PERFORMANCE ANALYSIS OF FWM IN MULTICHANNEL SYSTEMS

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Abstract: The basic aim of this paper is to provide an insight on how the process of Four Wave Mixing affects the overall performance of the multichannel system.

Index Terms: Wavelength Division Multiplexing, Dense Wavelength Division Multiplexing, Four Wave Mixing.

I. Introduction:

In optical communication systems the term nonlinearity refers to the dependence of the system on power of the optical beam/s being launched into the fiber cable. Nonlinear effects in optical fibers have become an area of academic research and of great importance in the optical fiber based systems. Several experiments in the past have shown that the deployment of high-bit-rate multiwavelength systems together with optical amplifiers creates major non linear effects such as SRS, SBS, SPM, XPM and FWM.

The system design engineers should not deploy high-bit-rate (>10Gbit/s per channel) multiwavelength systems without considering the nonlinear effects and their impact on these systems. We will also see various advantages and disadvantages of the above mentioned nonlinear effects in order to decide whether they affect the performance of these systems in a positive way or a negative way [1].

Nonlinearities in optical fibers originate due to the third order susceptibility (X^3). The real part of the equation gives us SPM, XPM and FWM while the imaginary part of the equation gives us SBS and SRS. The nonlinear effects depend on the transmission length of the optical fiber. The longer the optical fiber, the more the light interacts with the fiber material and the greater the nonlinear effects. On the other hand, if the power decreases while the light travels along the optical fiber, the effects of nonlinearity diminish.

II. WDM Systems:

In fiber-optic communications, WDM is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals. This allows for a multiplication in capacity, in addition to enabling bidirectional communications over one strand of fiber.

The term wavelength-division *multiplexing* is commonly applied to an optical carrier (described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (described by frequency). However, since wavelength and frequency are inversely proportional, and since radio and light are both forms of electromagnetic radiation, the two terms are equivalent.

Most WDM systems operate on single mode fiber optical cables, which have a core diameter of 9 µm. Certain forms of WDM can also be used in multi-mode fiber cables (also known as premises cables) which have core diameters of 50 or 62.5 µm.

WDM systems are divided in different wavelength patterns, *conventional* or *coarse* and *dense* WDM. Conventional WDM systems provide up to 16 channels in the 3rd transmission window (C-band) of silica fibers around 1550 nm. DWDM uses the same transmission window but with denser channel spacing. Channel plans vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 25 GHz spacing (sometimes called ultra dense WDM). New amplification options (Raman amplification) enable the extension of the usable wavelengths to the L-band, more or less doubling these numbers.

A WDM system mainly consists of the following components: transmitter (consisting of laser source, data source, modulators), receivers (consisting of photodiodes and filters), optical combiners, optical splitters and optical fiber cable. A simple WDM system can be seen in Fig. 1.

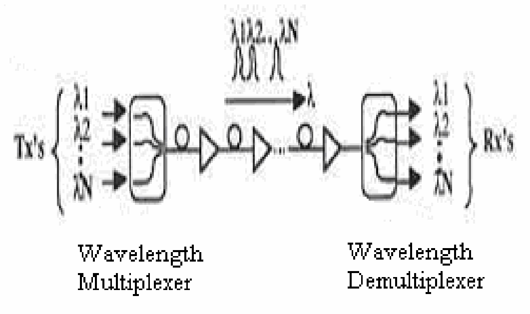

Fig. 1: Wavelength Division Multiplexing System

In a simple WDM system (Fig. 1), each laser must emit light at a different wavelength, with all the lasers_ light multiplexed together onto a single optical fiber. After being transmitted through a high bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. Each laser is modulated at a given speed, and the total aggregate capacity being transmitted along the high-bandwidth fiber is the sum total of the bit rates of the individual lasers. An example of the system capacity enhancement is the situation in which ten 2.5-Gbps signals can be transmitted on one fiber, producing a system capacity of 25 Gbps.

This wavelength-parallelism circumvents the problem of typical optoelectronic devices, which do not have bandwidths exceeding a few giga hertz unless they are exotic and expensive. The speed requirements for the individual optoelectronic components are, therefore, relaxed, even though a significant amount of total fiber bandwidth is still being utilized.

III. FOUR WAVE MIXING:

Assuming just two input frequency components ν1 and ν2 (with ν2 > ν1) which travel across the fiber optic cable, after interaction in a non linear medium, creates sidebands for each of the input waves. In effect, two new frequency components are generated: ν3 = ν1 - (ν2 - ν1) = 2 ν1 - ν2 and ν4 = ν2 + (ν2 - ν1) = 2 ν2 - ν1.

In general, for N wavelengths launched into a fiber, the number of generated mixing products or sidebands (excluding the original wavelengths) is given as $M = \frac{\left(N^3 - N^2\right)}{2}$. The FWM conversion efficiency is given by $\eta = \left[\frac{n_2}{A_{eff} D \left(\Delta \lambda\right)^2}\right]^{\frac{1}{2}}$, where n_2 is the core refractive index, A_{eff} is the effective area, D is the dispersion, and $\Delta\lambda$ is the channel spacing.

FWM is a nonlinear effect arising from a third-order optical nonlinearity, as is described with a $\chi^{(3)}$ coefficient. It can occur if at least two different frequency components propagate together in a nonlinear medium such as e.g. an optical fiber.

Assuming just two input frequency components ω_1 and ω_2 (with $\omega_2 > \omega_1$), we obtain a refractive index modulation at the difference frequency, which again creates sidebands for each of the input waves in the figure below. In effect, two new frequency components are generated: $\omega_3 = \omega_1 - (\omega_2 - \omega_1) = 2\,\omega_1 - \omega_2$ and $\omega_4 = \omega_2 + (\omega_2 - \omega_1) = 2\,\omega_2 - \omega_1$ [10].

FWM is also present if only three components interact. In this case the term $f_0 = f_1 + f_1 - f_2$ couples three components thereby generating Degenerate four wave mixing.
In bulk media, phase matching may also be achieved by using appropriate angles between the beams. FWM in fibers is strongly related to self-phase modulation and cross-phase modulation: all these effects originate from the Kerr nonlinearity and differ only in terms of degeneracy of the involved waves. If one likes, one may even see self- or cross-phase modulation as a kind of degenerate four-wave mixing.

FWM can have important deleterious effects in optical fiber communications, particularly in the context of wavelength division multiplexing where it can cause cross-talk between different wavelength channels, and/or an imbalance of channel powers. One way to suppress this is avoiding equidistant channel spacing.

FWM can transfer data to a different wavelength. A continuous wave pump beam is launched into the fiber together with the signal channel. Its wavelength is chosen half-way from the desired shift. FWM transfers the data from signal to the idler beam at the new wavelength.

Some of the advantages of FWM include parametric wavelength conversion, optical phase conjugation, demultiplexing of OTDM channels, wavelength conversion, and supercontinum generation. While some of its disadvantages are interchannel crosstalks, induction of noise and hence degrading the overall performance of the system.

IV. EXPERIMENTAL SETUP:

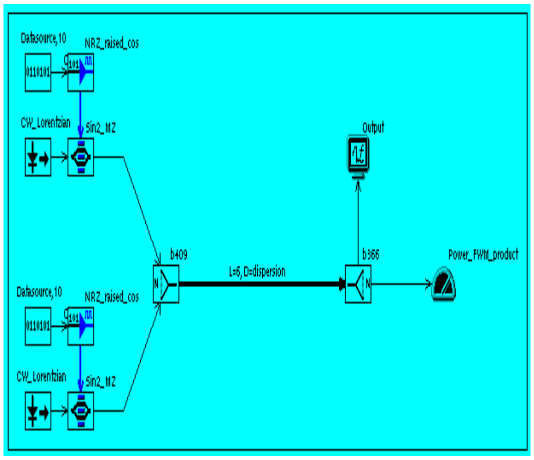

Fig. 1: Experimental Setup

The experimental setup in Fig. 1 contains data source, Continuous wave laser source, Mach Zender modulator, driver, splitter, combiner, spectrum analyzer, and a power meter. The data source produces data at a rate of 10 GB/s or higher in the form of ones and zeroes. This data is then transferred to the driver which is a device that is used to convert the binary zeroes and ones into electrical format i.e. NRZ or RZ format. The signal is then passed on to Mach Zender modulator. A modulator is a device that modulates carrier signal according to the modulating signal. Here the modulating signal is the one passed on from the driver and the carrier signal wavelength is provided by the continuous wave laser.

It must be noted that the optical signal is transmitted at a particular wavelength generated by the continuous wave laser and at a particular power level. The two optical signals of particular wavelength and power are multiplexed through combiner and are transmitted through the optical fiber cable. The optical signal at the receiving end is passed on to splitter through which multiple analyzing components can be attached to make analysis of the received signal.

V. RESULTS AND DISCUSSION:

In this experimental setup the two lasers are operating at center frequencies of 193.025 THz and 193.075. Fig. 2 shows the input wavelengths to the optical combiner, Fig. 3 shows the FWM cross products and Fig. 4 shows plot of power vs dispersion.

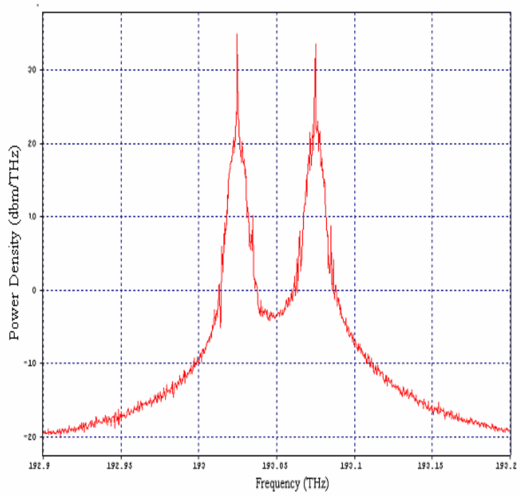

Fig. 2: Input Wavelengths (Power density vs Frequency)

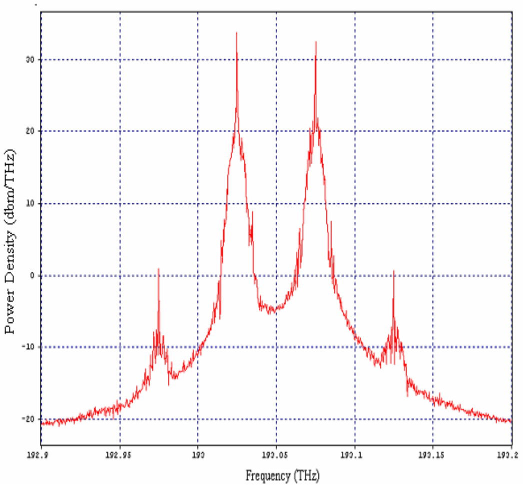

Fig. 3: Output Wavelengths (Power density vs Frequency)

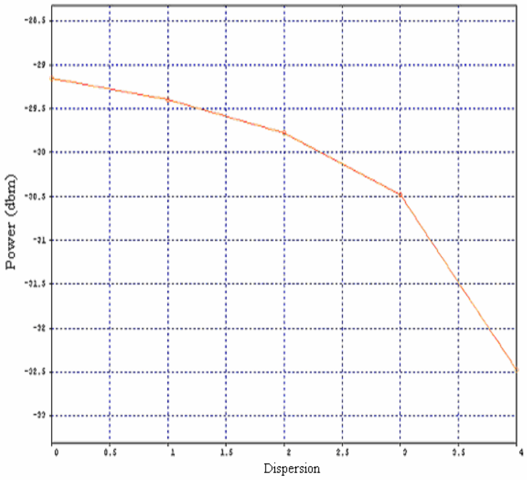

Fig. 4: Power vs Dispersion plot

VI. Conclusion:

Optical fibers exhibit a variety of nonlinear effects. Nonlinear effects are feared by telecom system designers because they can affect system performance adversely. Presence of these non linear effects in the optical fiber communication systems like WDM systems can adversely effect the communication between two receiving ends. That is it can lead to transference of wrong or incorrect data to the receiving end due to interchannel mixing if the sideband wavelengths generated due to FWM coincide with the original wavelengths carrying data.

These nonlinear effects can be managed through proper system design. There are many ways by which these nonlinear effects can be reduced. However, nonlinear effects are also useful for many device and system applications: optical switching, soliton formation, wavelength conversion, broadband amplification, demultiplexing, etc. New kinds of fibers have been developed for enhancing nonlinear effects.

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