INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY

VOL. 1, NO. 2, AUGUST 2006

# Four Wave Mixing in Closely Spaced DWDM Optical Channels

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***Abstract-* Present DWDM networks operating at 10.7 Gb/s in the C and L bands region have channel spacing no less than 25 GHz. We show that this limit is a constraint and smaller spacing may not be allowed without further optical and electrical pulse shaping.**

***Index Terms-* Four wave mixing, channel spacing, optical beat interference, DWDM Networks.**

## I. INTRODUCTION

Although wavelength division multiplexing (WDM) has been a known technology for several years, its early application was restricted to providing wide channel spacing in commercial systems. Accurate wavelength control of the transmitters as well as high selectivity optical filters allow the network to operate at precise wavelengths making dense wavelength division multiplexing (DWDM) the transmission technique of choice. Recently, laser sources and optical multiplexer and de-multiplexer technologies have been developed where optical carriers can be densely packed and integrated into a single fiber with multiple simultaneous high data rates such as 10 Gb/s, 40 Gb/s and higher rates. The optical spectral density in DWDM systems can be increased by various techniques: i) bandwidth efficient modulation, ii) wider optical bands and iii) closely packed optical channels in the available optical transmission band [1-2]. A combination of all these techniques is very attractive in efficiently designing high capacity networks. Interferometric crosstalk due to optical beat between various optical carriers has been reported. Various works, both theoretical and experimental have shown significant bit error rate degradation due to the optical beat interference [3-5]. In this paper, we discuss the limit in channel spacing in 10.7 Gb/s DWDM systems. We show, experimentally and by simulation, that the channel spacing is reduced to 12.5 GHz, a goal sought by various DWDM equipment vendors, the resultant optical beat interference (OBI) cause the optical signal to noise ratio (OSNR) to degrade dramatically when the channel spacing is less than 14 GHz and no electronic pulse shaping is used. Section II describes the experimental set up constructed to show how optical beat affects transmitted data stream and determine the limit on the channel spacing and the associated power penalties. The channel spacing limit is measured and is varied to quantify its effects on the integrity of the optical signal to noise ratio. Section III compares the results from the experiment and simulation, and Section IV gives the conclusion.

## II. EXPERIMENTAL SET-UP

The experimental setup is shown in figure 1. In this set-up, two laser sources were used to represent two adjacent channels in a DWDM network. Laser source 1 (LD1) is a tunable external cavity laser source with wide tuning capability of its center wavelength from 1480.000 nm to 1610.000 nm; the vendor specified line-width is less than 10 MHz. The second laser is a fixed wavelength distributed feedback laser source with a mode suppression ratio of 37 dB and a center wavelength at 1532.223 nm. Light from the fixed wavelength source is directed through a polarization controller and is externally modulated by single

*INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY*

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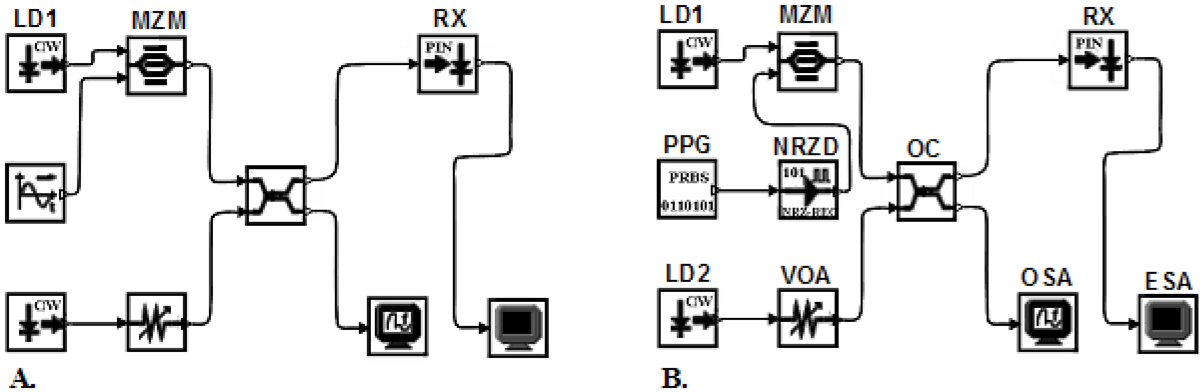



Fig 1. Experimental Set-up: A) Sinusoidal signal as the data signal B) Pseudorandom bit sequence as the data signal; LD1: Laser Diode 1 (fixed wavelength DFB laser), LD2: Laser Diode 2 (external cavity tunable laser), MZM: Mach-Zehnder modulator, PPG: Pulse Pattern Generator, SGN: Signal Generator, VOA: Variable Optical Attenuator, OC: 3-dB Optical Coupler, OSA: Optical Spectrum Analyzer, RX: Receiver, OSC: Oscilloscope,

arm chirp free Mach Zehnder modulator. Both sinusoidal and pseudorandom sequences were used as the diagnostic signals. A 3-dB optical coupler combined the output light from the tunable modulated laser and the fixed CW laser source.

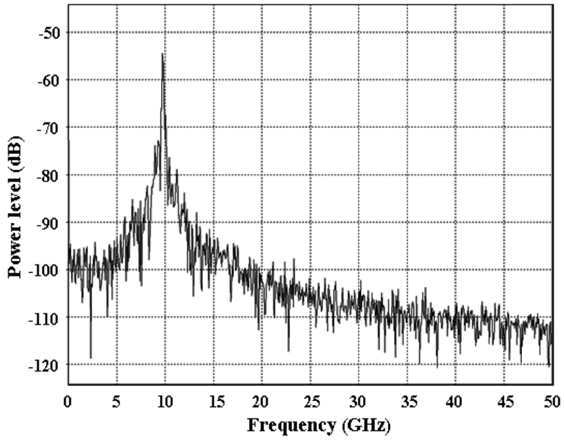
One side of the output of the coupler is fed to an optical spectrum analyzer for further measurements. Light from the tunable laser source is sent through a variable optical attenuator (VOA), which is used to equalize the input powers to the optical coupler. The output of the detector is detected by a PIN receiver, which can be considered linear in the frequency range of interest. The receiver output was displayed on the RF spectrum analyzer and a personal computer was used to read the RF spectrum analyzer output. The output of optical detector was also fed to an oscilloscope to get the eye diagram of the modulation data signal.

## III. RESULTS AND DISCUSSION

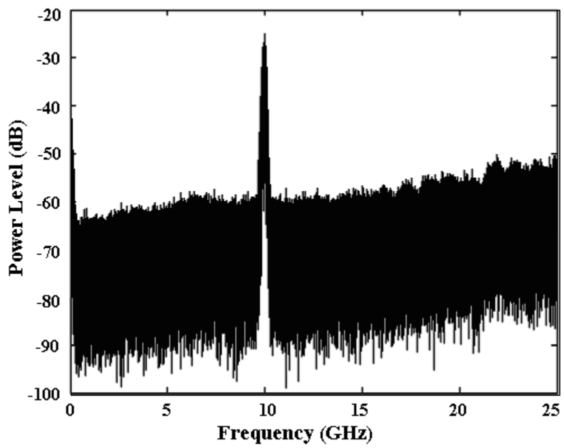
The center wavelength of laser source 1 ($\lambda_1$) which is a fixed laser was 1532.223 nm. The center wavelength of the laser source 2 ($\lambda_2$) was set at 1532.24 nm so that the channel spacing in terms of frequency ($\Delta\nu$) was 12.17 GHz. The wavelength of tunable source was increased with increments of 0.02nm. Both the powers at the input of optical coupler were adjusted to 0 dBm using VOAs. Laser source 1 was externally modulated with 10 GHz sinusoidal signal and the output signal was monitored as the wavelength of laser source 2 was changed. The observed signal was completely distorted when the channel spacing was set at 9.8 GHz or less corresponding to a $\lambda_2$ = 1532.30nm.

As the channel spacing was increased, slight improvement in the retrieved signal was observed from here on. At a channel separation of 14.5 GHz, the signal id distortion free and the optical beat interference is harmless even when the modulation index was increased to 60 %. The RF spectrum and the optical spectrum are shown in figures 2 and 3 respectively at a beat frequency of 9.8 GHz with out any modulated signal from both the experiment and simulation.

As the wavelength of the tunable laser was further increased, the effect of optical beat on the message signal reduced and at a beat frequency of 14.95 GHz ($\lambda_2$=1532.34nm), the received signal was best. Figures 4 and 5 show the electrical spectrum and the retrieved signal with the message as sinusoidal signal at 10 GHz at this beat frequency respectively.

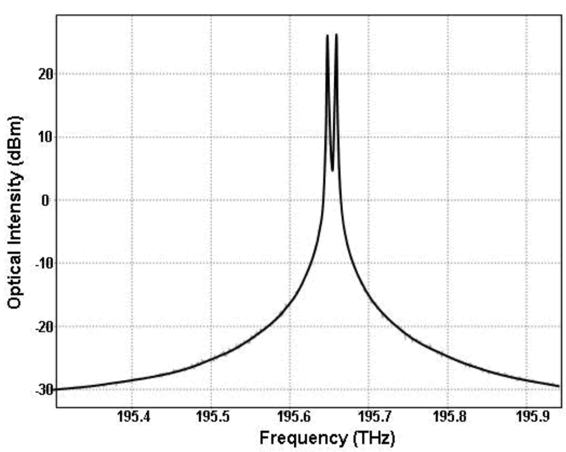



**A.**




**B.**

Fig 2. The RF spectrum observed without modulation at a beat frequency of 9.8 GHz from: A. Simulation and B. experiment

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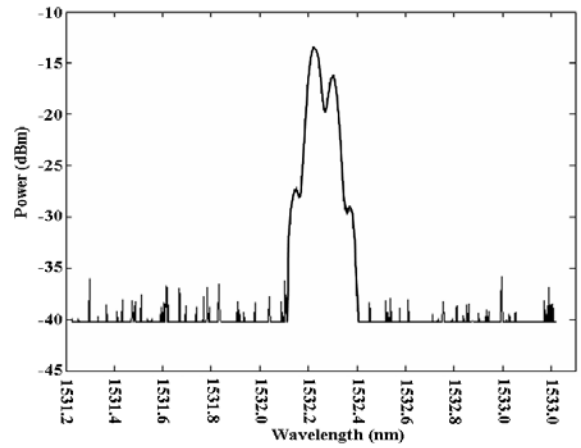
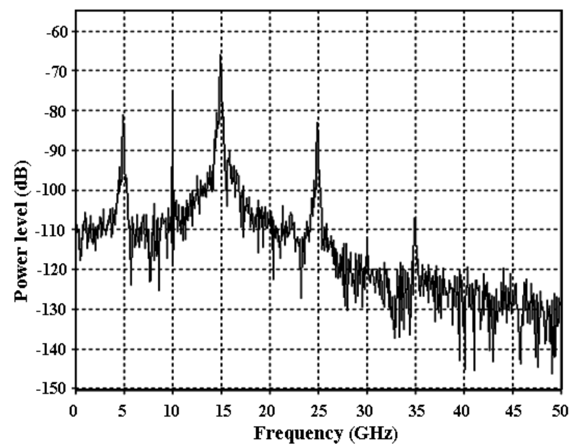
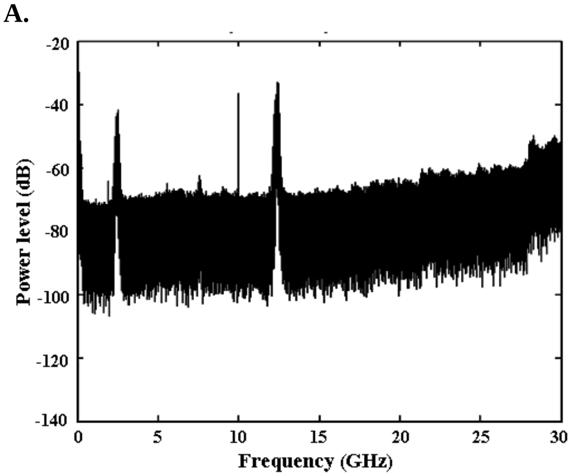



**B.**

Fig3. The optical spectrum observed without modulation at a beat frequency of 9.8 GHz from: A. Simulation and B. experiment.

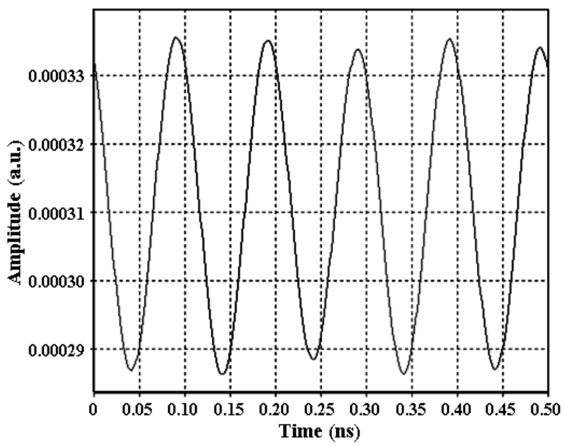



**A.**

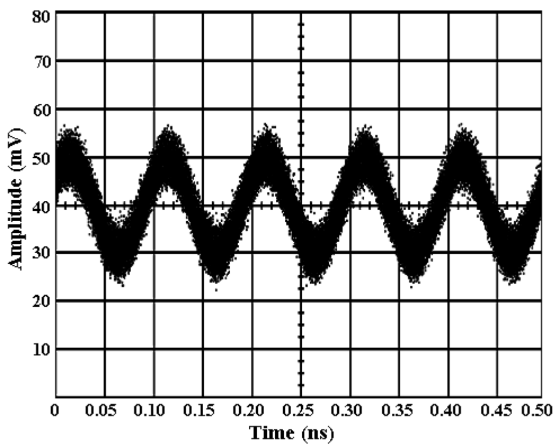



**B.**

Fig 4. RF spectrum with 10GHz sinusoid message signal at a beat frequency of 14.95 GHz from: A. simulation and B. Experiment.

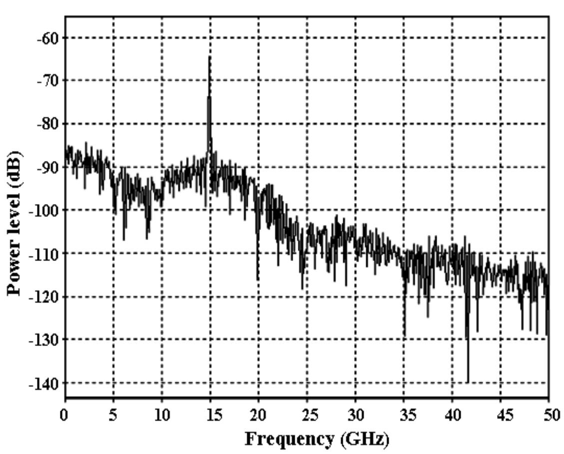



**A.**

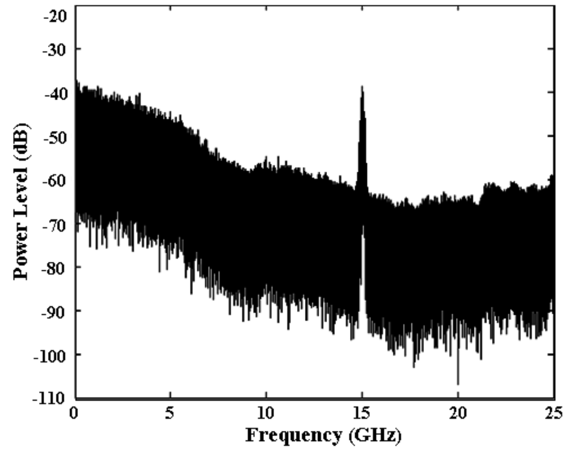



**B.**

Fig 5. Retrieved message signal (10GHz sinusoid signal) at the receiver with a beat frequency at 14.95 GHz from A. Simulation and B. Experiment.




**A.**

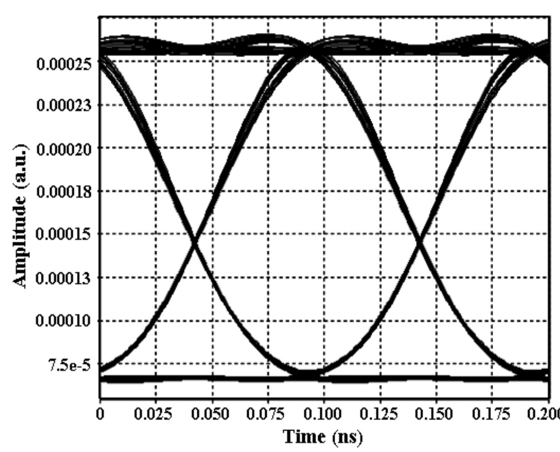



**B.**

Fig 6. RF spectrum with 10 Gb/s pseudorandom data stream as message signal at a beat frequency of 14.95 GHz from: A. Simulation and B. Experiment.

The same experiment and simulation was carried out with 10Gb/s pseudorandom sequence modulated to one of the lasers and it was seen that the message could not be retrieved until the spacing between two lasers was about 15 GHz.

Figure 6 and 7 show the electrical spectrum and the retrieved eye diagram of the 10Gb/s pseudorandom sequence at a beat frequency of 14.95 GHz respectively from both experiment and simulation




**A.**

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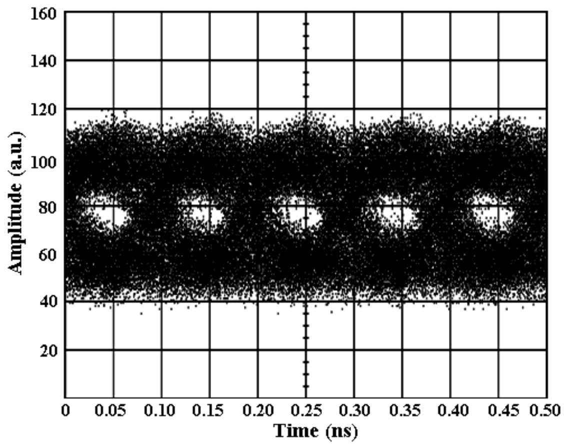


**B.**

Fig 7. Retrieved message signal (10 Gb/s pseudorandom data stream) at the receiver with a beat frequency at 14.95 GHz from: A. Simulation and B. Experiment.

## IV. CONCLUSION

In this paper we have shown experimentally and by simulation that the optical beat between two channels in a DWDM network has a considerable effect on the message streams and in turn limits the channel spacing. We set the limit on the channel spacing and it cannot be less than 15 GHz in a DWDM network with message streams at 10 Gb/s in order to have negligible effect of optical beat interference. The channel spacing of 15 GHz is much less than the one used in a commercial DWDM network, which is around 40 – 50 GHz. Thus we can say that the channel spacing can be reduced to 15 GHz for a good performance of DWDM network with increased accommodation of channels.

## REFERENCES

[1] T. Ito, K. Fukuchi, K. Sekiya, D. Ofasaham, R. Ohhira and T. Ono, "6.4 Tb/s WDM transmission experiment with 0.8 hit/s/Hz spectral efficiency", *ECOC'OO*, Munich, Germany, 2000, PD 1.1

[2] H. Bissessur, G. Charlet, C. Simonneau, S. Borne, L. Pierre, C. De Barros, P. Tran, W. Idler, and R. Dischler, "3.2 Tb/s c-band transmission over 3 x 100km with 0.8 bit/s/Hz efficiency", *ECOC'O1*, Amsterdam, the Netherlands, 2001, PD 1.3

[3] H. Kim, and A.H. Gnauck, "10 Gb/s 177 km transmission over conventional single mode fiber using a vestigial sideband modulation format", *Electron. Lett.*, 2001, Vol. 37, pp. 1533-1534, Dec 2001.

[4] C.X. Yu, S. Chandrasekhar, T. Zhou, and D.T. Neilson, "Vestigial sideband filtering at 10 Gb/s using a 12.5 GHz channel-spacing demux", *Electron Lett.*, 2002, Vol. 38, pp. 237-238, Feb 2002.

[5] T. Tsuritani, A. Agata, I. Morita, K. Tanaka, and N. Edagawa, "Performance comparison between DSB and VSB signals in 20 Gb/s- based WDM systems", *OFC'O1*, Anaheim, CA, USA, 2001, MM5.