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Effect of Crosstalk in Optical Component

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Abstract--Optical networks have emerged as a solution to the rapidly increasing demands. Now, the optical data is transmitted over long distances without the need for O-E-O conversion as the data is directly transferred in the fiber as an optical signal. Crosstalk is the major limitation with all optical networks, which results from the intermixing/leakage of signals routed in optical switches with the desired signal. Optical components such as cross-connectors, routers, and add-drop multiplexers are prone to crosstalk. Crosstalk is divided into two types Linear and Non linear crosstalk. Intra-channel crosstalk results from the crosslink of signals with the same wavelength as the transmitted signal. Furthermore, depending on the phase noise of the signal and interferers, crosstalk can also be classified as coherent and incoherent. Inter-channel crosstalk occurs when the transmitted signal and interferers have different wavelengths. Routing and adding-dropping signals in optical networks are a key factor to get high flexibility and transparency of the system. The effect of crosstalk in optical components is explained in this paper and, in particular optical crosstalk regarding cross connectors and add-drop multiplexer is presented.

Keywords: Optical network, Cross connector, Add-drop Multiplexing.

I. INTRODUCTION

Optical communication is an extremely fast growing technology, driven mainly by the increasing need for global expansion of the internet and, in particular, multimedia communications and other data-dense applications. The huge bandwidth potential of optical fibers seems to be able to accommodate the increasing amount of network traffic today and much more in the future. The emergence of new applications that require high band width such as video services, medical imaging and distributed CPU interconnections requires novel solutions with high throughputs of the order of terabits per second. The efficient use of the optical bandwidth is of paramount importance in order to meet the future data capacity needs [1].

The Wavelength Division Multiplexing (WDM) technique is a very promising solution for the effective exploitation of the optical spectrum and the successful construction of the next generation of Broadband Optical Networks. Use of the WDM technology can simply and cost effectively multiply the capacity of the already installed fiber infrastructure by increasing the number and the spectral efficiency of the employed wavelength channels. The advent of wavelength division multiplexing WDM has a major impact on the evolution of high transmission networks [2]. The first generation of optical networks provides a point-to-point transmission service and, in these networks, the process of signal grooming (routing and switching) involves translating between the optical and electrical (optical-electrical-opticalOEO).The drawbacks of such opaque transmission are the cost, space requirements, power consumption and heat dissipation. In order to make a cost effective network, development in optical components technology such as optical Multiplexer/De-multiplexers (MUX/DEMUX), Add/Drop Multiplexers (OADM), Optical Cross Connects (OXC) and switches leads to the second generation of WDM networks (all-optical or transparent networks). All optical networks have emerged as a solution to keep up with the constantly increasing throughput demand. The major drawback associated with the WDM networks is crosstalk which is caused by non ideal performance of optical nodes that contain a wavelength selection and switching devices [3]. In order to fulfill the required throughput of the WDM networks, the number of wavelengths per channel in an optical fiber should be high; however, the limited bandwidth of optical components, such as an optical amplifier, will lead to closely spaced wavelength channels. The process of de-multiplexing of closely spaced wavelength channels along the light path will result in the presence of system impairments resulting from the residual of the de-multiplexed channels and this gives rise to linear crosstalk [4]. The optical power in the fiber link is the combination of individual channels. This means that the power will be so high and the fiber will no longer be a linear medium and nonlinear crosstalk will affect the system performance [5]. Both linear and nonlinear crosstalk represents the major limitations of WDM networks, and will lead to errors in the received signal, increasing the bit error rate and degrading the overall system efficiency. Depending on the optical filters we can identify two types of linear crosstalk: “in-band” and “out-band” crosstalk. Optical outband crosstalk is usually the crosstalk with spectral location out of the pass band of optical filter and also it is called inter- channel crosstalk and appears between channels of different wavelengths. The possibility of suppressing this type of crosstalk by using a narrow band filters made it less harmful. Furthermore, if the crosstalk has a spectral location inside the optical pass band, this means that the signal and interferers have closely spaced wavelengths, then the crosstalk will exhibit in-band or intra-channel crosstalk. This type of crosstalk is more harmful and causes serious degradation on system performance due to the difficulty of

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removing it by optical filters therefore it will propagate with WDM channels along the network and the destructive effect of this type of crosstalk will be accumulated within each node it passes through [6].

At the receiver the signal and crosstalk will be detected by a photo diode and will pass through an electric filter, the electrical filter band width will determined wither the crosstalk is electrical in band which means the spectral difference between the signal and crosstalk is less than electrical band width, or the crosstalk is electrical out band for the case that spectral difference greater than the electrical band width. The major limitation in system performance in the presence of crosstalk will be result mainly from electrical in-band crosstalk which can also be divided into homodyne and heterodyne crosstalk [7].

In the electrical domain, if the signal and the crosstalk have the same nominal frequency, $\Delta f=0$, then the crosstalk will be homodyne, otherwise if the signal and crosstalk are closely spaced in frequency then the crosstalk will be heterodyne. Homodyne crosstalk is also classified as coherent and incoherent crosstalk, depending on the laser coherent length. If the signal crosstalk beating occurs within the laser coherent time, then homodyne crosstalk is classified as coherent crosstalk otherwise it will be incoherent. A comparison between coherent and incoherent homodyne crosstalk was made in [8], the results shows that, in an optical cross connect, OXC, the power penalty caused by coherent crosstalk (for the propagation delay less than coherent time of laser and less than a bit period) is greater than the power penalty in the incoherent case. The crosstalk in an optical cross connect results from the adjacent WDM channels and from a delayed version of the signal itself after traveling through different paths in switching matrix. The propagation delay time is compared with the bit period in order to further classify the coherent crosstalk. The cross connect consists mainly of WDM de multiplexer, WDM multiplexer and a switch matrix to perform channels grooming. When an optical signal passes through OXC, there can be many cross talk contributions. The number of contributions leaked from each signal with the same wavelength of the desired signal will be random and depend on the state of OXC. Also, the propagation delay difference which will determine the crosstalk type is also changed in a random fashion. Therefore the transmission performance will vary from time to time. To assess the system performance, the signal to noise ratio (SNR) represent a good estimate to measure system tolerance. However, bit error rate and power penalty may offer extra explanation for system performance dependence on different factors.

II. PERFORMANCE EVOLUTION CRITERIA OF THE OPTICAL NETWORK

A. Optical Receiver Model

Generally, the optical receiver consists of a photo detector followed by an electrical integrator and filter. For on/off keying, the integrated pulse energy is compared with a decision threshold value. The photo current of the receiver is proportional to the square power of the incident optical field, and this will result in multiple beating terms represent the desired signal and cross talk. If the optical power emanating from a laser source is P_s , then the optical field in fiber can be considered as a continuous wave CW of the form

$$\overrightarrow{E_s}(t) = \vec{r}\sqrt{P_s(t)}\exp[jw_s t + j\emptyset_s(t)] \quad (1)$$

Where r_s represent the state of polarization, the frequency of light, and $\emptyset_s(t)$ the instantaneous optical phase. After the propagation of the optical signal in the transmission fiber, many cross talk terms will combine, and the form of the optical field at the photo detector can be written as

$$\overrightarrow{E_{ph}(t)} = \overrightarrow{E_s}(t) + \sum_k \overrightarrow{E_x}(t)$$

$$\overrightarrow{E_{ph}(t)} = \vec{r_s}\sqrt{P_s b_s(t)}\exp[jw_s t + j\emptyset_s(t)] + \sum_{k=1}^{N} \vec{r_k}\sqrt{\epsilon_k P_s b_k(t)}\exp[jw_k t + j\emptyset_k(t)]$$

Where $E_k = P_k/P_s$ is the relative power of the k-th crosstalk component, $b_s(t)$ and $b_k(t)$ represents the binary symbols forming the amplitude modulating signal $\epsilon\{0,1\}$

The photo current after the receiver will be proportional to the square of the field, as in the equation (3)

$$i_{ph}(t) = \rho\left|\overrightarrow{E_{ph}(t)}\right|^2 = \rho\left|\overrightarrow{E_s}(t) + \overrightarrow{E_x}(t)\right|^2 \quad (3)$$

$$i_{ph}(t) = P_s[b_s(t) + \sum_{k=1}^{N} b_k(t)\epsilon_k + 2\sum_{k=1}^{N} \vec{r_s}\vec{r_k}\sqrt{\epsilon_k}\sqrt{b_k(t)b_s(t)}\cos[(w_s - w_k)t + \emptyset_s(t) - \emptyset_k(t)] + 2\sum_{k=1}^{n-1}\sum_{l=k+1}^{N} \vec{r_l}\vec{r_l}\sqrt{\epsilon_k\epsilon_l}\sqrt{b_k(t)b_l(t)}\cos[(w_s - w_k)t + \emptyset_k(t) - \emptyset_l(t)]] \quad (4)$$

From equation 4, the first term represents the signal power, the second term is the electric out-band cross talk power, the third term is the beating effect between the desired signal and the interfering crosstalk which represents the signal-crosstalk beat noise, and the fourth term is the crosstalk-crosstalk beat noise which is of less importance in the study of the system performance in terms of crosstalk impairments [9]. The most important crosstalk contribution is the signal-crosstalk beat noise which can be considered as a random variable in term of the phase. The probability density function of the beating term which can be expressed as $\gamma=\alpha\cos\varphi$ where is a uniformly distributed random variable between 0 and 2π and α is the amplitude of the

noise term, the PDF for this function can be represented as arc-sine function

$$f(\gamma) = \begin{cases} \frac{1}{\pi\sqrt{\alpha^2-\gamma^2}} & -\alpha < \gamma < \alpha \\ 0 \end{cases} \quad (5)$$

For a high number of interferers, the overall probability density function represents the combination of individual pdfs given by equation 5, which is usually approximated for Gaussian distribution with a mean depending on the transmitted signal power and variance representing the noise power. The accuracy of the crosstalk effect measurement will depend on the approximation method used to describe the overall noise at the receiver. Different approximations and assessment methods have been used in the published literature as shown in table above.

B. Q-Factor

The presence of two-level transmission in digital communications leads to different levels of noise associated with each level. Hence, there are two discrete signal-to-noise ratios, which correspond to the signal level. In order to calculate the overall probability of error, both of the signal-to-noise ratios must be considered. The two SNRs can be combined in a single quantity that gives a good estimation of the system performance called Q factor.

C. Bit Error Rate

The system performance can be assessed by calculating the probability of error and power penalty of the received signal. There are different methods for evaluation the BER, and all of them depend mainly on the assumption used to represent the noise contributions of different crosstalk component. At the receiver, the thermal noise and shot noise has a Gaussian a probability distribution function pdf the presence of crosstalk will add extra noise in the received current. The total noise current will have a pdf different from that for shot noise and thermal noise. Using a Gaussian approximation, the total noise current will have a Gaussian pdf with mean and variance depending on the transmitted signal. Using this approximation tends to give upper floor for the value of BER [16]. Also, this approximation could be used to give a good result in the case of a high number of crosstalk interferers provided that the contributions of the entire components are considered equal.

III. CROSS TALK IN ALL OPTICAL NETWORKS

A. Optical Cross Connectors And Routers

In a wavelength length division multiplexing network, high speed signals must be multiplexed densely in frequency to increase spectral efficiency and increase the amount of data traffic. However, to flexibly handle any change in traffic demand, optical networks are required to have switching component such as optical add/drop multiplexers, and/or optical routers. Optical cross connectors, OXC, are considered an essential network element, and mainly constructed from de-multiplexers, space switches and a multiplexers. Signals of different wavelength entering at each input port of OXC first will be de-multiplexed and then switched using space switches and finally multiplexed depending on the switching matrix for new output port. While cross connecting wavelengths from input to output fibers, OXC introduce intra-band crosstalk because of the non-ideal switching [17]. When an optical signal passes through an OXC, many crosstalk contributions are combined with the signal. The state of OXC and traffic load will determine the number of the crosstalk contributions of the same wavelength as the signal. Both types of homodyne crosstalk (coherent and incoherent) will be present with the desired signal at the receiver. Some studies have shown that, for specific OXC architectures, the coherent crosstalk may also cause noise depending on the propagation time, but at this time it will be compared with bit period [8]. Coherent crosstalk causes fluctuation of signal power, and it may cause noise depending on the relation of delay difference with bit period of the signal. In designing of OXC, the optical propagation time difference should be set to be longer than the laser coherent time in order to reduce the impact of crosstalk.

An array wave guide grating, is AWG also used to perform optical switch in all optical networks. Signals of different wavelengths from different input ports are coupled for the first propagation region in AWG and then propagate in the wave guide array of different lengths provided that the length difference between each adjacent wave guide is equal, at the second free propagation region the light of different wave length with different phases will concentrate depending on the phase shift for a specific output ports. AWG have been used widely as routers in optical networks [18]. The crosstalk problems occurring in this type of router result from signal leakages between different ports and, consequently, this will restrict the port numbers. Generally, the crosstalk in AWGs used as optical routers in results from using the same wavelength in more than one input-output port connection and to get more accurate results for crosstalk effect estimation, the worst case should be considered in which all input ports are connected to output ports using the same wavelength simultaneously. For this case, the leakage of intra band crosstalk will be maximum resulting in a high impact on system performance. Proper router design and perfect choice of router dimensions between outputs ports may reduce interfering between channels, and applying a specific switching schedule to prevent the use of the same wavelength for more connections at the same time will help to reduce the impact of crosstalk in

optical communication networks.

B. Optical Add/Drop Multiplexers

Optical add/drop multiplexers (OADMs) play major roles in WDM ring and bus networks to link the network with local transmitters and receivers. OADMs could be either reconfigurable or fixed wavelength, depending on the way of adding or removing wavelengths from system. For OADMs, the process of adding and dropping wavelengths changes depending on the states of switches inside the OADMs. As a result of using switches, both coherent and incoherent crosstalk should be considered in the calculations of BER and system degradation. In the case of fixed wavelength add-drop multiplexers, no switches will be used and then each node will be used to add and drop a specific wavelength. Due to the plethora of OADM structures in the literature, this paper focused on the two most common OADM technologies: Bragg gratings and arrayed waveguide grating (AWGs).

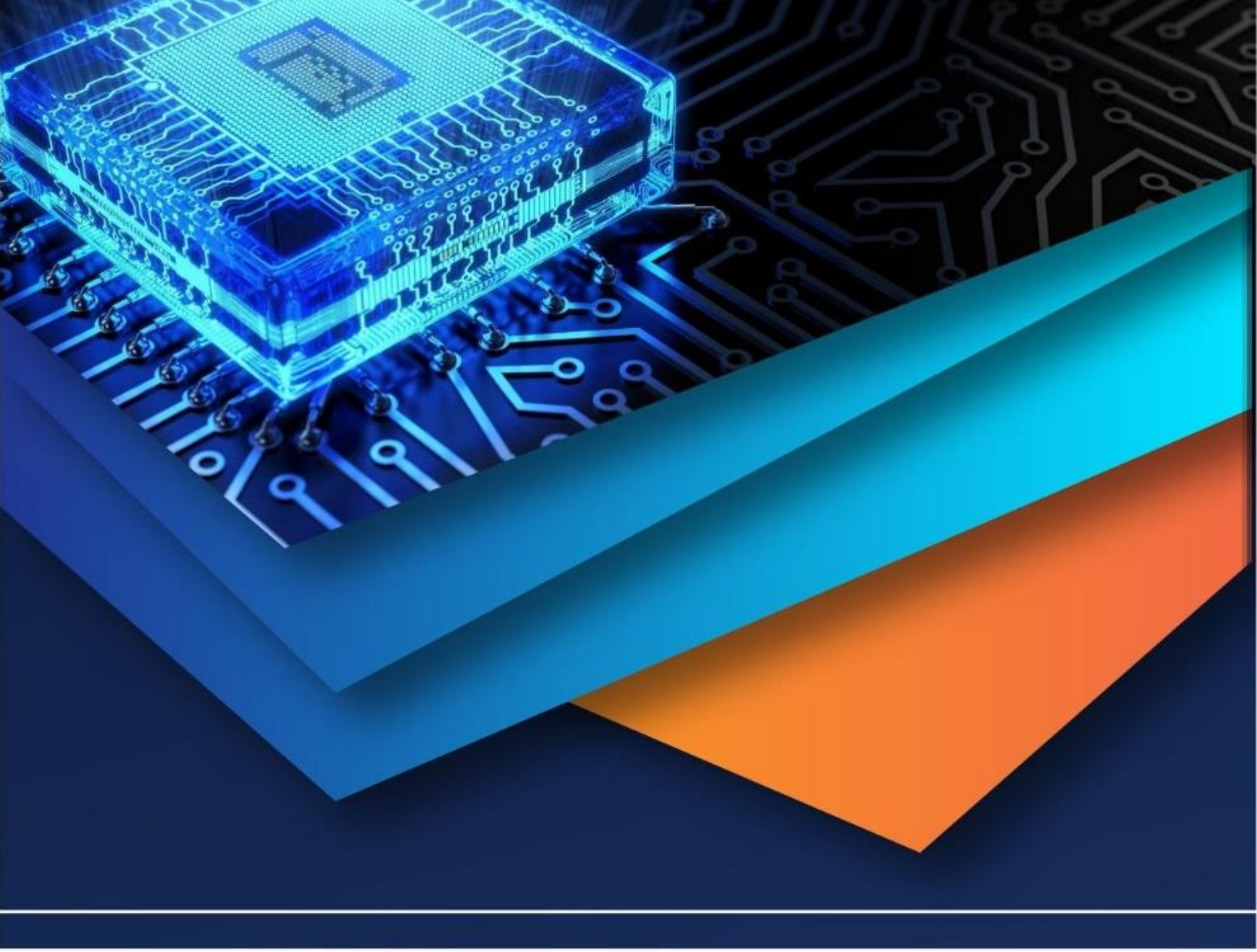
IV. CONCLUSION

An explanation of the crosstalk in all optical networks has been presented in this paper. Crosstalk is a major limitation in optical networks. Crosstalk can be either linear or nonlinear, nonlinear crosstalk results from the nonlinear behavior of the refractive index of the fiber. Four wave mixing, self phase mixing, and cross phase mixing may cause extra system degradation in long haul networks. Linear crosstalk is also divided in to two types: inter-channel and intra-channel, inter-channel crosstalk results from the leakage of the signal with a different wavelength from that of the desired signal. It is less problematic since its spectrum lies out of the optical band and is relatively easy to remove using optical filtering. Intra-channel crosstalk is more problematic since it is difficult to remove once occurred. It can also be classified as coherent and incoherent depending on the source of the noise and the laser coherence time.

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