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# Investigation of four wave mixing effect with different number of input channels at various channel spacing

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ABSTRACT

In this paper the design, implementation and performance analysis of four wave mixing (FWM) in optical communication system for different number of input channels is presented using various values of channel spacing. Here, all the input channels have been spaced evenly at various values like 6.25 GHz, 12.5 GHz, 25 GHz, 40 GHz, 50 GHz with the different number of channels at the input i.e. with 2, 4, 6, 8, 12 input channels. The simulation results reveal that the four wave mixing is minimum when the channel spacing is maximum i.e. 50 GHz with minimum number of channels i.e. 2 input channels. It is observed that on increasing the channel spacing, the interference between the input frequencies decreases and hence the four wave mixing also decreases. Also, on increasing the number of input channels/users, the interference between the input frequencies increases and thus, the four wave mixing also increases.



## 1. Introduction

As broad-band Internet access is rapidly penetrating world markets and homes, Internet traffic is increasing rapidly in the core network. Associated with the expansion of broad-band is the paradigm shift in telecommunications from voice-optimized to IP centric networks [1]. Optical networks have been considered as the only means to ensure delivery of large capacity links in a flexible, dynamic and reliable way [2]. Optical transparent networks have attracted much attention as a potential solution to the future capacity and flexibility requirements in optical communication systems. There are several key components required to realize fully transparent optical networks: optical switches, optical add-drop multiplexers and wavelength converters [3]. Dense wavelength division multiplexing (DWDM) is a fiber optic transmission technique that employs light wavelengths to transmit multiple data signals [4] and to make an effective usage of the fiber bandwidth and achieve high system capacity [5]. To improve system performance, understanding nonlinear optical effects in long haul transmission systems, such as DWDM systems, is important. Optical fiber nonlinearities can lead to interference, distortion and excess attenuation of the optical signals, resulting in performance degradation. The most common nonlinear optical effect of importance in optical fiber communication systems results from the fiber nonlinear refractive index. The nonlinearity in the refractive index is known as Kerr nonlinearities. The Kerr nonlinearity gives rise to different effects such as self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) [6]. FWM may induce light path bit error rate (BER) fluctuations in dynamic networks that can affect the optical signal to noise ratio (S/N) and quality of service (QoS) in transparent networks under highly complex nonlinear effect [7] and influence the frequency chirp and extinction ratio in the system [8]. Four-wave mixing is one of the dominating degradation effects in wavelength-division-multiplexed (WDM) systems with dense channel spacing and low chromatic dispersion on the fiber. If in a WDM system, the channels are equally spaced, the new waves generated by FWM will fall at channel frequencies and thus, will give rise to crosstalk. In case of full in-line dispersion compensation i.e. 100% dispersion compensation per span, the FWM crosstalk occurs at its maximum level since the FWM products add coherently in each span [8]. Four-wave mixing (FWM) is a parametric process in which different frequencies interact and generate new spectral components by frequency mixing [9]. The magnitude of FWM efficiency depends on channel power, channel spacing and fiber dispersion but is independent of the bit rate [10]. In the transmission of dense wavelength-division multiplexed signals, FWM is to be avoided but for certain applications, it provides an effective technological basis for fiber-optic devices. FWM also provides the basic technology for measuring the nonlinearity and chromatic dispersion of optical fibers. FWM has

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proved useful in applications such as real-time holography, super continuum generation, and soliton communication systems [11]. The most common configuration involves a self-focusing nonlinearity and a backward geometry, in which the initial pump beams counter propagate to create a reflection grating.

Daikoku et al. [12] conducted single-polarization 160 Gbit/s-based field transmission experiments. Single-channel transmission and 8 WDM transmission with 300 GHz channel spacing over the inter-city 200 km SMF was achieved by utilizing 160 Gbit/s RZ-DPSK signals and a simple PMD compensator. Randhawa et al. [13] presented a novel channel allocation method based on optical Golomb ruler that allows reduction of the FWM effect while maintaining bandwidth efficiency. The unequal channel spacing allocation method was proposed to reduce four-wave-mixing crosstalk in high capacity long-haul repeater less WDM light wave systems. Hwang and Tonguzc [14] described the comparisons of power penalty due to FWM between equal channel spacing and the unequal channel spacing for the 20-channel WDM system. Brackett et al. [15] presented an architectural approach for very-high-capacity wide-area optical networks. The dense multi-wavelength technology based network was scalable in terms of the number of networked users, the geographical range of coverage and the aggregate network capacity.

Up till now, many methods have been proposed to reduce the four wave mixing effect. The four wave mixing effect has been analyzed for different values of fiber length and dispersion parameter but the comparison of four wave mixing on the basis of number of input channels/users at different channel spacing has rarely been done. In this paper, the effect of four wave mixing at the output is considered for different number of channels i.e. 2, 4, 6, 8, 12 at various values of channel spacing i.e. 6.25 GHz, 12.5 GHz, 25 GHz, 40 GHz, 50 GHz.

This paper is divided into different sections. In Section 1, the introduction of four wave mixing effect is presented. In Section 2, the schematic model is proposed. Section 3 describes the simulation setup for an optical communication system implementing these requirements. In Section 4, the comparison of four wave mixing on the basis of different number of input channels/users at various channel spacing values is done in terms of eye diagrams, BER and $Q$-factor. Section 5 gives the conclusion of this paper.

## 2. Schematic model

The schematic model for an optical communication system implementing the four wave mixing effect for different number of channels at different channel spacing is presented in Fig. 1. The number of input channels varies as 2, 4, 6, 8 and 12. The input channel consists of a continuous wave laser, modulator, data source and a modulator driver. The channel spacing is set at different values as specified earlier. The signals transmitted from each of these

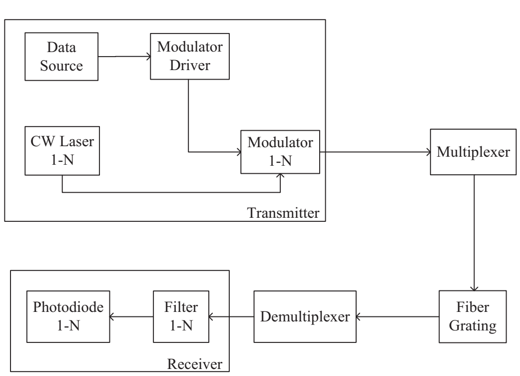


**Fig. 1.** Schematic model.

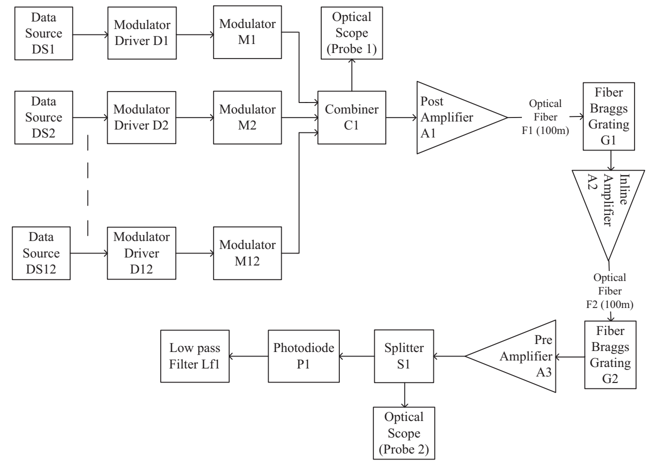


**Fig. 2.** Simulation setup.

transmitters are combined together using a multiplexer. Then the multiplexed signal is sent over the fiber which adds the on linear effects like four wave mixing in the transmitted signal. Then the signal is passed through the receiver via Fiber Grating. The receiver contains the PIN photodiode and a low pass filter which is used to reconstruct the input signal.

## 3. Simulation setup

The simulation setup for showing the effect of changing the number of input channels at various channel spacing on four wave mixing is shown in Fig. 2. The continuous wave laser (L1–L12) in the transmitter section is used to create the carrier signal. In this setup, twelve users are taken in account whose wavelengths have a specific difference i.e. spacing between them is defined. The wavelength of first user has been kept at 192.975 nm. The wavelengths of next users are set as per the spacing requirement i.e. at frequency difference of 6.25 GHz, 12.5 GHz, 25 GHz, 40 GHz and 50 GHz. The number of input channels/users varies as 2, 4, 6, 8 and 12 with each value of channel spacing. The data source (ds1–ds12) is used to generate the random input data bit sequence at the bit rate of 10 Gbps. The light signal modulates the input data. The modulator (m1–m12) is driven by the modulator driver (d1–d12) which decides the input data format. The input data format used here is non-return to zero (NRZ) raised cosine. The modulated data from all the users is combined using a combiner (c1). The post amplifier (a1) amplifies the signal before allowing it to enter into the fiber to avoid losses. Then this signal is sent over the fiber of length 100 km. The attenuation, dispersion and nonlinear effects are activated. Then the signal is passed through the Fiber Bragg Grating (g1) which is used to compensate the dispersion at each step. The in-line amplifier (a2) amplifies the signal in the transmission medium itself. Then the signal is again passed through a fiber (f2) and Fiber Bragg Grating (g2). Then pre-amplifier (a3) is used to amplify the signal before allowing it to enter into the receiver section. After amplification, the signal reaches the receiver. At the receiver, the signal is demultiplexed by using a splitter (s1) which splits this signal into the same number of signals as were transmitted. The photodiode (p1) is used for optical to electrical conversion. Then the signal is passed through the low pass filter (Lf1) and the final output signal is received. An optical scope (probe1) is attached at the output of combiner to examine the input signal. Another optical scope (probe2) is placed at the output of splitter to examine the four wave mixing effect in frequency spectrum. An electrical scope (scope2) is kept at the receiver output to examine the eye diagrams, BER and $Q$-factor.