

Sensitivity testing in optical communication systems

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An optical receiver can be characterized from 'Sensitivity'. i.e. the optical Signal to Noise Ratio (OSNR) required to achieve a given bit error rate. The sensitivity testing is as performance measuring tool in many optical communication systems and this paper concentrate on such optical communication systems. The sensitivity depends on receiver's characteristics and the shape of the received pulse. In this paper BER versus SNR of wireless optical system is analyzed.

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1. Introduction

To check the performance of any optical digital communication system the sensitivity test is the standard tool. The result of the sensitivity testing helps to recognize the problem in an optical communication system. To check the accuracy of the received data sensitivity measurements are performed at the receiver end. The paper focuses on several forms of optical receiver sensitivity as figures of merit to analyze the performance of a digital optical receiver.

The optical receiver performs the conversion of optical bits to electrical bits and even the system is digital the performance of a system as a whole depends on analog characteristics of the optical receiver. But most of the time the performance of the system is tested only in digital form because the analog characteristics of the receiver are hidden in compactly integrated systems. The variations in results by testing of receiver sensitivity provide the guide lines for characterizing the main performance of completed receiver [1].

The sensitivity in this report is measured by product of measuring BER versus input power to the receiver under test. The paper concentrates on analyzing behavior of the receiver for the ideal signaling conditions.

2. Optical receiver

In order to provide inexpensive, reliable and high speed performance the optical receivers are heavily integrated. Fig. 1 shows the main ports of the optical receiver.

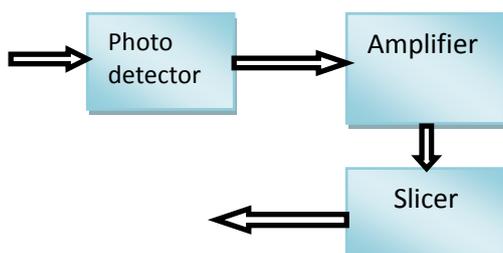


Fig. 1. Optical receiver.

The light from the optical connector is presented to the photo detector. The output of the photo detector is an electrical current and it is directly proportional to the input incident optical power. The second block in typical digital optical receiver is amplifier. The signal which is received is normally weak, and is converted to electrical signal from optical signal by photodiode and the weak electrical signal is passed to an amplifier so that it can amplify it and increase the power of electrical signal level. The amplified signal is then passed through filter to make it noise free. The amplified signal is inputted to the slicer. The slicer converts the analog signal to more of digital one. When the amplifier's output exceed the decision level the slicer give a digital one at the output and when amplifier's output falls below decision level the slicer give a digital zero. The output digital signal from slicer is still asynchronous and it may represent the digital data poorly as compared to the original data that is transmitted.

3. The basic optical sensitivity measurements

In optical digital communication the binary data is encoded as a stream of logical ones and zeros. The most common encoding technique that is non return to zero (NRZ) is assumed for this paper. In NRZ coding the logical one is represented by a pulse of light and the absence of the light represents zero. The case which is discussed for NRZ is the ideal case. In real case, as the limitation of laser light the one is represented by brighter light and zeros are represented by the dimmer period [1]. To recover the original data there must be a minimum difference in the amount of instantaneous optical power present in the individual ones and zeros, that is to convert the optical signal that is received at receiver to the electrical signal. The optical power is necessary for the signal to be recovered with fewer amounts of errors [3]. The receiver will start to generate more errors as the average optical power decreases. The basic concept behind the optical sensitivity measurement is that describe how much optical power is needed for the digital optical receiver to extract the original data with less amount of

errors. The characteristics of transmitter can affect the sensitivity of receiver in that if the extinction ratio is low, there is less optical difference between the ones and zeros that are transmitted. The extinction ratio is the ratio of two optical power levels, of a digital signal generated by an optical source. The slow rising and falling edges of transmitter can badly affect the receiver sensitivity. The receiver sensitivity is also badly affect if the transmitter some noise impairments [1].

4. Receiver sensitivity

The receiver sensitivity refers to optical signal to noise ratio (OSNR) that result in specific BER or in other words we can say that the sensitivity of digital optical receiver is defined as the average input power at which the receiver generates a specified bit BER. The specified BER for high speed communication system like 10Gbps optical communication system is 10^{-12} . Most commonly sensitivity is defined as power level and it is measured in dBm.

In optical communication systems, sensitivity is a measure of how weak an input signal can get before the bit-error ratio (BER) exceeds some specified number. The standards body governing the application sets this specified BER. For example, SONET specifies that the BER must be 10^{-10} or better. Gigabit Ethernet and fiber Channel specifications require a BER of 10^{-12} or better. This BER is the foundation for determining a receiver's sensitivity. In the design of an optical receiver, such as a small form factor optical transceiver module, it is vital that the module be capable of converting and shaping the optical signal while meeting or surpassing the maximum BER. The influence of noise on the signal will determine the sensitivity of the system. The portion of the receiver that contributes the most noise is the optical-to-electrical conversion provided by the photo detector and the Trans impedance amplifier (TIA). The sensitivity results strongly depends the measurement conditions including the quality of factor transmitted signal, the amount of input noise, the pattern at which the data is transmitted and the data rate [2].

As we are assuming ideal NRZ, so for ideal NRZ data to go across single mode fiber (SMF), the rough of sensitivity is straight forward. This section of the paper concentrate on this simplified case to highlight the main issues [4].

5. Sensitivity measurement systems:

The sensitivity measurement systems mainly contain common elements and these elements are illustrated in Fig. 2 and 3.

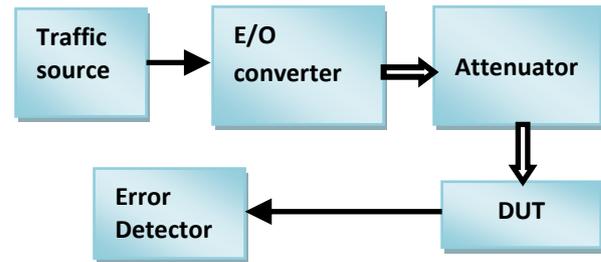


Fig. 2. Sensitivity testing of a DUT.

The different elements of sensitivity measurement are defined.

Traffic Source:

The traffic source provides the binary encoded data. This binary encoded data is the data that the receiver is expected to recover. The test data is mostly the variation of a pseudo random binary sequence (PRBS) pattern because bit error in real time is straight forward, but any data type will be enough means it will meet our requirement as long as there is a mechanism that quantify how many errors the receiver is making and the traffic source is the representative of the signals that the receiver will come across in regular use [3].

Electrical to optical (E/O) convertor:

Since the ideal case is discussed in this report and in ideal case we assume that the optical signal which is presented to receiver is noise free and it has well behaved eye diagram offering minimal inter symbol interference (ISI) and fast fall and rise time [4].

Attenuator:

The detailed diagram of calibrated attenuator is shown in Fig. 3. The elements of calibrated attenuator ensure that the device under test (DUT) a well characterized optical power level during testing.

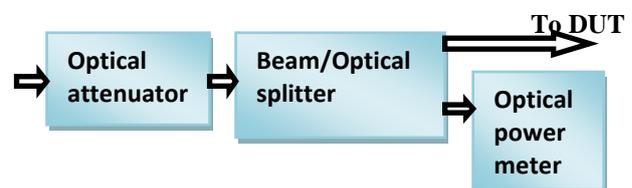


Fig. 3. Elements of calibrated attenuator.

Optical attenuator:

An optical attenuator is a device used to reduce the power level of an optical signal. Ideally it does not affect any characteristics of optical signal except optical power. This assumption is reasonable for tests using single mode fiber. The attenuator can change the characteristics of multimode fiber [8].

Beam/Optical splitter:

A beam/optical splitter are used to splits a beam of light in two. Beam splitters with single mode fiber used for the single mode behavior to split the beam. The splitter is done by physically splicing two fibers "together" as an X.

Optical power meter:

An optical power meter is normally used to measure the energy in an optical signal. This metering is simple to achieve in single mode fiber using a calibrated optical splitter. There are specially designed multimode splitters that reduce the undesired variation of in multimode fiber [5]. A typical OPM device consists of a calibrated sensor, display and management units.

It is very important to design power metering subassembly for high reproducibility, as even a change of 0.1dbm will result in large change in BER near the sensitivity limit [6]. Using just DUT without power metering will not work properly as it will result in inferior calibration of the signal that will pass through DUT.

Error detector:

Error detector is used for counting errors in the recovered data stream [7]. The error detector counts total number of bits and total bit errors for the specified period of time and thus yields BER.

Bit Error Ratio:

The bit error rate (BER) or more accurately the bit error ratio is the main quality indicator of an optical communication system, as it gives the probability of bit errors. Naturally, a low BER is required for accurate transmission of data. The BER of a digital communication system can be defined as the estimated probability that any bit transmitted through the system will be received in error, e.g., a transmitted "one" will be received as a zero and vice versa. In practical tests, the BER is measured by transmitting a finite number of bits through the system and counting the number of bit errors received. The ratio of the number of bits received erroneously to the total number of bits transmitted is the BER. The quality of the BER estimation increases as the total number of transmitted bits increases. In the limit, as the number of transmitted bits approaches infinity, the BER becomes a perfect estimate of the true error probability. In some texts, BER is referred to as the bit error rate instead of the bit error ratio. Most bit errors in real systems are the result of random noise, and therefore occur at random times as opposed to an evenly distributed rate. Also, BER is an estimate formed by taking a ratio of errors to bits transmitted. For these reasons, it is more accurate to use the word ratio in place of rate [2]. Experimentally, the BER is simply measured by detecting the received signal, comparing with the transmitted signal and then counting the errors.

$$BER = \frac{\text{Number of Errors}}{\text{Total number of bits}} \quad (1)$$

6. Simulated system

The following digital communication system is simulated.

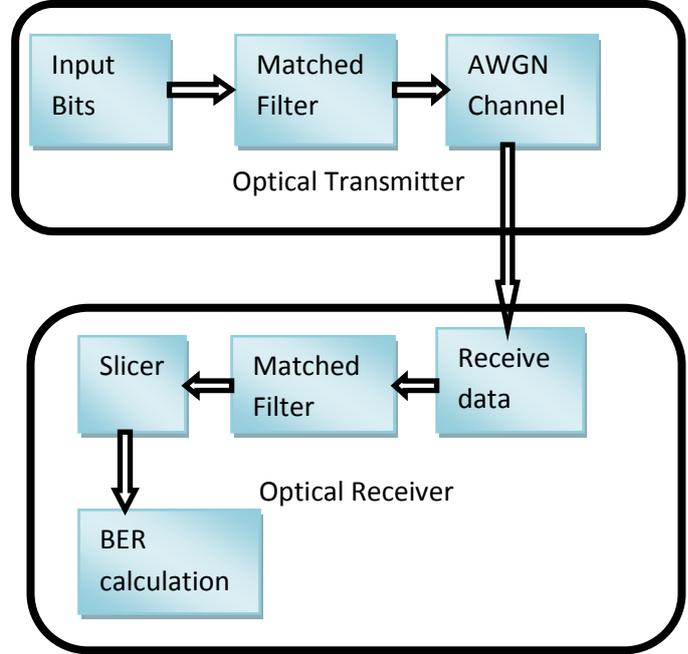


Fig. 4. Block diagram of communication system.

Simulated results:

At the transmitter side the input bits stream of zeros and ones are generated first. These bits are then passed through matched filter. The resultant eye diagram after the data is passed through matched filter is shown in Fig. 5.

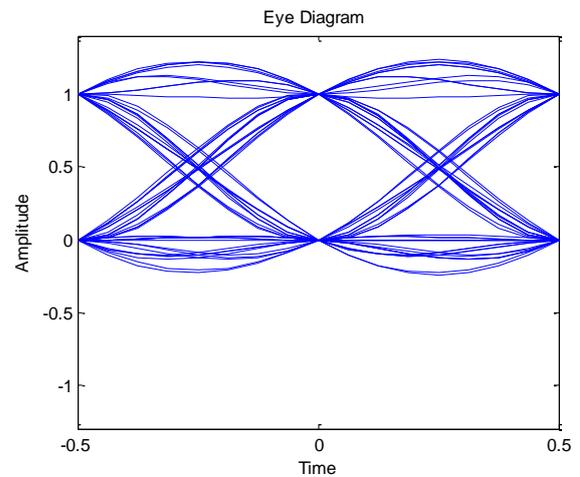


Fig. 5. Eye diagram after match filter at transmitter.

The openness of the eye in Fig. 6 shows that there is no ISI. This data is passed through AWGN channel and the data is received at receiver end. The received data with noise is passed through matched filter at the receiver of an optical communication system. The result of the received data after passing through matched filter is shown with the help of eye diagram in Fig. 7.

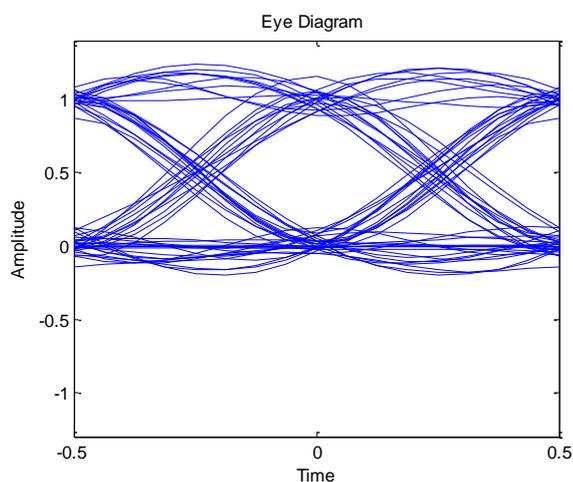


Fig. 6. Eye diagram after match filter at receiver.

The openness of the eye in Fig. 6 shows little ISI. The ISI is because of the channel noise added to it during transmission. The filtered data is passed through slicer. The slicer converts the analog signal to about digital one. When the output exceed the decision level the slicer give a digital one at the output and when output falls below decision level the slicer give a digital zero.

At the end BER is calculated with respect to different signal to noise ratio (SNR). The BER tends to decrease as the SNR is increased and the plot of BER versus SNR is shown in Fig. 7.

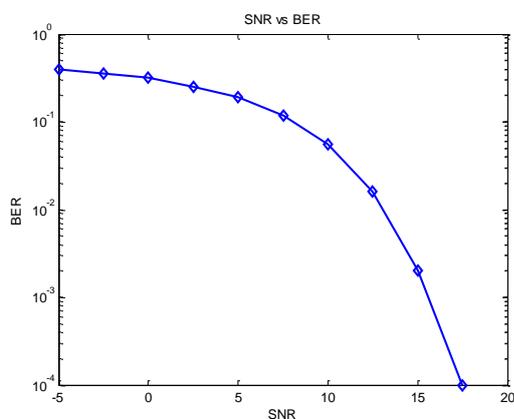


Fig. 7. SNR vs BER.

7. Conclusion

Sensitivity testing generally requires the input power to DUT receiver is varied and the BER is determined for different SNR. The elements of sensitivity testing system are discussed and they play a very important role in measuring the performance of optical receiver. The chapter focuses on several forms of receiver sensitivity as figures of merit to explain the performance of digital optical receiver. The sensitivity is defined to cause the receiver to operate at specified BER value. The variation in BER while increasing the SNR is discussed and the effect of increasing SNR on BER is explained. It is concluded that sensitivity plays a vital role in analyzing the performance of optical digital communication systems, especially in systems that are providing high speed.

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References

- [1] D. Derickson, M. Müller, Pearson Education, 2007.
- [2] J. Redd, visited on 24 August, 2014.
- [3] G. Tang, JDS Uniphase Corporation, October 2008.
- [4] L. Andreas, N. Kaneda, Ut-Va Koc, Young-Kai Chen, Conference on Optical Fiber Communication and the National Fiber Optic Engineers Conference, (OFC/NFOEC), pp.1,3, March 2007.
- [5] X. Liu, D. Du, G. Mourou, IEEE Journal of Quantum Electronics, **33**(10), 1706 (1997).
- [6] J. C. Cartledge, IEEE Transactions on Communications, **26**(7), 1103 (1978).
- [7] Anbo Wang, Se He, Xiaojian Fang, Xiaodan Jin, Junxiu Lin, J. Lightwave Technol., **10**, 1466 (1992).
- [8] Yong Zhao, Yanbiao Liao, Shurong Lai, Photonics Technology Letters, **14**, 1584 (2002).

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