponding link budget. Start with the transmitter output power on the left side of the chart. The typical launch power is -12.5 dBm. However, the transmitter LED output power can vary by ±2 dB due to manufacturing variability of the LED itself. Therefore, the output power can be as high as -10.5 dBm or as low as -14.5 dBm. The block is shaded between these two values. **F**urther transmitter variations of ±2 dB result from the effects of temperature on the electronics and the electro-optics (e.g., LED or laser). Another potential ±2 dB of loss is due to variations in the optical coupling to the transmitter output. The effects of aging, typically 1-3 dB, should be included in the system's design. The next factor involves the losses due to optical connectors that may be in the optical path. The graphic allows 2 dB for this factor. For this system, the loss due to the optical fiber itself amounts to 4 dB/km of length. Multiply this value times the actual length to determine the loss due to the fiber considerations for temperature effects associated with most fibers usually yield ±1 dB.

The next factor, variation in loss at the receiver, requires a large-area detector to eliminate the effects of this parameter. Finally, a 3 dB safety margin should be built into all systems. At each step, any variation causes the shaded band to enlarge. On the right side of the chart the receiver has to cope with optical inputs as high as -5.5 dBm and as low as -31.5 dBm. Or stated differently, the receiver would need an optical loss range or optical dynamic range of 26 dB.
A discussion of the decibel is necessary to understand these link loss values. The decibel (dB) is a convenient means of comparing two powers. It is always a ratio between two numbers. For fiber optics, the ratio is usually the transmitter output power compared to the receiver input power. The equation to calculate a decibel is: dB = 10 x $\log_{10}(Power_1/Power_2)$ The decibel describes all loss mechanisms in the optical path of a fiber optic link. For example, a given AM video link may tolerate a maximum of 9 dB of optical loss. How much light actually reaches the receiver? Table 1 describes the decibel to power conversion. According to the table, 12% of the optical power actually reaches the receiver, so 88% of the light output by the transmitter was lost somewhere along the way. If the link could tolerate 20 dB of optical loss, only 1% of the transmitter's optical output would reach the receiver. To determine the amount of light reaching the receiver, take any two values that total the dB of optical loss in question. For example, 15 dB is the total of 10 dB and 5 dB. The corresponding power out for 15 dB is 3.2% according to Table 1. This value is also attainable by multiplying the corresponding percent values for the two dB readings, 10 dB and 5 dB, to get the desired result, e.g. 10% times 32% is 3.2%. Thus, 3.2% of the light actually reaches the receiver

Table 1

dB	Power Out as a % of Power In	% of Power Lost	Remarks
1	79%	21%	---
2	63%	37%	---
3	50%	50%	1/2 the power
4	40%	60%	---
5	32%	68%	---
6	25%	75%	1/4 the power
7	20%	80%	1/5 the power
8	16%	84%	1/6 the power
9	12%	88%	1/8 the power
10	10%	90%	1/10 the power
11	8%	92%	1/12 the power
12	6.3%	93.7%	1/16 the power
13	5%	95%	1/20 the power
14	4%	96%	1/25 the power
15	3.2%	96.8%	1/30 the power
16	2.5%	97.5%	1/40 the power
17	2%	98%	1/50 the power
18	1.6%	98.4%	1/60 the power
19	1.3%	98.7%	1/80 the power
20	1%	99%	1/100 the power
25	0.3%	99.7%	1/300 the power
30	0.1%	99.9%	1/1000 the power
40	0.01%	99.99%	1/10,000 the power
50	0.001%	99.999%	1/100,000 the power

We have to take into consideration the transmitter optical output power, receiver sensitivity, *and* optical link loss budget. An application that requires a 10 dB maximum optical link loss budget will operate the same using a transmitter with a 0 dBm output and a receiver with -10 dBm sensitivity or a system with a transmitter with a -10 dBm output and a receiver with -20 dBm sensitivity. By specifying only the required maximum optical loss, the most economical transmitter/receiver pair can be utilized. The only time that transmitter optical output power and receiver optical sensitivity need to be specified is when the transmitter and receiver are bought separately. In that case, the maximum optical link loss budget need not be specified.
An attempt has been made to design an optimum link satisfying the optical budget constraints. The chief components are : [A] Transmitters (1)Pulse generators (2)Optical sources -CW laser, Directly-modulated laser[B]Optical fibers(1)Nonlinear dispersive fiber [C]Receivers(1) Photodetectors-PIN photodetector[D]Amplifiers(1)Optical-EDFA [E]Visualizers (1)Optical-Optical spectrum analyzer(2)Electrical
There are three types of connections: optical, electrical and logical. All of the connections represent some kind of signal channel and do not necessarily represent a physical object such as a wire. The port types of the connecting components determine the connection type. Of course, these port types must match. For example, the connection between a pseudorandom bit sequence generator and an electronic pulse generator is logical; the connection between an electronic pulse generator and the modulating signal input of a Mach-Zehnder modulator is electrical.

II. DESIGN OF THE LINK AND OPTIMIZATION

Optical source:optical signals are generated by components such as lasers.Optical signals accommodate different types of signal representations.-
sampled signals ,parameterized signals, noise bins.
Sampled signals:optical signals can accommodate any arbitrary number of signal bands. In the simplest case, there is one single frequency band when a single ,continuous frequency band represents the waveform of all modulated optical carriers. A single optical source(like cw laser) produces a single frequency band. The frequency band represents the complex sampled optical field of the signal in two polarizations. This type of optical signal is a sampled signal. When two or more sampled signals are combined ,the individual signals will join into a new sampled signal if their simulation bandwidths overlap.The resulting signals called sampled signals –in this case each sampled signal is propagated using a separate sampled optical field.
Parameterised signals:The signal description based on the signals covers the majority of physical phenomena affecting the system design.When designing a system where the power budget analysis and the fast signal-to-noise ratio estimations are the main performance evaluation results,signal channels can be approximated by their average power,assuming that the detailed waveform of their data streams are not important.Parameterised signals are time –averaged descriptions of the sampled signals based on the information about the optical signal
Noise bins:Noise bins represent the noise by the average spectral density in two polarizations using a coarse spectral resolution.The resolution can be adapted to maintain the accuracy of the simulation.the main advantage using noise bins is to cover the wide spectrum of the optical signals or to represent the noise outside the sampled signal bandwidths.
The Pseudo –Random Bit sequence generator sends the bit sequence to the NRZ pulse generator. The pulses modulate the Laser Measured. The modulated signal is transmitted through an optical fiber cable for long haul transmission. We can also use an EDFA to enhance the signal strength and a MZI switch for switching the signal to the desired output port. The photodetector PIN(APD can also be used) receives the optical signal attenuated by the optical attenuator.(optional).The low pass Bessel filter filters the electrical signal.
Optical Spectrum Analyzer: Displays the modulated optical signal in the frequency domain.
Optical time domain visualizer :displays the modulated optical signal in the time domain.
Oscilloscope visualize: Displays the electrical signal after the PIN in time domain.
BER analyzer: Measures the performance of the system based on signal before and after the propagation. The optical power meters measured the power at each of the strategic points in the link.

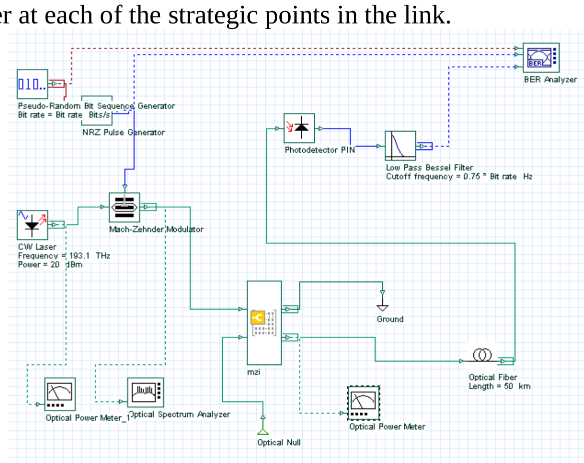

Fig. 2 Link designed with an incorporated MZI switch

The powers measured were 1.507 e-007 w at OPM and 3.2 e-002 w at OPM_1

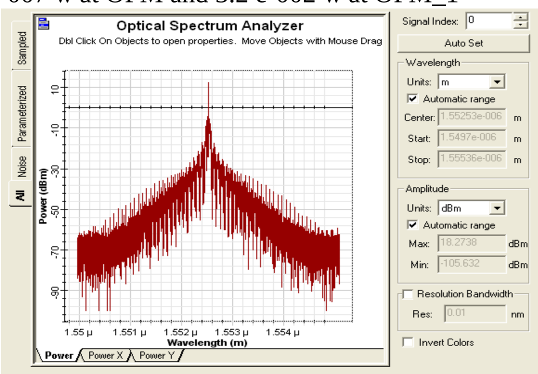

Fig. 3 Result of optical spectrum analyser

We have used the optimization tool in the context of parameter extraction.Thermal noise parameter of PIn is extracted to get a receiver sensitivity of -17 dBm .The transmitter power is selected to be 0 dBm.The bit rate is 10Gbs and the average received power is -17 dBm when the attenuation is 14.5 dB.The thermal noise factor of PIN comes out to be 5e-

22 W/Hz.After running the optimisation for about 3 passes the optimiser will find the thermal noise parameter to get a maximum Q factor of 14.24 when the recceived average power is -17 dBm.The proper thermal noise is found to be 5e-22 w/hz.

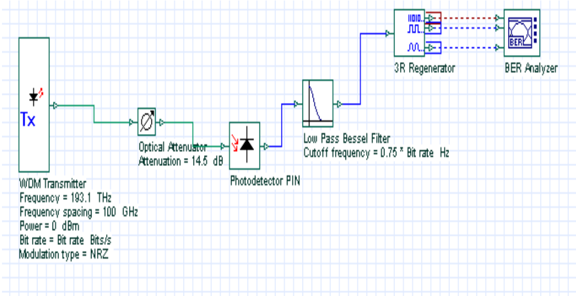

Fig. 4 Project layout for the extraction of thermal noise parameter of PIN

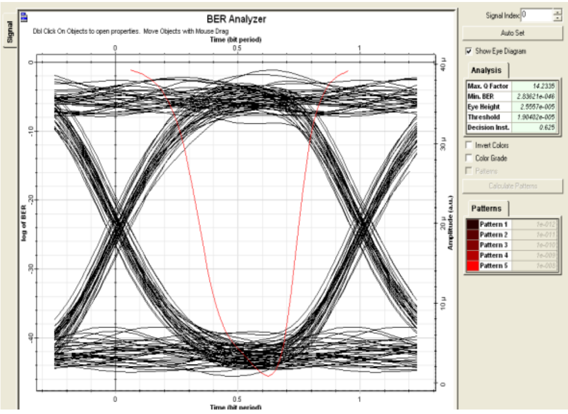

Fig. 5 Thermal noise factor of PIN with the received average signal power

There are two fundamental noise mechanisms in photodetector:
Shot noise and thermal noise.
The layout details the signal degraded by the thermal and shot noise in the PIN photodetector..The low pass filter has a cut off frequency with the same value as the bit rate.The upper system has photodetector without thermal noise,the only noise generated at the output is the shot noise which is signal amplitude dependent.

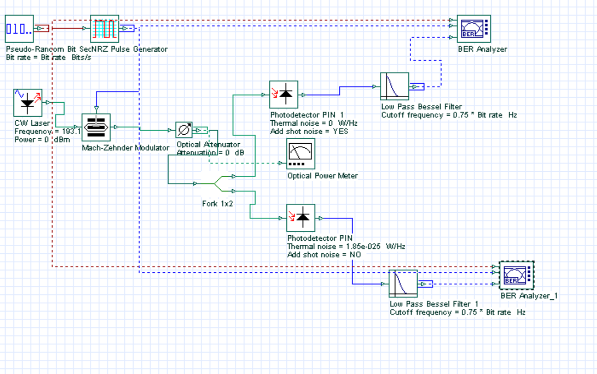

Fig. 6 Layout for receiver shot and thermal shot

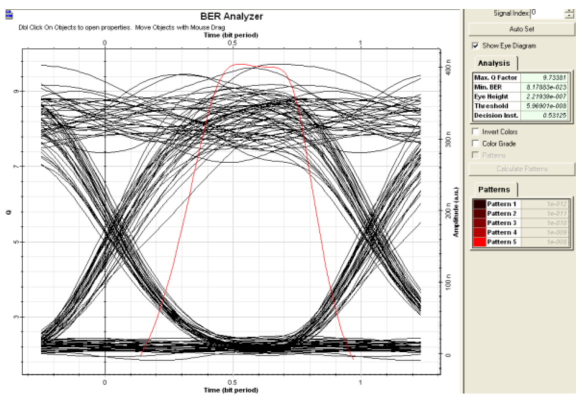

Fig. 7 Receiver Shot noise

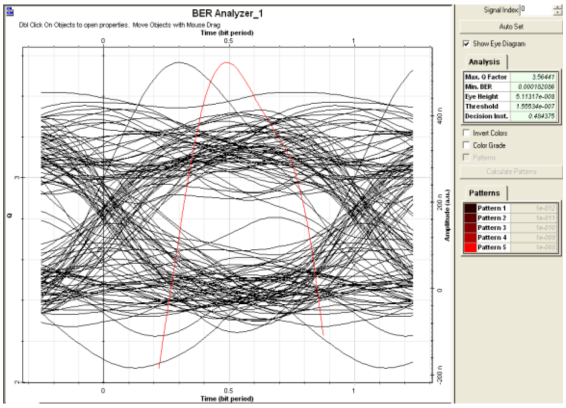

Fig. 8 Receiver thermal noise

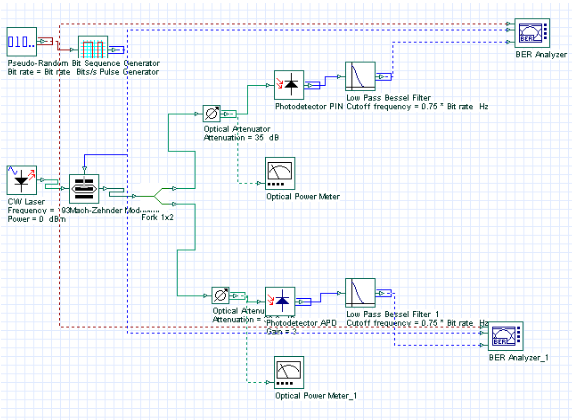

Fig. 9 Receiver PIN x APD

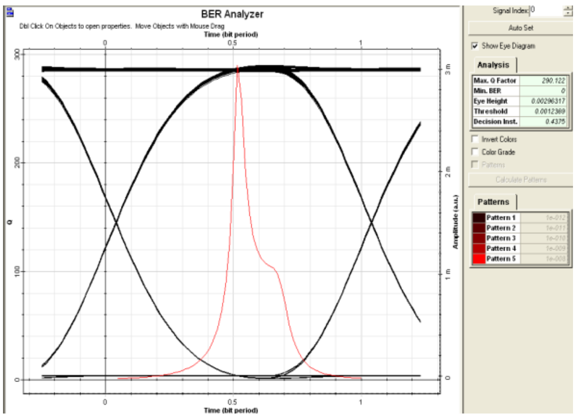

Fig. 10 APD Q factor

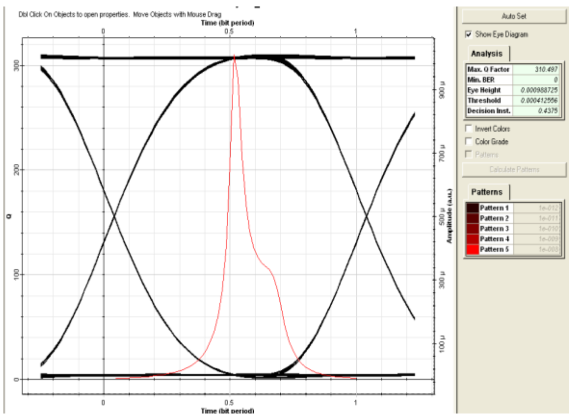
Fig. 11 PIN Q factor

The lower system has the photodetector with shot noise, the only noise generated at the output is the thermal noise which is signal amplitude independent.

The receivers with APD generally provides a higher SNR for the same incident optical power.The improvement in the SNR is due to the internal gain thet increases the photo current by the multiplication factor. The APD photdetector system has a Q factor higher than the one with PIN photodetector for a multiplication factor of 3.If we increase the multiplication factor there is a point at which the shot noise degrades the system performance,therefore it is important to find the optimum APD gain.If we run the same simulation and vary the value of multiplication factor we can see the evaluation of Q factor. For a gain higher of 16 there is no advantage to using the APD ,because it will not improve the receiver sensitivity.

The performance criteria for digital receivers if governed by the bit error rate (BER) defined as the probability of incorrect identification of a bit by the decision circuit of the receiver .The layout shows the BER and Q factor at the data recovery stage for different values of input power. If we change the signal input power, we can calculate Q factor and BER vs attenuation.

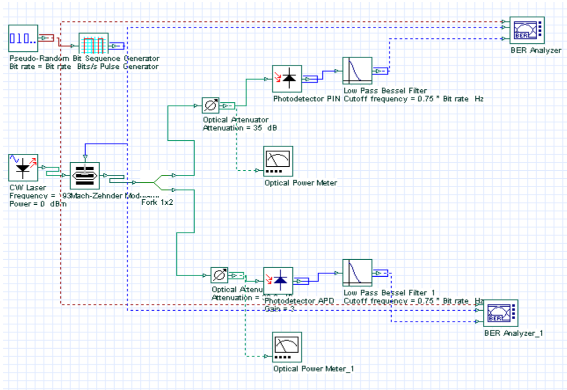

Fig. 12 Layout for receiver minimum received power

The layout shows the minimum optical power that a receiver needs to operate reliably with a BER below a specific value .We calculate the input power by targeting a BER of 10^{-9} a Q factor equal to 6 for a PIN photodetector and an APD.

The powers measured at the optical power meter visualisers were 1.507 e-007 w;-38.218 dBm at OPM and 7.214 e-008;-41.418 dBm at OPM_1

A simple source of power penalty is related to the energy carried by 0 bits.Some power is emitted by the transmitters even in the off state.The layout includes an external modulated laser where we can specify the extinction ratio at the modulator. We vary the value of ER and we calculate the q factor at the receiver.

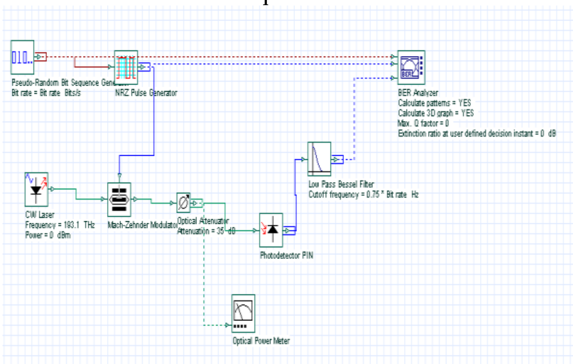

Fig. 13 Layout for sensitivity degradation –ER

III. CONCLUSION

In this paper we have designed an optimum optical link for best performance with the purview of compatibility of the designed MZI switch. An extensive study has been made to study the thermal noise parameter for a specific receiver sensitivity, receiver noise for PIN,receiver noises-shot and thermal,receiver sensitivity-BER, receiver sensitivity-minimum input power and finally sensitivity degradation with ER(extinction ratio).In future study can be made for incorporating a switching architecture in the designed link for minimum switching time and to make a comprehensive study of the various losses.

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