Design Optimization of 10Gbps Optical Telecommunications Receivers

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Abstract

In fiber optic telecommunication systems, a pre-amp Erbium Doped Fiber Amplifier (EDFA) can be used in combination with a PIN photodetector at the input stage of the optical receiver to increase the receiver sensitivity by amplifying the photon detector incoming optical signal. The combination of a preamp EDFA and a PIN photodetector is the best alternative to Avalanche photodetector in optical telecommunications receivers. In this paper, the noise-loaded performance of a 10 Gigabits/second (10Gbps) optical telecommunications receiver was characterized, and the receiver performance was optimized experimentally to improve the optical receiver Bit Error Rate (BER) performance.

The extensive testing of the 10Gbps optical telecommunication receiver transmission performance presented in this paper demonstrate that optimization of preamp-PIN design based 10Gbps optical telecommunications receivers can best be performed through experimental work that focuses on the optical receiver noise performance characterization and analysis. This is the preferred performance characterization method for optical telecommunications receivers, and it was performed in this work through testing the 10Gbps optical receiver transmission performance under different operating conditions.

Introduction

In this paper, the author has characterized and analyzed a 10Gbps optical telecommunication receiver BER performance under the same conditions it is subjected to in the field. The preamp EDFA and the PIN photo detector were analyzed as one block to account for signal-spontaneous beat noise in the PIN photo detector since signal-spontaneous beat noise becomes the dominant noise element in the photon detector when used in the optical receiver after the pre-amp EDFA [1-3].

The optical telecommunications receiver transmission performance was characterized under different operating conditions, and the test results were graphed and analyzed. Since the pre-amp EDFA is an integral part of the tested 10Gbps optical receiver, the pre-amp should be characterized as a component in the optical receiver transmission performance. Stand-alone EDFA analysis was performed by many researchers [4&5]. This performance analysis level is the best way to characterize the pre-amp noise performance.

Pre-amp EDFAs are becoming an integral part of the optical receiver since their performance is interrelated to the performance of the receiver photo detector. The photo detector is either a PIN diode or an Avalanche photo diode (APD) [6]. APDs have better sensitivity, lower values, than PIN diodes, but they exhibit excess noise that degrades the optical receiver performance. PIN diodes have a better noise performance, but APDs better sensitivity. So, the best receiver performance, BER and sensitivity, can be obtained by using a combination of a pre-amp EDFA for good sensitivity and a PIN photo detector for low noise [7]. So, the basic design of a 10G optical telecommunication receiver consists of a preamp EDFA, a PIN photo detector (PD), and an electrical low pass filter (LPF). Figure 1 shows the basic block diagram of a high performance 10G optical telecommunications receiver.

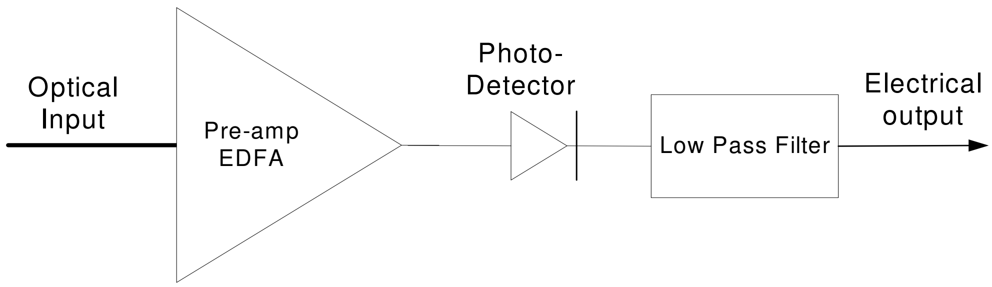

Figure 1: Block diagram 10G Optical Telecommunication Receiver

The use of a pre-amp EDFA in a PIN diode based design of an optical receiver improves the receiver sensitivity in the order of 25 dB [5]. This saves in the cost of the overall system by reducing the number of repeaters required in the system. If an RZ to NRZ conversion is required, a limiting amplifier is used to perform that job. Since the low pass filter is a passive component, the noise characterization performance will focus on the ASE noise generated by the pre-amp that affects the photo detector. This ASE is in the band of the signal. The work presented in this paper helps researchers understand optical receiver design trade-offs and explore the advancement of 10Gbps optical receiver design.

The test results of the optical receive transmission performance is measured at different operating conditions. The total input power to the pre-amp is controlled using the common attenuator, the pre-amp output power is controlled by controlling the pump output power, and the signal wavelength control is performed at the optical transmitter side of the system.

In order to analyze the 10Gbps optical telecommunications receiver, a 10Gbps optical telecommunication system test set-up was used to perform the optical receiver testing. This set-up has the ability and flexibility to perform the following control and measurements:

1- Optical Receiver Transmission Performance Measurement
2- Optical Input and Output Measurements
3- Isolate and study EDFA noise
4- Optical Noise Source control
5- Optical Signal Source control

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6- Optical Input SNR control
7- Optical Input Control

The following sections present the test results and analysis of a 10Gbps optical receiver at different operating conditions that resembles the field operating conditions.

10Gbps Optical Telecommunication Receiver BER Performance

In optical receivers, the dominant noise source is amplified spontaneous emission from the optical pre-amplifier preceding the photon detector. The optical receiver transmission BER and sensitivity performance is the gauge by which optical receivers are characterized. BER and sensitivity performance characterize the ability of the receiver to perform up to the transmission performance specifications under the same test conditions as those where the receiver operates in the field. So, BER and sensitivity transmission performance were used to analyze the optical receiver behavior under different operating conditions.

When testing the optical receiver transmission performance, the sensitivity and bit error rate are important for system design. An improvement in the receiver sensitivity results in a cost saving due to the longer span between repeaters while an improvement in the receiver bit error rate performance results in a better margin for the overall transmission system. So, it is important to optimize the optical receiver BER and sensitivity performance.

The effects of the optical amplification in the pre-amp EDFA as a function of the pre-amp input power, output power, and the input signal wavelength on the optical receiver transmission performance are analyzed here for this work in order to characterize the optical receiver transmission performance, the receiver must be subjected to the same operating conditions existing in the terminal where the optical receiver needs to be installed.

10Gbps Optical Telecommunication Receiver BER Performance Analysis at Different Input Power Levels

The 10Gbps optical telecommunication receiver was tested with a signal to noise ratio of 9 dB at different input powers and an output power of –15 dB at a wavelength of 1552 nm, the transmission performance (BER). Figure 2 presents the 10Gbps optical telecommunication receiver transmission performance change at different input powers with the input signal to noise ratio set to 9dB.

The results presented in figure 2 represent the 10Gbps optical telecommunications receiver sensitivity test results. Since the pre-amp is used at the input of the optical receiver. The optical receiver sensitivity is equal to the pre-amp sensitivity. Sensitivity for optical receiver is defined as the input power level at which BER of the tested device is 1 E-10. The sensitivity test is not a noise-loaded test, so the noise attenuator is disabled during this test. These results illustrate the changes of the optical receiver noise-loaded performance at different pre-amp inputs above the sensitivity point of the receiver.

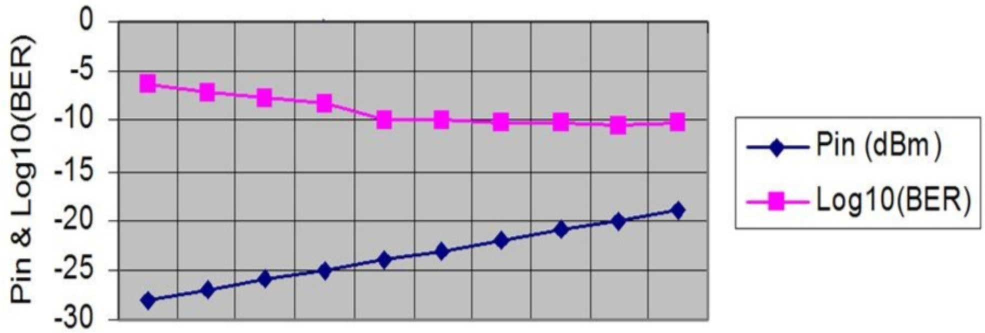

Figure 2: 10Gbps Optical Telecommunication Receiver BER Performance Test Results at SNR of 9dB

From figure 2, we see that an increase in the pre-amp input power results in a better transmission performance for the system. This is a result of the decrease in the amplified spontaneous emission generated in the pre-amp. An increase in the input signal results in more stimulation of the erbium ions in the meta-stable state, and that leaves less natural decay, and that leaves less ions to be emitted spontaneously.

The optical receiver transmission performance test results in this section are consistent with the pre-amp input change simulations in the last chapter. This means that the optical receiver transmission performance testing can be used to characterize the pre-amp performance at different input power levels. Computer simulation can't be used to determine sensitivity here since the pre-amp needs to be operating as part of the optical receiver to perform this test.

10Gbps Optical Telecommunication Receiver BER Performance Analysis at Different Input Power Levels

10Gbps optical receiver noise free sensitivity tests were performed to determine the lowest input power level under which the optical receiver will operate properly. The transmission performance test is used to determine the performance level of the optical receiver under noise loaded conditions. Figure 3 gives the optical receiver sensitivity.

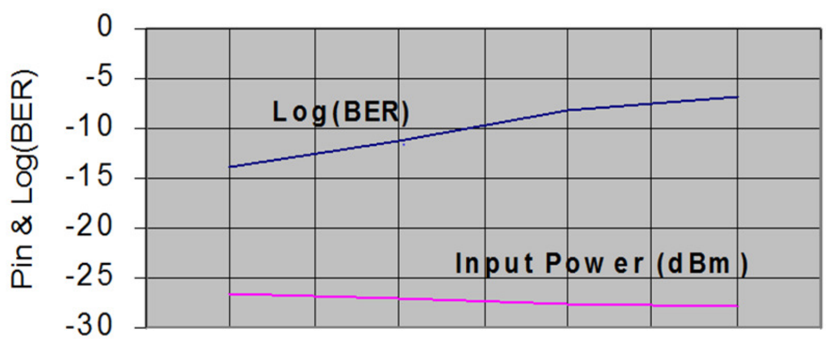

Figure 3: 10Gbps Optical Receiver BER Performance Vs. Sensitivity Test Results

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The changes of the optical receiver noise free performance at different pre-amp inputs above the sensitivity point of the receiver are illustrated in figure 4. From this figure, we see that an increase in the pre-amp input power results in a better transmission performance for the system. This is a result of the decrease in the amplified spontaneous emission generated in the pre-amp. An increase in the input signal results in more stimulation of the erbium ions in the meta-stable state, and that leaves less natural decay, and that leaves less ions to be emitted spontaneously.

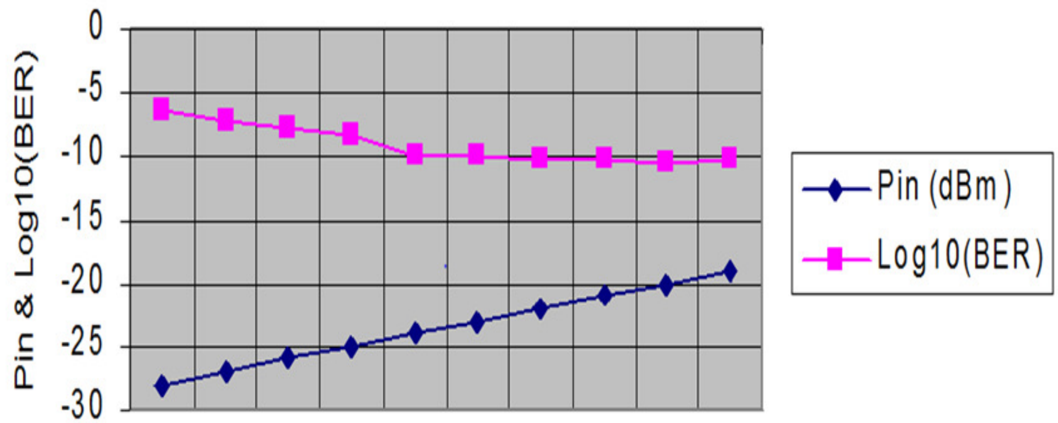

Figure 4: 10Gbps Optical Telecommunication Receiver BER Performance Test results at 9dB SNR

10Gbps Optical Telecommunication Receiver BER Performance Analysis at Different Output Power Levels

When testing with Pre-amp input signal power set to -22dBm and a signal to noise ratio of 9 dB, the system performance was monitored. Figure 5 gives the system transmission performance change at different output powers with the pre-amp input signal power set to -22dBm at 1550nm after normalizing the receiver transmission performance test results.

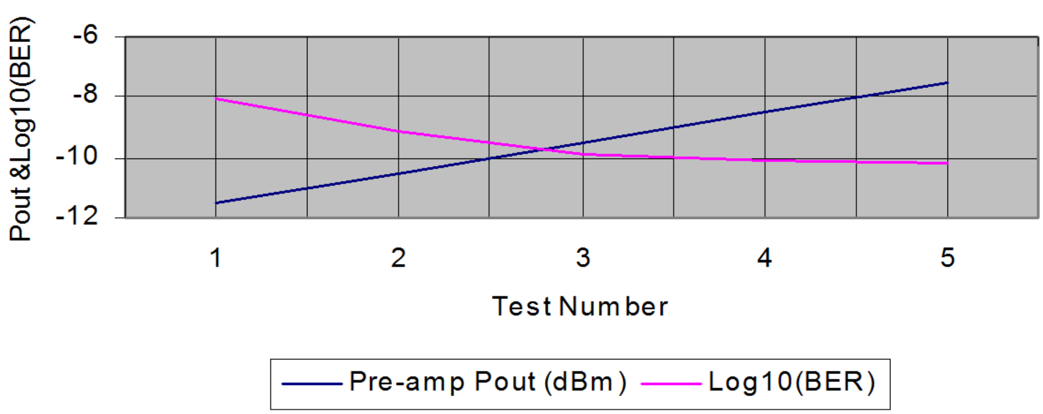

Figure 5: 10Gbps Optical Telecommunications Receiver BER Performance Test Results at different pre-amp output power values

The test results of figure 5 show that the system transmission performance is improved as the pre-amp output power is increased. This happens because an increase in the EDFA output power caused more electrons to be stimulated to the lower state. This reduces the amplified spontaneous emission of the pre-amp EDFA. As the pre-amp Pout increases from –11.5dBm to –7.5 dBm, the optical receiver transmission performance improves from a BER value of 8.9 E-9 at the higher output power value to 6.5 E-11 at the lower optical output power value.

10Gbps Optical Telecommunication Receiver BER Performance Analysis at Different Output Power Levels

The increase of the pre-amp optical output power value means that more pumping is needed. This results in more stimulated emission of the ions in the metastable state. This leaves less ions in the metastable state to radiate to the ground state spontaneously generating more spontaneous noise which is amplified in the fiber generating more amplified spontaneous emission. The pre-amp output power should be optimized during the pre-amp design stage where special attention has to be given to the saturation region of the output power.
When testing with Pre-amp input signal power set to -22dBm and a signal to noise ratio of 9 dB, the system performance was monitored. When normalizing the optical receiver transmission performance test results and plotting these results, we get the graph of figure 6. The results of figure 6 show that the system transmission performance is improved as the pre-amp output power is increased. This happens because an increase in the EDFA output power caused more electrons to be stimulated to the lower state. This reduces the amplified spontaneous emission of the pre-amp EDFA. As the pre-amp Pout increases from –11.5dBm to –7.5dBm, the optical receiver transmission performance improves from a BER value of 8.9 E-9 at the higher output power value to 6.5 E-11 at the lower optical output power value.

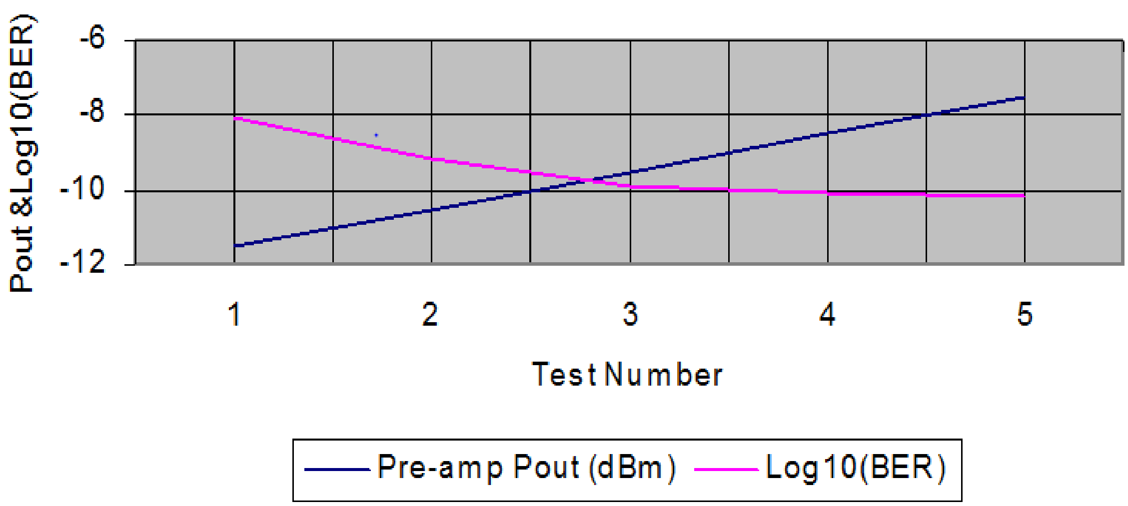

Figure 6: 10Gbps Optical Receiver BER Performance Test Results at Different Preamp output power Levels.

The increase of the pre-amp optical output power value means that more pumping is needed. This results in more stimulated emission of the ions in the metastable state. This leaves less ions in the metastable state to radiate to the ground state spontaneously generating more spontaneous noise which is amplified in the fiber generating more amplified spontaneous emission. The pre-amp output power should be optimized during the preamp design where special attention has to be given to the saturation region of the output power.

10Gbps Optical Telecommunication Receiver BER Performance Analysis at Different Signal Wavelengths

When testing the 10G optical telecommunications receiver with a signal to noise ratio of 6.5 dB at different input Power values at three different wavelengths (λ) of the input signal and an EDFA output power of –6dBm, the transmission performance (BER) was recorded for each condition. figure 7 gives the test results of the 10Gbps optical telecommunications receiver transmission performance change at different input powers and different input signal wavelengths with Preamp Pout set to -6dBm after normalizing the optical receiver transmission performance test results.

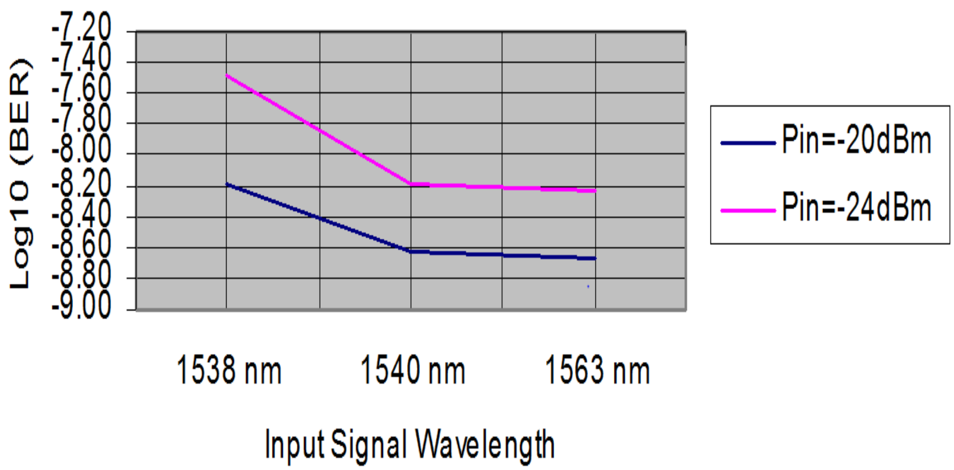

Figure 7: 10Gbps Optical Telecommunication Receiver BER Performance Test Results at different input powers and different input signal wavelengths with pre-amp pout set to -6dBm

The test results of figure 7 show that the optical receiver transmission performance improves as the input signal wavelength is increased in the range of the tested signals. These tests were done at two input signal power values. The top line shows the transmission performance at –24dBm while the bottom one shows the optical receiver transmission performance at –20dBm. The results of figure 7 shows that he optical receiver transmission performance change analysis at the optical receiver level is good enough to analyze the change of performance for the 10G optical telecommunications receiver.

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To study the effect of changing the input signal power and wavelength at the pre-amp level, the pre-amp pump bias current was tested and monitored. Since a pre-amp EDFA is a constant output EDFA, the pre-amp pump bias current needs to be accounted for in this analysis. So, pre-amp was characterized experimentally to see the effects of changing the input signal power and wavelength on the pump current required to maintain a constant output. For this test, the pre-amp output was set to +11dBm. The experiment was repeated for 4 input signal wavelengths. Figure 8 gives the pump bias current needed to maintain a constant output at different input signal values.

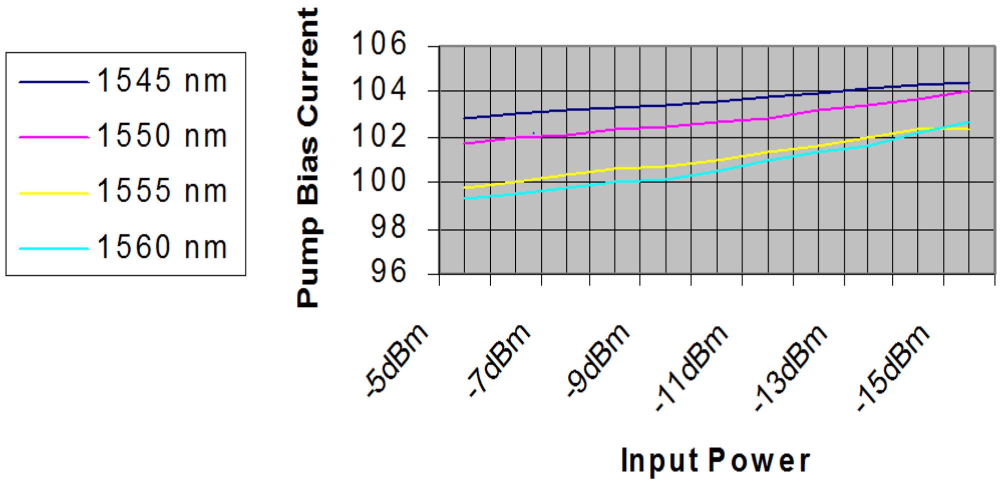

Figure 8: Test Results for 10Gbps Receiver Preamp Pump bias current vs. input signal power and wavelength

From Figure 8, we see that an increase in the input signal power requires less pump current to maintain the same pre-amp output power, and an increase in the input signal wavelength, between 1545nm and 1560 nm, requires less pump current to maintain the same pre-amp output power. The pump bias current, as a function of the input signal power and wavelength, is given in figure 8. The pump bias current given here is the current needed to maintain the pre-amp output power at +11dBm. From figure 8, we see that the pump bias current is inversely proportional to both the input power and the input signal wavelength.

10Gbps Optical Telecommunication Receiver BER Performance Analysis for Optimal Transmission Performance

In this section, Pre-amp EDFA is used at a fixed wavelength. So, it was tested here at a signal-to-noise ratio of 9 dB at a fixed wavelength of 1550 nm. The transmission performance was monitored, and when plotting these results, after normalizing BER, we get the graph of Figure 9.

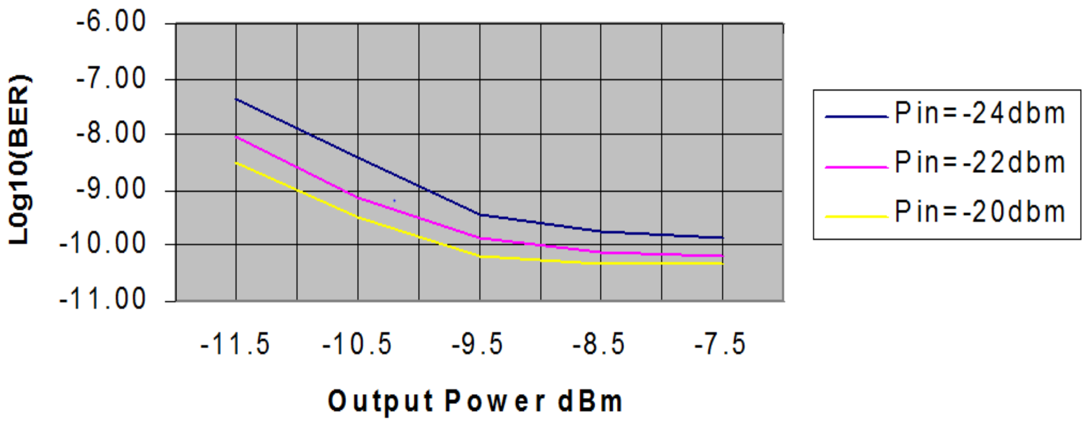

Figure 9: 10Gbps Optical Receiver BER Performance Test Results at different input and output power levels

When testing the pre-amp EDFA at different input powers and signal to noise ratios at an output power of –15dBm and at a wavelength of 1550 nm, the transmission performance of the 10G optical telecommunications receiver due to these changes was monitored. When normalizing BER and plotting these results, we get the graph of Figure 10

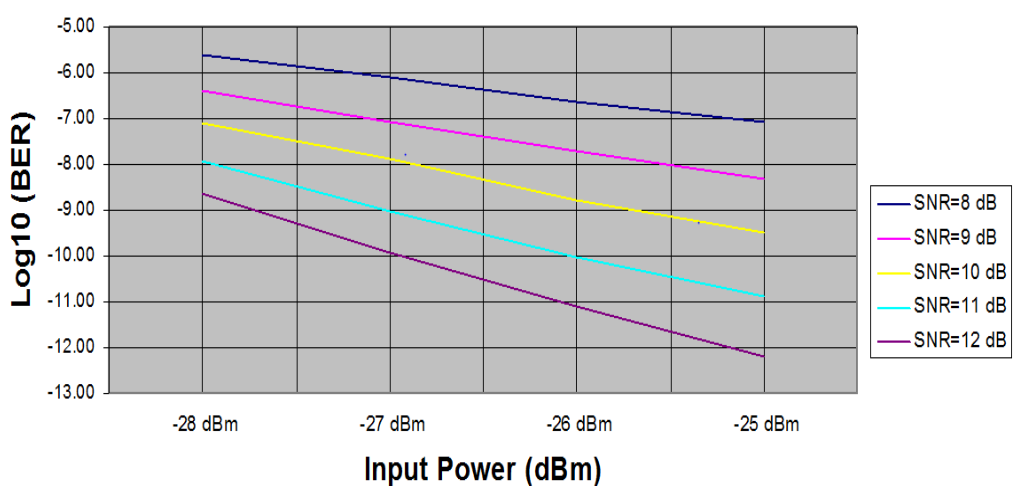

Figure 10: 10Gbps Optical Telecommunication Receiver BER Performance Test Results at different input powers and different input signal to noise ratios

The test results of figure 10 show the relation between the optical receiver input signal to noise ratio and the optical receiver input power to the optical receiver transmission performance. As the input optical signal to noise ratio is increased, the performance of the optical receiver improves. An increase of the input signal to noise ratio at the same input power means that less noise is passing through the pre-amp.

Conclusion

In this paper, a 10Gbps optical telecommunications receiver noise performance was characterized to optimize the optical receiver BER performance. A pre-amp EDFA is used in combination with a PIN photodetector at the input stage of the optical receiver to increase the receiver sensitivity by amplifying the photon detector incoming optical signal. The combination of a preamp EDFA and a PIN photodetector was found to be a better choice than using an Avalanche photodetector at the input of the receiver.

In order to optimize the performance of 10Gbps optical telecommunications receivers, the pre-amp EDFA and photon detector need to be optimized as one subsystem. Then the pre-amp EDFA needs to be fine-tuned at the optical receiver level to achieve optimal optical receiver transmission performance.

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Biography

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