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DISTORTION MINIMIZATION WITH ADAPTIVE FILTER FEEDBACK IN VISIBLE LIGHT COMMUNICATION

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ABSTRACT

This paper presents a comparison of the signal estimation with the existing threshold approach and Adaptive feedback filter based approach. The adaptive feedback filter is a best estimation of optical signal even in the presence of noise. In optical communication system as the link length increases signal gets more and more distorted. So, it becomes difficult to estimate the signal. Adaptive feedback filter is a recursive filter, which provides an estimate with minimum mean square. Optical communication system modeling is done with state-space equation. The variances of the noise introduced at various stages (photo detector, amplifier) of the optical communication system are considered. Measurements of the bit error rate at various signal to noise ratios and also at different number of samples in a bit are observed, which represents that an increase in signal to noise ratio or the number of samples in a bit causes the bit error rate to decrease. Estimation of optical signal using adaptive feedback filter reduces the BER effectively.

Key words: OFC, BER, SNR, threshold based estimation, Adaptive feedback filtering

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1. INTRODUCTION

Fiber optics has gained prominence in the past decade in telephony, metropolitan communications, submarine trunks, railway signaling and control, cable television, computer networks, communication and control in hazardous environments (chemical, nuclear, etc.) and data transmission and distribution. [1]These major applications have been possible in these areas due to its primary advantages like large bandwidth, lower attenuation, immunity to interference, small size and weight, compatible with modern microelectronic technology and high security. The problem of estimating the fundamental frequency for a given signal is a classical problem in signal processing, various solutions have been suggested to solve this problem. the problem is encountered for various applications such as coding of speech and audio, automatic music transcription, determination of rotating targets in radar etc. Though various solutions are proposed for the estimation of signal the correlator approach is found to be more precisely used in various communication system. Considering to optical fiber communication system the existing communication model uses the same concept of correlation and thresholding for the estimation of signal. This approach found suitable under high SNR system, but with the decrease in SNR making noise effect more effective than signal strength it is observed that the estimation level fall down. The enhancement to the estimation method using Adaptive feedback filter is found to be suitable solution to this problem. There are four distinct generations of fiber-optic transmission systems each new generation overcame a limitation of its predecessor. The first generation, deployed in the 1970's**,** uses multimode fibers at short wavelengths near 850 nm. First-generation systems suffer from three severe limitations: attenuation, chromatic dispersion, and modal dispersion. The attenuation of optical fiber, which limits the distance between transmitter and receiver, is about 2 dB/km for wavelengths near 850nm. The dispersion of fiber, which limits the speed at which data can be transmitted, causes short rectangular pulses to spread temporally into long smooth pulses as they propagate. Chromatic dispersion occurs because light at different frequencies travels through the fiber at different speeds. Second-generation systems, introduced in the 1980's, avoid chromatic dispersion by operating at 1300 nm, the wavelength of minimum chromatic dispersion in fiber. A secondary advantage of 1300 nm is its lower attenuation, only 0.5dB/km.Again, this generation uses multimode fiber, and thus still suffers from modal dispersion. Third-generation systems came of age in the mid-1980's, again operating at 1300 nm, but this time through single mode fibers; the core radius of a single-mode fiber is chosen small so that only a single mode can propagate. Hence, third generation systems avoid modal dispersion as well, but still suffer from a transmission loss of about 0.5 dB/km. The minimum attenuation of optical fiber, about 0.2 dB/km, occurs for wavelengths between 1450 and 1650 nm. To exploit this immense low-loss bandwidth of over 25,000GHZ**,** fourth generation systems shifted operation up to 1500 nm.

2. PROPAGATION MODEL

Optical communication systems, using both free space and fiber optic propagation have been the subject of intense research for many years due primarily to the greatly increased bandwidths available. In addition, free space optical communication systems benefit from the high directionality of the transmitter sources so that frequency allocations are unnecessary and for secure channels, the probability of intercept is very low. Improvement of data rate and bit-error performance has been given high priority, in order to recognize the full potential of the medium. In the design of communication system receivers, a common approach is to model the noise present in the received signal as additive noise due to the channel characteristics and receiver electronics. Typically, the noise variance will be the same for the various signal levels, leading to a matched-filter type of detector algorithm with a threshold that is constant or proportional to average received power. If different signal levels have different noise variances, then the matched filter is no longer optimal and detector decision algorithms can be derived which result in order of magnitude improvements in the system bit error rate. In fiber systems, optic beams generated by light sources carry the information. The normally empty conduction band of the semiconductor is populated by electrons injected into it by the forward current through the junction, and light is generated when these electrons recombine with holes in the valence band to emit a photon. This is the mechanism by which light is emitted from an LED, but stimulated emission is not encouraged, as it is in the injection laser, by the addition of aa optical cavity and mirror facets to provide feedback of photons. Laser diodes and light-emitting diodes are the most common sources. Their small size is compatible with the small diameters of fibers and their solid structure and low power requirements are compatible with modern solid state electronics. A light emitting diode is a *pn* junction semiconductor that emits light when forward biased. The LED can operate at lower current densities than the injection laser, but the emitted photons have random phases and the device is an incoherent optical source. Also, the energy of the emitted photons is only roughly equal to the band gap energy of the semiconductor material, which gives a much wider spectral linewidth (possibly by a factor of 100) than the injection laser. The linewidth for an LED corresponds to a range of photon energy between 1 and $3.5\,KT$, where K is the boltzmann's constant and T is the absolute temperature. This gives line widths of 30 to 40 nm for GaAs-based devices operating at room temperature. Thus the LED supports many optical modes within its structure and is therefore often used as a multimode source, although more recently the coupling of LEDs to single-mode fibers has been pursued with success, particularly when advanced structures have been employed. Lower optical power coupled into the fiber, lower modulation bandwidth and harmonic distortion are the several drawbacks of LED's in comparison with injection lasers. However, although these problems may initially appear to make the LED a less attractive optical source than the injection laser, the device has a number of distinct advantages which has given it a prominent place in optical fiber communications. As there are no mirror facets and striped geometry they are simple to fabricate. The simpler construction of the LED leads to much reduced cost which is always likely to be maintained. The LED does not exhibit catastrophic degradation and has proved far less sensitive to gradual degradation than the injection laser. It is also immune to self pulsation and modal noise problems. So, it is very reliable. The light output against current characteristic is less affected by temperature than the corresponding characteristic for the injection laser. Furthermore, the LED is not a threshold device and therefore raising the temperature does not increase the threshold current above the operating point and hence halt operation. So, it is generally less temperature dependent. Due to its lower drive currents and reduced temperature dependence, temperature compensation circuits are unnecessary. So, the driver circuitry is so simple. Ideally, the LED has a linear light output against current characteristic, unlike the injection laser. This can prove advantageous where analog modulation is concerned. These advantages combined with the development of high radiance, relatively high bandwidth devices have ensured that the LED remains an extensively used source for optical fiber communications. Structures fabricated using the GaAs/AlGaAs material system are well tried for operation in the shorter wavelength region. In addition, more recently there have been substantial advances in devices based on the material structure for use in the longer wavelength region especially around 1.3μm. LEDs therefore remain the primary optical source for non telecommunication applications while injection lasers find major use as single-mode devices within single-mode fiber systems for long-haul, wideband applications. In addition, LEDs have been shown to launch acceptable levels of optical power into single-mode fiber and therefore may well find use in short-haul single-mode fiber telecommunication systems in the future.

3. INTERFERENCE MINIMIZATION

Noise is the term generally used to refer to any spurious or undesired disturbances that mask the received signal in a communication system. In optical fiber communication systems we are generally concerned with noise due to spontaneous fluctuations rather than erratic disturbances. The ultimate performance of communication system is usually set by noise fluctuations present at the input to the receiver. Noise degrades the signal and impairs the system performance. In an optical receiver, the essential sources of noise are associated with the detection and amplification processes. The following figure depicts the various sources of noise associated with the detection and amplification processes in an optical receiver employing direct detection. Detection of the weakest possible optical signals requires that the photo detector and its following amplification circuitry be optimized so that a given signal-to-noise ratio is maintained. The power signal-to-noise ratio S/N at the output of an optical receiver is defined by,

$$\frac{S}{N} = \frac{\text{signal power from photocurrent}}{\text{photodetector noisepower + amplifier noise power}} \quad (1)$$

The noise sources in the receiver arise from the photo detector noises resulting from the statistical nature of the photon-to-electron conversion process and the thermal noises associated with the amplifier circuitry. To achieve a high signal-to-noise ratio, the photo detector must have a high quantum efficiency to generate a large signal power and the photo detector and amplifier noises should be kept as low as possible. The principal noises associated with photo detectors are quantum noise, dark-current noise generated in the bulk material of the photodiode and surface leakage current noise. The quantum or shot noise arises from the statistical nature of the production and collection of photoelectrons when an optical signal is incident on a photo detector. The quantum theory suggests that atoms exist only in certain discrete energy states such that absorption and emission of light causes them to make a transition from one discrete energy state to another. The frequency of the absorbed or emitted radiation is related to the difference in energy E between the higher energy state E_2 and the lower energy state E_1 by the expression:

$$E = E_2 - E_1 = hv \quad (2)$$

Where h is the plank's constant. These discrete energy states for the atom may be considered to correspond to electrons occurring in particular energy levels. This quantum nature of light must be taken into account at optical frequencies. These quantum fluctuations dominate the thermal fluctuations. The detection of light by a photodiode is a discrete process since the creation of an electron-hole pair results from the absorption of a photon, and the signal emerging from the detector is dictated by the statistics of photon arrivals. Hence, the statistics for monochromatic radiation arriving at a detector follows a discrete probability distribution which is independent of the number of photons previously detected. The mean square shot-noise

$$i_{NS}^2 = 2eI\Delta f \quad (3)$$

Where e is the magnitude of the charge of an electron, I is the average detector current and Δf is the receiver's bandwidth. From the above equation shot noise increases with current. Thus, shot noise increases with an increase in the incident optic power. This differs from thermal noise, which is independent of the optic power level. The current I in equation (2.23) includes both the average current generated by the incident optic wave and the dark current I_D. Then,

$$i_{NS}^2 = 2e(i_s + I_D)\Delta f \quad (4)$$

Where i_s is the photocurrent . The photodiode dark current is the current that continues to flow through the bias circuit of the device when no light is incident on the photodiode. This is a combination of bulk and surface currents. The bulk dark current i_{DB} arises from electrons and/or holes which are thermally generated in the *pn* junction of the photodiode. The surface dark current is also referred to as a surface leakage current or simply the leakage current. It is dependent on surface defects, cleanliness, bias voltage and surface area. Thermal noise, also called Johnson noise originates within the photo detector's load resistor R_L . Electrons within any resistor never remain stationary. Because of their thermal energy, they continually move, even with no voltage applied. The electron motion is random, so the net flow of charge could be toward one electrode or the other at any instant. Thus, a randomly varying current exists in the resistor. This is the thermal noise current i_{NT} . The average noise power generated within the resistor is $R_L i_{NT}^2$, where i_{NT}^2 is the mean-square value of the thermal noise current. The noise current adds to the signal current generated by the photo detector. The mean-square value of the thermal noise current is

$$i_{NT}^2 = \frac{4kT\Delta f}{R_L} \tag{5}$$

Where k is the Boltzmann's constant, T is the absolute temperature (K) and Δf is the receiver's electrical bandwidth. The thermal noise power delivered to the load is

$$P_{NT} = 4kT\Delta f \tag{6}$$

Amplifier normally follows the photo detector to boost the receiver signal to a useful level. In an ideal situation, both signal and noise powers would be multiplied by the amplifier's power gain G . Then, the signal-to-noise ratio at the amplifier output would equal that at the input. Unfortunately, real amplifiers not only multiply the input noise but also produce noise of their own. This reduces the signal-to-noise ratio. Let the added noise is represented by P_{out} watts. If this power has to be included in signal-to-noise ratio calculations, then it can be done by assuming an ideal amplifier and adding a thermal-noise source at its input that produces noise power $P_{in} = P_{out}/G$ watts. Now the amplifier-noise temperature T_a is defined in such a way to produce this power. That is, using equation (6),

$$P_{in} = \frac{P_{out}}{G} = 4kT_A\Delta f \tag{7}$$

Combining this with the load resistor's thermal noise yields the equivalent input thermal-noise power

$$P_N = 4k(T + T_A)\Delta f = 4kT_e\Delta f \tag{8}$$

where T is the temperature of the resistor and

$$T_e = T + T_A \tag{9}$$

is the equivalent system-noise temperature. The actual thermal noise appears to come from a resistor operating at temperature T_e. Signal-to-noise ratios are computed by simply replacing the actual system temperature T with the effective system-noise temperature T_e. Considering the noise figure F rather than the noise temperature T_A, F is the property defined by

$$F = 1 + \frac{T_A}{T_s} \tag{10}$$

where T_s is some reference temperature. The equivalent system-noise temperature is

$$T_e = T + T_A = T + (F-1)T_s \tag{11}$$

where we eliminated T_A by using equation (2.30). If reference temperature equal to the system temperature,

($T_s = T$). Then, $T_e = FT$, and the total output noise power becomes

$$P_o = GP_N = G4kT_e\Delta f \qquad = G4kFT\Delta f \tag{12}$$

solving for the noise figure yields

$$F = \frac{P_o}{G4kT\Delta f} = \frac{P_o}{GP_{NT}} \tag{13}$$

where the load resistor's thermal noise power P_{NT} is identified by the equation (13). This permits to define the noise figure as the thermal-noise power at the output divided by the product of the power gain and the input thermal noise. To use this definition, F must be measured at the temperature of the load resistor. For an ideal amplifier, $P_o = GP_{NT}$ and the noise figure is unity.

4. NOISE ESTIMATION

For a shot-noise-limited system, the photo detection processor counts the number of electrons produced during each bit interval and compares this number with a threshold. If the count exceeds the threshold, then the receiver assumes a 1 was transmitted. If the count is less than the threshold, then a 0 is assumed. Errors occur when receiving 0's because the dark current occasionally contains enough electrons during a single bit interval to exceed the threshold. The dark currents found in detector manufacturer's literature are the average values. The instantaneous dark current varies randomly about this number. It can reach relatively large values for short periods of time. When receiving 1's, errors occur if the number of electrons produced by the combination of the signal-plus-noise currents does not exceed the threshold. This happens if the noise current is large enough and if it adds out of phase with the signal current during most of a single bit interval. In this way the total current occasionally falls below that needed to reach the threshold count. This type of error can even occur when there is no dark current.

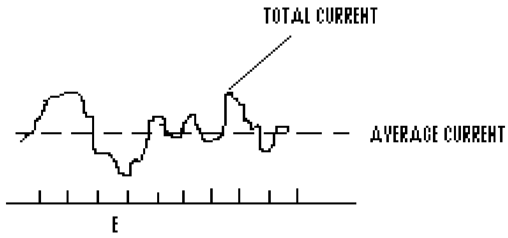

Figure 1 signal plus shot noise current

The signal-generated shot noise alone may decrease the total electron count. We can illustrate this last statement by referring to Fig.1, showing the received current when the incident power is constant. (We can imagine this is the current when a series of 1's is received in a NRZ system.) On the average a constant current flows through the detector circuit. However, the instantaneous current deviates randomly about the average value, owing to the random generation and recombination of charge carriers (this is the signal's shot noise). There is a finite probability that the number of electrons generated will be less than the threshold during any one bit interval. Interval E in the figure is an example in which an error occurs because of the small current during one bit interval. The error probability depends on the average number of photoelectrons n_s generated by the signal during the bit interval τ when a 1 is received. In terms of incident optic power, n_s is given by

$$n_s = \frac{\eta P \tau}{hf} = \frac{i_s \tau}{e} \tag{14}$$

Where η is the quantum efficiency, hf is the photon energy, and i_s is the signal current. The error rate also depends on the average number of electrons n_n produced by the dark current I_D. This is

$$n_n = \frac{i_D \tau}{e} \tag{15}$$

When 1's and 0's are equally likely, the threshold that minimizes P_e is

$$k_T = \frac{n_s}{\ln(1 + n_s / n_n)} \tag{16}$$

The actual threshold count k_D is an integer that set equal to k_T if k_T is itself an integer. Otherwise k_D is set equal to the closest integer that is greater than k_T. If there is almost no dark current ($n_n \cong 0$), then equation 3 yields a threshold just barely above zero. We set the actual threshold count to one electron ($k_D = 1$). Since there is virtually no dark current, the detected count will always be zero, and there will be no errors when the system transmits 0's. Arrival of a 1 is assumed by the detection of one or more electrons. The only reason that errors occur at all in this situation is that the incoming photon stream may not generate any photoelectrons during a particular bit interval. When the incident power is constant, we can determine the average number of photons per bit. However, the actual number arriving during any one bit interval varies randomly about this value. When the average is low (say, just a few photons/bit), it is entirely possible that no photons will actually strike the detector during some bit intervals. Additionally, the detector quantum efficiency is only an average value. For example, if $\eta = 0.80$, then photons generate electrons only 80% of the time. From another point of view, a photon has an 80% probability of generating a free electron. It is possible that several incoming photons, on occasion, will not free any electrons at all during the bit interval. Of course, the larger the (average) number of incident photons, the less the likelihood of producing no electrons when transmitting 1's and the lower the error rate. As noted previously, the random excitation of charge carriers is the source of shot-noise current. Explanations of errors based directly on this probabilistic behavior or on the resulting random currents are equivalent. Suppose that the dark current produces an average of $n_n = 20$ electrons per bit and there are an average of $n_s = 10$ photoelectrons for each bit. The threshold, from equation (3) is $k_T = 24.7$,so we set the threshold count at $k_D = 25$. Always the threshold must be set above the average noise count. Errors can occur when the system transmits 1's or 0's. As explained earlier in this section, there is a finite probability that many more than the average number of dark current electrons will be generated. If 25 or more are electrons produced when a 0 is being received, then an error results. When a 1 is received, on the average there will be $n_s + n_n = 30$ electrons per bit. This count will drop below 25 on occasion, causing errors. Raising the threshold closer to 30 makes it more likely that incident 1's will not produce enough electrons to equal, or exceed the threshold. More 1 errors result, and 0's are less likely to reach the new threshold. In general, increasing the threshold increases the 1 errors and reduces the 0 errors. Decreasing the threshold will decrease the 1 errors at the expense of the 0 errors. In any case, the optimum threshold provides for minimum errors. A disadvantage of shot-noise-limited system is that the optic power and the noise must be known in order to set the threshold optimally. Since the error rate increases rapidly as the threshold moves away from the optimum, precise determination of the optimum threshold is critical. Figure 2 illustrates how thermal noise produces detection errors. The ideal (noise less) received current is shown in fig. 2 (a). It is followed by the actual current [fig. 2(b)], showing the effects of added noise and filtering. This current is sampled near the end of each bit interval (where the pulses are most likely to reach their maximum amplitudes) with the result appearing in fig. 2 (c). At this point, the amplitude of each sample is compared with a reference (or threshold) value. The threshold current is set somewhere between zero and the ideal current expected when a 1 arrives (i_s in the figure). If the sample exceeds the threshold, then it is further processed as a1. If the sample is lower than the threshold, it is treated as 0. Fig. 2 (d) shows the resulting data pattern.

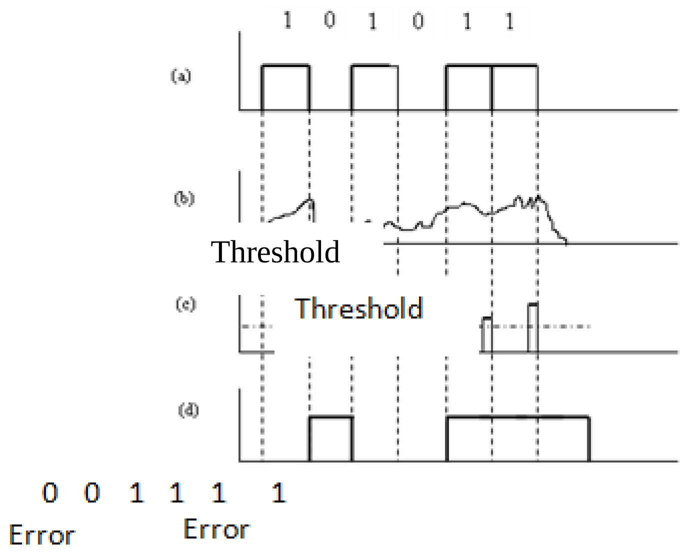

Figure 2 (a) Ideal receiver current (b) Actual current (c) Sampled current (d) resulting data pattern

Let us look a little closer at the reasons for the distorted pulse train in fig. 2(b). when a 0 arrives, an ideal receiver produces no current. In reality, thermal noise and dark current shot noise produce random currents. The noise current may be low on the average, yet still large enough during some bit intervals to exceed the threshold. In this case, an error occurs. When a 1 is received, the ideal current is constant [see level i_s in fig. 2(a)]. In the actual receiver, noise may add out of phase with the desired current, causing the total to occasionally dip below the threshold level. Again, an error results. The figure illustrates errors in detecting both 1s and 0s. Clearly, the threshold cannot be too close to zero, for this would increase the number of errors when detecting 0's. It cannot be too close to the ideal level i_s either, because errors in detecting 1s would occur more frequently. As might be expected, the threshold level producing the fewest errors is half the ideal current received when a 1 arrives. (We see the threshold current equal to 0.5 i_s). This is the optimum threshold if 1s and 0s are equally likely, a situation that exists for most messages. If the received power changes (e.g., owing to aging of the light source), then the threshold must be reset. It is worth summarizing that the decision (0 or 1) in a thermal-noise-limited system is made by comparing the signal-current amplitude with a predetermined threshold level. Using a threshold of 0.5 i_s results in the probability of error

$$P_e = \frac{1}{2} - \frac{1}{2} erf\left(0.354\sqrt{\frac{S}{N}}\right) \tag{17}$$

where erf is the error function . The signal-to-noise ratio used in determining P_e is the thermal-noise limited value.

5. SIMULATION RESULT

Results with and without adaptive filter are shown in figs. 3- 15. Four types of plots based on the observations are plotted. For every simulation one of the parameters, signal-to noise ratio or the number of samples are varied and the resultant plots are observed.

- Signal affected by noise at different signal-to noise ratios. Fig. 3 shows the signal when SNR =30. As the signal-to-noise ratio is decreased to SNR =20 noise effect is more on the signal. It can be clearly understood by the fig. 4.
- Fig. 5 – 8 shows the threshold detection of 1 or 0 bits at various number of samples. If more than half of the samples are greater than the threshold a 1 bit is detected otherwise a 0 is detected.
- Fig. 9 – 11 shows the number of samples versus percentage error plots. It can be clearly understood from these plots that as the signal-to-noise ratio increases or the number of samples increases the percentage of error is decreasing. Here, the simulation is performed with and without adaptive filter.
- Fig. 12 – 15 shows the signal-to-noise ratio versus bit error rate plots at different simulation inputs. These figures illustrates that the bit error rate decreases with increase in signal to noise ratio.

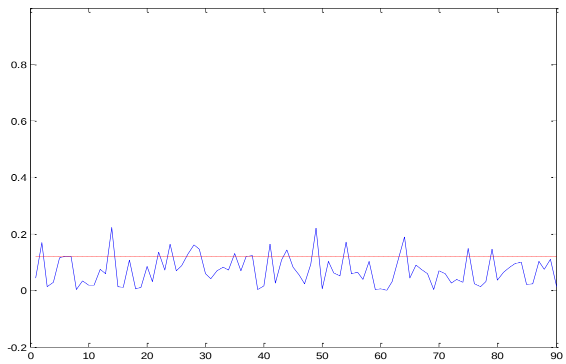

Figure 3 Noise Effected Signal When SNR=30

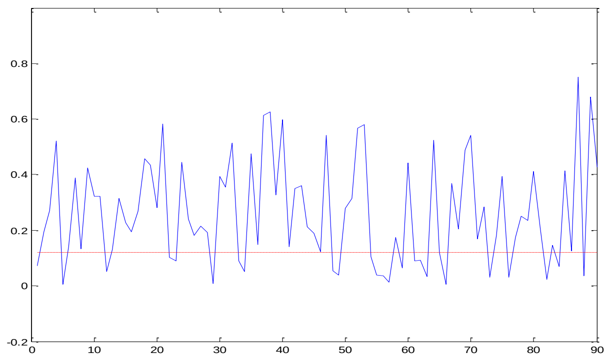

Figure 4 Noise Effected Signal When SNR=20

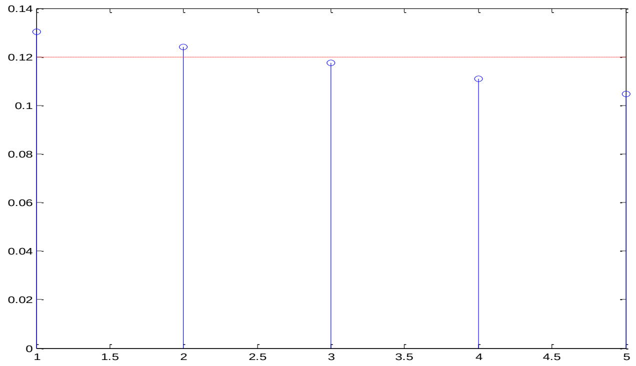

Figure 5 Detection of bit 0 when No. of Samples = 5

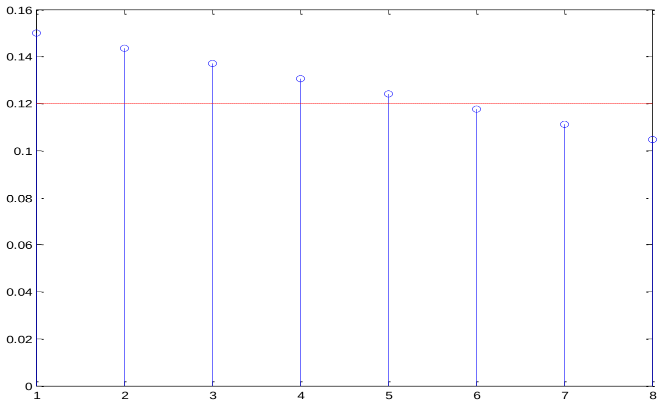

Figure 6 Detection of bit 1 when No. of Samples =8

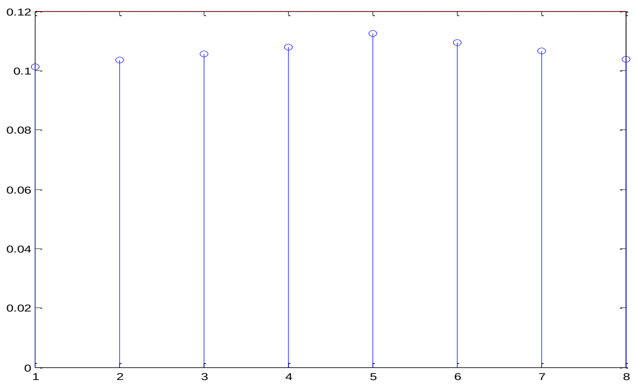

Figure 7 Detection of bit 0 when No. of Samples = 8

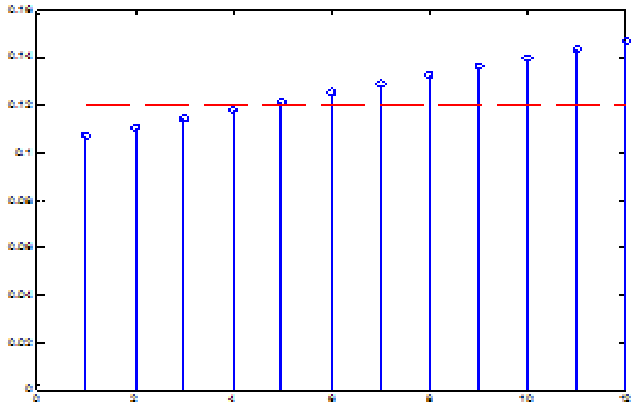

Figure 8 Detection of bit 1 when No. of Samples = 12

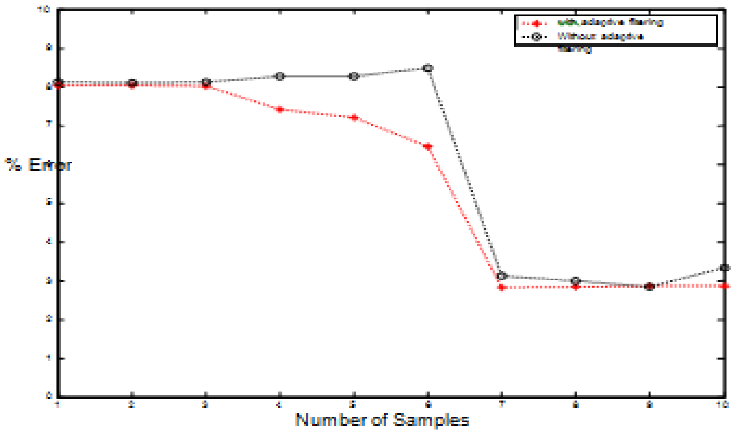

Figure 9 No. of Samples vs Error when SNR = 30 and Samples=10

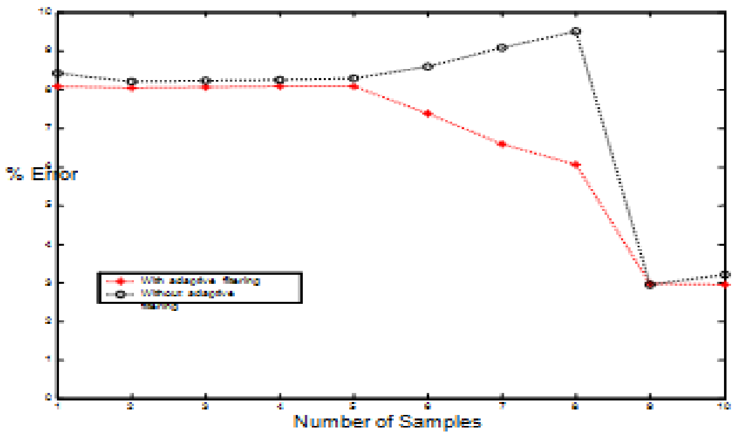

Figure 10 No. of samples vs Error when SNR = 20 and Samples =10

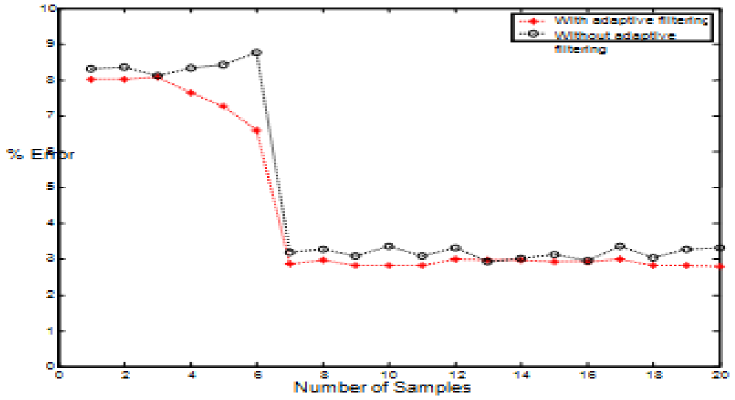

Figure 11 No. of Samples vs Error when SNR = 30 and Samples=20

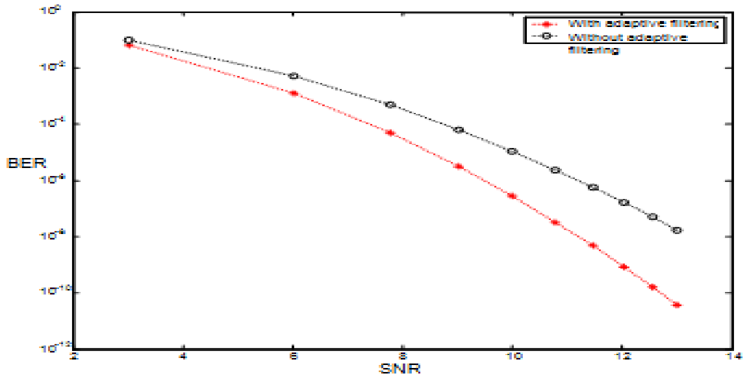

Figure 12 SNR vs BER for SNR = 20 and Samples=10

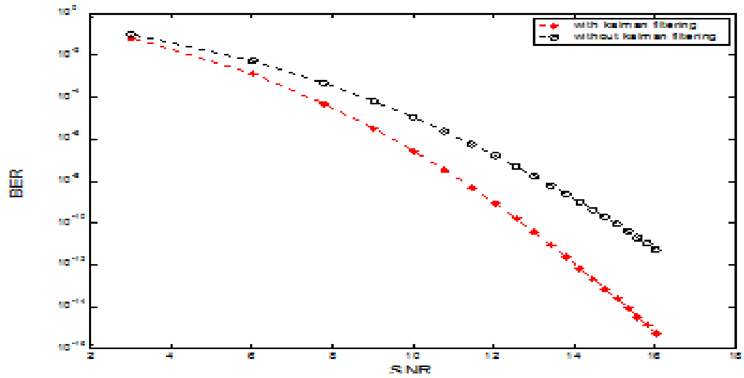

Figure 13 SNR vs BER for SNR = 30 and Samples = 20

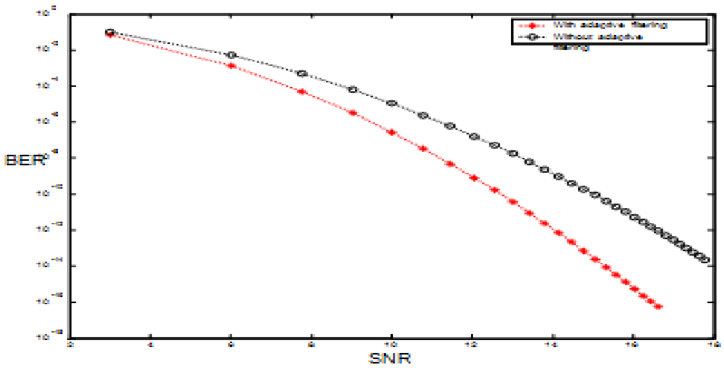

Figure 14 SNR vs BER for SNR = 30 and Samples=10

6. CONCLUSIONS

This paper develop the approach of estimating signal based on Adaptive estimation is found to be more accurate as compared to the thresholding method. From the observation it is found that the % error fall down with the increase in samples considered for prediction using Adaptive filtering. The Bit error rate Factor is also observed to be decreasing with the increase in SNR and seen to be more accurate with Adaptive filtering than the thresholding method. From all the above observations it could be concluded that Using Adaptive filter optimum detection scheme we can reduce the probability of error (i.e., the bit error rate) and by increasing the number of samples the percentage of error can also be decreased for a optical fiber communication system.

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