International Conference on Information and Communication Technology
ICICT 2007, 7-9 March 2007, Dhaka, Bangladesh

PERFORMANCE LIMITATIONS OF A SUBCARRIER MULTIPLEXED OPTICAL TRANSMISSION SYSTEM DUE TO OPTICAL BEAT INTERFERENCE

S. Bhowmick, Tanzina Khaleque, Shamim Reza, S. P. Majumder,
Department of Electrical & Electronic Engineering
Bangladesh University of Engineering & Technology (BUET), Dhaka 1000, Bangladesh
Email: tanzina_82@yahoo.com

ABSTRACT

A theoretical performance analysis is presented for a subcarrier multiplexed (SCM) optical transmission system in presence of optical beat interference (OBI) which occurs during the photodetection process for non-return to zero (NRZ) and delay modulation (DM) linecoding. A suitable bandwidth of 890-950 MHz is selected and channel bandwidth of 200 KHz and carrier separation of 250KHz is considered. Results are evaluated in terms of signal to OBI ratio for the two linecodig schemes. It is found that there is a significant increase in the SIR and hence the number of subcarriers can be achieved by employing Miller code compared to NRZ for the same data rate. For example, for a number of subcarriers of 10, the achievable SIR is about 36 for Miller coded system compared to 10 dB for NRZ coded system.

1. INTRODUCTION

The demand for ultra-large capacity transmission systems for long-haul communications systems and future multi-media services is increasing rapidly [1]. Multiplexing of optical signals promises to meet this demand. Several approaches being possible depending on the application of subcarrier multiplexing (SCM) which offers great application potential [1-2].

Optical transmission with subcarrier multiplexing (SCM) is a scheme where multiple signals are multiplexed in the radio frequency (RF) domain and are used to modulate directly a laser diode. Because of simple and low cost implementation, SCM has been proposed to transmit multi-channel digital signals using direct detection [1-2].
Performance of an optical transmission system with RF subcarrier multiplexing (SCM) is affected by the beat interference generated due to beating of the subcarrier frequency components during the photodetection process which limits the the allowable subcarrier power, the optical modulation index and maximum number of subcarrier channels that can be multiplexed in an optical channel for transmission over a single mode fiber (SMF). Researches have been carried out recently to evaluate the impact of OBI on the performance of an SCM WDM system [3-4]. In this paper, investigation is carried out to evaluate the impact of OBI on the performance of an optical transmission system with RF subcarrrier multiplexing and to determine the effectiveness of linecoding schemes like NRZ and Miller code (MC) in minimizing the effect of OBI.
The paper is organized as follows. In section 3, the OBI problem is discussed mathematically. Section 3.2 gives the short description of Delay modulation. The simulation results and corresponding discussions are included in section 4. Finally the summary and the conclusion is drawn in section 5.

2. SYSTEM BLOCK DIAGRAM

The block diagram of an optical WDM system with SCM under consideration is shown in Fig.1. The receiver block diagram is shown in Fig.2

3. MATHEMATICAL ANALYSIS OF OBI

3.1 NRZ

There are M number of subcarriers in a given optical channel , as shown in the Fig 1 , having the same average power. Each of these fields can be represented by

$$e_i(t) = \sqrt{s_i}(t) \text{ ....(1)}$$

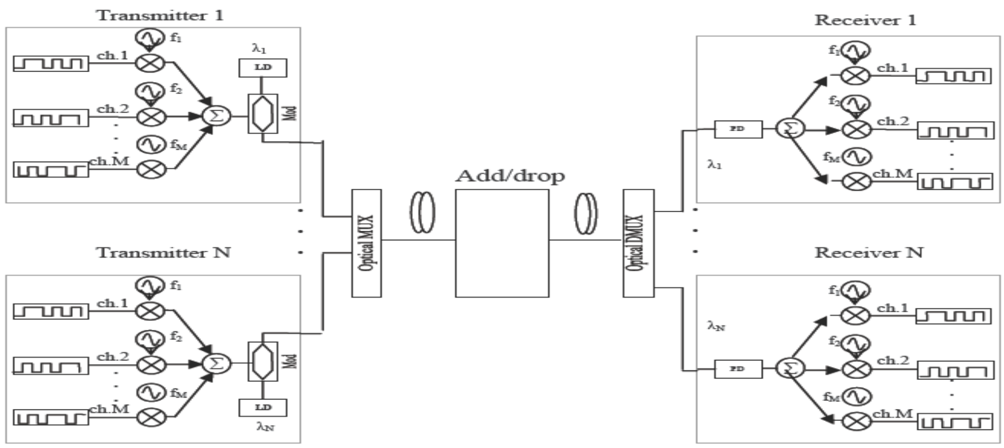

Fig. 1 SCM/WDM system architecture

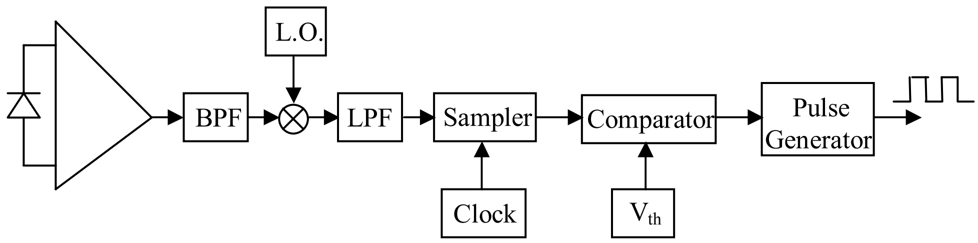

Fig. 2 Block diagram of a coherent optical receiver for detection of SCM optical signal

where the intensity modulation by an RF subcarrier of center frequency f_i is represented by

$$s_i(t) = 1 + m(t)\cos(2\pi f_i t) \quad ....(2)$$

where $m(t)$ is NRZ data signal with bit duration τ.

The total field in an optical channel is the sum of M fields can be represented as

$$e(t) = \sum_{i=1}^{M} e_i(t) \quad ....(3)$$

The electric field at the output of the fiber is given by

$$e_o(t) = [e(t) \otimes h_f(t)]e^{-\alpha L} \quad ....(4)$$

Where α is the fiber attenuation coefficient, L is the fiber length and $h_f(t)$ represents the fiber impulse response. The photo-detector converts this field into an electrical signal proportional to the field intensity. Photo-detector output current is then given by

$$i(t) = R\left|e_o(t)^2\right| + n(t) \quad ....(5)$$

where R is responsivity of the PD and n(t) represents the noise due to photo-detector and preamplifier. By expanding equation (4), signal component and cross component of photo-detector output can be expressed as

$$i_s(t) = \sum_{i=1}^{M} e_i^{\,2}(t) \quad ....(6)$$

$$i_c(t) = \{2\sum_{i=1}^{M}\sum_{l=i+1}^{M} e_i(t)e_l(t)\} \quad ....(7)$$

Here $i_c(t)$ contributes nonzero beat interference term. The output of the PD is passed through a pre-amplifier followed by a band pass filter. If any of the spectral components of $i_c(t)$ falls within the bandwidth of any one of the M users BPF, it will cause optical beat interference (OBI).

The frequency spectrum of the i-th sub-carrier's (channel) signal component can be obtained by taking Fourier transform of $i_{si}(t)$ as

$$I_{si}(f) = \int_{-\infty}^{+\infty} i_{si}(t)e^{-jft}df$$

$$= 2\pi\delta(f) + (\tau/2)*[\mathrm{sinc}\{\tau(f+f_i)\} + \mathrm{sinc}\{\tau(f-f_i)\}]e^{-jf\tau/2} \quad ....(8)$$

where f_i represents the i-th subcarrier frequency.

The power spectrum of the i-th subscriber's signal component can be expressed as [5]

$$P_{si}(f) = [I_{si}(f)]^2$$
$$= 4\pi^2\delta(f) + (\tau^2/4)[\mathrm{sinc}^2\{\tau(f-f_i)\} + \mathrm{sinc}^2\{\tau(f+f_i)\}] \quad \text{……………(9)}$$

Using band pass filter , output signal power of the desired sub-carrier can be expressed as

$$P_{isig} = \int_{f_i - B/2}^{f_i + B/2} P_{si}(f)df$$
$$= \int_{f_i - B/2}^{f_i + B/2} (\tau^2/4)[\sin c^2\{\tau(f-f_i)\}]df \quad \text{…….(10)}$$

where B is the specified bandwidth of the sub-carrier or bandwidth of the BPF.

Here $[\sin c^2 \tau(f+f_i)]$ term falls outside the range of integration. Similarly, the frequency spectrum of the composite cross component can be expressed as

$$I_c(f) = \int_{-\infty}^{+\infty} i_c(t)e^{-jft}df \quad \text{……...................(11)}$$

The power spectrum of the composite cross component can be expressed as

$$P_c(f) = [I_c(f)]^2 \quad \text{..................................(12)}$$

The cross component present in the required bandwidth B is

$$P_{icross} = \int_{f_i - B/2}^{f_i + B/2} P_c(f)df \quad \text{…….....................(13)}$$

This P_{icross} is the source of the optical beat interference (OBI).

The signal to interference ratio (SIR) is defined as the ratio of the signal power in (9) to the power of the cross component in (12) within the required bandwidth . So SIR can be expressed by the following equation

$$\text{SIR} = P_{isig} / P_{icross} \quad \text{…………………………(14)}$$

3.2 Delay Modulation (Miller Coding)

DM encoding is also known as the Miller code. The modulator has four encoder states and the source is binary. Four base band signals are available. Which one is transmitted depends both on the present digit and the previous transmitted bit. Each state is identified by the label of the previously transmitted signal.[5].Power spectrum of delay modulation is shown in Fig 3.

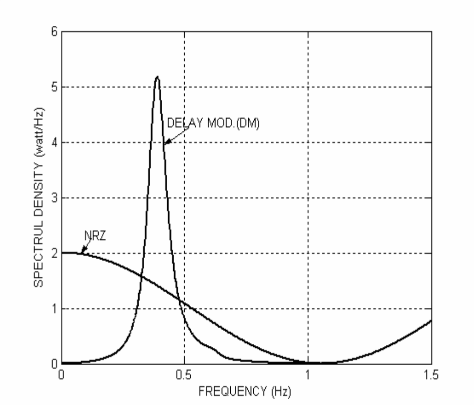

Fig. 3 Power spectrum of Miller coded (delay modulation) baseband signal.

4. RESULTS AND DISCUSSION

A multiuser SCM system for a total bandwidth of 890-950 MHz was simulated using MATLAB. In this simulation, allocated bandwidth for each user is 200 KHz with carrier separation 250 KHz. The modulated RF carriers in an SCM system then intensity modulate each optical carriers in WDM system. Fig 4 and Fig 5 shows the spectrum of signal and cross components respectively obtained from simulation. The signal and cross spectra were estimated using a 131072 point FFT. The cross term components having dominant values all fall out of required bandwidth of channel. Fig 6 is the comparative representation of SIR versus number of channels with and without linecoding. The figure shows that there is a significant increase in the SIR for Miller coded SCM system compared to NRZ SCM system for the same data rate with a given number of subcarrier channels and channel bandwidth. Without linecoding, the SIR drastically reduces for 250 KHz carrier separation and performance is limited to 2-3 channels, and performance improves with the increase in separation as shown for 500 KHz separation. Still the SIR value is not sufficient. Again, with the increase in the carrier separation with the same channel bandwidth the total channel number becomes less. Now in the case of linecoding, the performance is satisfactorily improved. For example, for the same optical modulation index with 10 multiplexed subcarrier channels each having a bandwidth of 200 kHz with channel spacing of 500 kHz, the available SIR is approximately 10 dB for NRZ coded SCM system. The corresponding SIR available with MC coded SCM system is approximately 36 dB even at a lower channel separation of 200 kHz which can further be improved to 52 dB when the channel separation is creased to 250 kHz. Further, for a given SIR of 20 dB, the MC coded SCM system can allow up to 70 subcarrier channels corresponding to a carrier separation of 200 kHz which can be increased drastically to more than 100 subcarrier channels when channel separation is increased to 250 kHz.

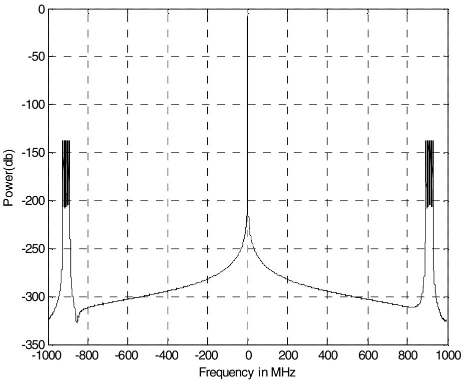

Fig. 4 Spectrum of signal component in an SCM system.

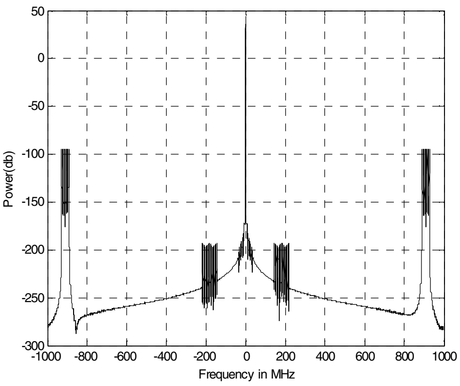

Fig. 5 Spectrum of cross components at the receiver output of an SCM system.

Fig. 7 shows the ultimate simulation result of SIR versus number of channels with linecoding. It was simulated up to 180 channels with SIR much higher than the minimum acceptable value. So it is evident that number of channels can be increased above 180 before reaching the minimum required value of SIR

5. CONCLUSION

A theoretical analysis is presented to evaluate the limitations imposed by Optical Beat Interference on the performance of an SCM optical transmission system. Performance results reveal that OBI limits the number of subcarriers that can be multiplexed in an optical channel while employing NRZ linecodes. However, by employing Miller Codes, the limitations of OBI on SCM system performance can be reduced with increase in the value of the SIR. The analysis can be easily extended to a subcarrier multiplexed dense wavelength division multiplexing (SCM-DWDM) transmission system.

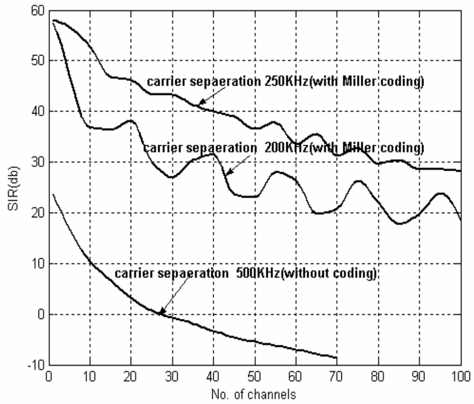

Fig. 6 SIR versus number of channels in an SCM system with NRZ and Miller code.

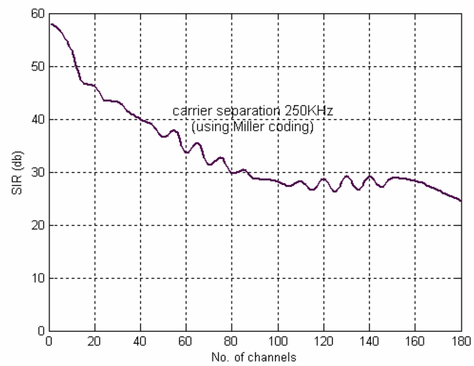

Fig. 7 SIR versus number of channels in an SCM system with Miller code.

REFERENCES

[1] K. P. Ho. H. Dai, C. Lin, S. K. Liaw, H. Gysel, and M. Ramachandran, "Hybrid wavelength division multiplexing systems for high capacity digital and analog trunking applications", *IEEE Photon. Technol. Lett.* , vol. 10. pp. 297-299, Feb 1998.

[2] P. A. Greenhalgh, R. D. Abel, and P. A. Davies, "Optical prefiltering in subcarrier systems", *Electron. Lett.* , vol. 28, p.2054, Nov 1992.

[3] M. M. Bant and M. Kahverad, "Effects of laser diode intensity modulation index on optical beat interference in subcarrier multiplexed wavelength division multiple access networks", IEEE Trans. Commun., vol. 43, no. 2,3,4, Feb, Mar, Apr. 1995 pp. 1636-1643.

[4] S. L. Woodward and M. R. Phillips, " Optimizing subcarrier multiplexed WDM transmission links", IEEE J. Lightwave Technology, vol. 22, no. 3, Mar 2004, pp. 773-778.

[5] S. P. Majumder, M. S. Alam, R. Gangopadhyay, "Effect of Nonuniform Laser FM Response on the Performance of Multichannel Heterodyne FSK Systems Using Optical Amplifiers", IEEE Journal of Lightwave Technology, vol.15, no.2 February 1997.