International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Investigations on Spectral Efficiency of Optical Communication System Using Wavelength Division and Sub Carrier Multiplexing

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Abstract: ***The growth of optical fiber communication had been tremendous over the past few decades. Multichannel optical systems using Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM), Sub Carrier Multiplexing (SCM) and their combinations were developed in order to utilize the huge bandwidth provided by the optical fiber. In WDM, several optical carriers of different wavelengths modulated by low bandwidth baseband data streams are transmitted. In SCM, several Gigahertz wide sub carriers each carrying analog or digital data are multiplexed in radio frequency domain and this composite signal is subsequently modulated on to a Terahertz optical carrier. SCM makes better use of available bandwidth when compared to WDM. The most significant advantage of SCM in optical communication is its ability to place different optical carriers closely together. The bandwidth utilization is further improved by a hybrid WDM/SCM system in which each WDM wavelength carries an SCM composite signal. The simulation and performance comparison of a four channel WDM, a four channel SCM and a hybrid WDM/SCM system was done using Optisystem 12.0.***

Keywords: Wavelength Division Multiplexing, Sub Carrier Multiplexing, Spectral Efficiency, Optisystem, Q Factor.

1. Introduction

An estimated one third of the world's population is online now, a proportion that is sure to grow. More users imply more services and more demand for bandwidth. Optical fiber communication offers an enormous potential bandwidth for data transmission. In order to utilize this huge bandwidth offered by the optical fibers, new transmission technologies involving Time Division Multiplexing (TDM), Wavelength Division multiplexing (WDM), Sub Carrier Multiplexing (SCM) and their combinations were developed.

The TDM strategy which was adopted in order to increase the bit rate carried by a single wavelength channel is highly sensitive to chromatic dispersion, non linear crosstalk and Polarization Mode Dispersion (PMD) because of the wide bandwidth of the signal. Later WDM technology was developed which used low bit rates and power in a wavelength channel by spreading the transmission capacity into various wavelength channels. Hence problems in TDM strategy like chromatic dispersion, non linear crosstalk and PMD was mitigated by the use of WDM system [1].

To further leverage the efficiency of bandwidth utilization, SCM was developed. SCM has a simple and low cost implementation. In SCM, several sub carriers, each carrying analog or digital data are multiplexed in Radio Frequency (RF) domain and the composite signal is then transmitted using a Terahertz optical carrier. SCM has better spectral efficiency when compared to WDM, since multiple signals can be transmitted using a single wavelength and it is less subjected to dispersion when compared to TDM, as the data rate in each sub carrier is low [2]. One additional advantage of SCM is that sub carriers can be modulated using various modulation formats including phase modulations because RF carriers have stable phase. Also because the bit rate granularity is smaller which facilitates channel add/drop, the combination of WDM and SCM can potentially make optical networks more flexible and increase its spectral efficiency.

2. System Design

The simplified block diagram of WDM system is shown in Figure 1. At the transmitting end there are several independently modulated light sources, each emitting signals at a unique wavelength. The baseband data sequence is provided by Pseudo Random Binary Sequence (PRBS) Generator which is then encoded by a Non Return to Zero (NRZ) encoder. This data will be used to modulate the light source via a Mach Zehnder Modulator (MZM). Here a multiplexer is needed to combine these optical outputs into a continuous spectrum of signals and couple them onto a single fiber.

At the receiving end a demultiplexer is required to separate the optical signals into appropriate detection channels for signal processing. The photo detectors will be used to detect the baseband data, since they are usually sensitive over a broad range of wavelengths. To prevent spurious signals from entering a receiving channel, that is, to give good channel isolation of the different wavelengths being used, the demultiplexer must exhibit narrow spectral operation or very stable optical filters with sharp wavelength cut offs must be used. The tolerable inter channel crosstalk levels can vary widely depending on the application.

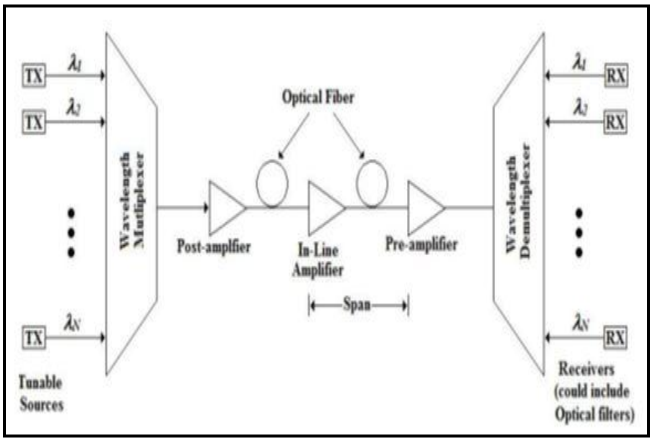

Figure 1: Simplified block diagram of a WDM system

A four channel WDM system is simulated in optisystem software, the simulation layout of which is shown in Figure 2. Here four PRBS generators generate four different data signals at a bit rate of 1 Gbps which are encoded using a NRZ pulse generator. These signals are used to modulate optical carriers generated by CW lasers of frequencies 193.1 THz, 193.2 THz, 193.3 THz, and 193.4 THz with a 10 dBm power, using MZM. These signals are then multiplexed using a 4×1 WDM multiplexer (MUX). This composite signal is then transmitted through the single mode fiber of length 50 km.

At receiver end, a 1×4 WDM demultiplexer (DEMUX) is used to split this optical signal into four signals. These demultiplexed signals are then applied to photo detectors centered at frequencies 193.1 THz, 193.2 THz, 193.3 THz, 193.4 THz respectively, which will convert these optical signals directly into baseband signal. Low Pass Filters (LPFs) are used to filter out the higher frequency components. And at the output of LPFs we will get the data signals which were initially transmitted. Then an eye diagram analyzer can be used to generate the eye diagram, which can be used for the performance analysis of the system.

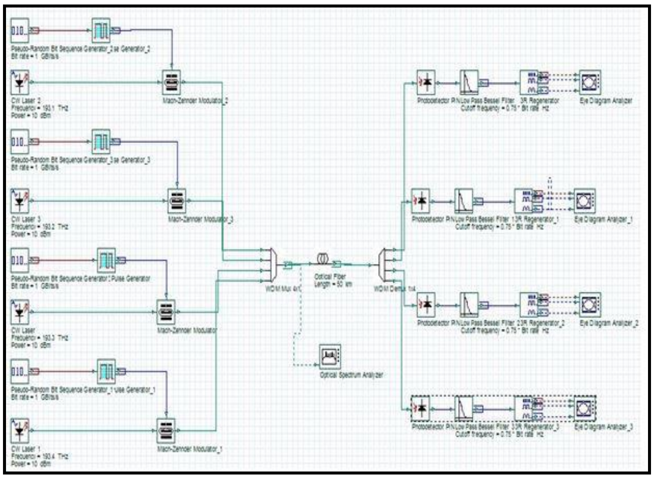

Figure 2: Simulation layout of a 4 channel WDM system

SCM follows a different approach compared to WDM and is spectrally efficient when compared to WDM. In an SCM infrastructure, the baseband data generated by a PRBS generator is first modulated on a Gigahertz wide sub carrier as shown in Figure 3 via an electrical Phase Shift Keying (PSK) modulator that is subsequently modulated on the optical carrier generated by a CW laser via a MZM. This way each signal occupies a different portion of the optical spectrum surrounding the centre frequency of the optical carrier. At the receiving side, as normally happens in a commercial radio service, the receiver is tuned to the correct subcarrier frequency, filtering it out of other subcarriers and is detected using a photo detector.

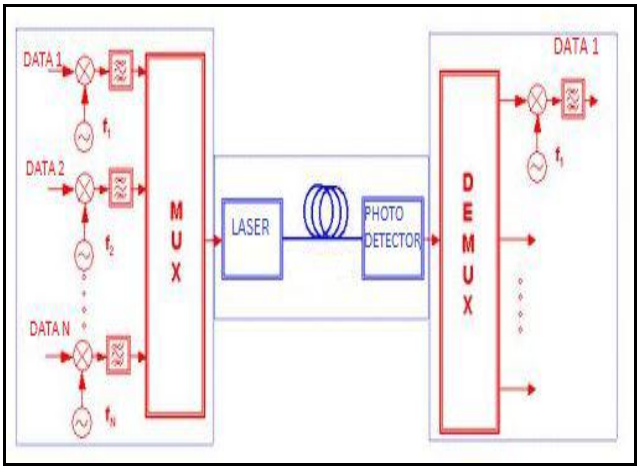

Figure 3: Simplified block diagram of SCM system

A four channel SCM system is simulated in optisystem software. The simulation layout of an SCM system for four users is shown in Figure 4. Four PRBS generator, generate four different data signals at a bit rate of 1 Gbps. These data signals are used to modulate four different electrical carriers having frequencies 10 GHz, 15 GHz, 20 GHz and 25 GHz respectively. This modulation is done by electrical PSK modulator. To remove unwanted frequencies these signals are passed through band pass Bessel filters (frequencies same as carrier frequencies and bandwidth= 1.5×Bit Rate). These signals are then combined using electrical 4×1 power combiner and this combined signal is used to modulate an optical carrier generated by a CW laser of frequency 193.1 THz with a power of 10 dBm by a MZM. This modulated signal is then transmitted through the single mode fiber of length 50 km.

At receiver end an optical 1×4 power splitter is used to split this optical signal into four signals. These optical signals are then passed through optical band pass filters (frequencies 193.110 THz, 193.115 THz, 193.120, 193.125 THz respectively and band width= 1.5×Bit Rate). These filtered signals are then applied to photo detectors which will convert these optical signals directly into baseband signals. LPFs are used to filter out the higher frequency components. And at the outputs of LPFs we will get data which was initially transmitted. Then an eye diagram analyzer can be used to generate the eye diagram, which can be used for the performance analysis of the system.

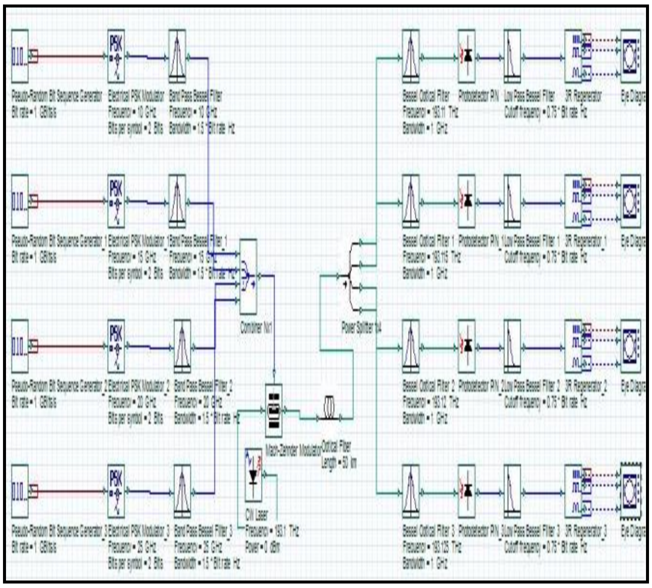

Figure 4: Simulation layout of a 4 channel SCM system

The basic configuration of a WDM/SCM optical system is shown in Figure 5. Here, n independent high speed digital signals are mixed by N different microwave carrier frequencies fi. These are combined and optically modulated onto an optical carrier. Then m wavelengths are multiplexed together in an optical WDM configuration. At the receiver, an optical demultiplexer separates the wavelengths for individual optical detectors. Then, RF coherent detection is used at the SCM level to separate the digital signal channels. Channel add/drop is also possible at both the wavelength and SCM levels.

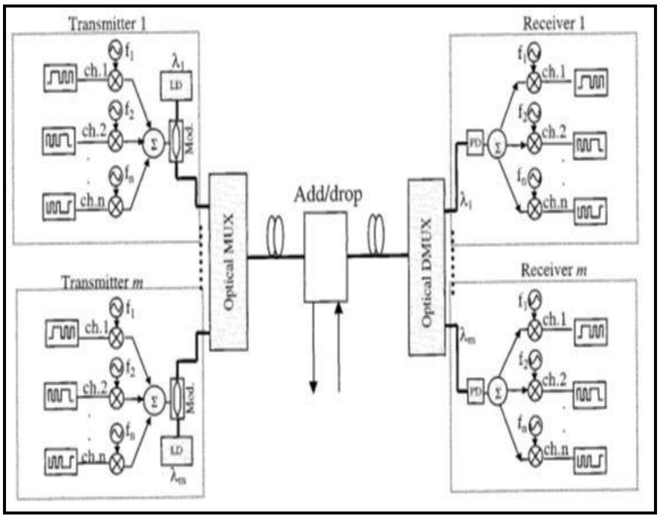

Figure 5: Basic configuration of a WDM/SCM optical system

A hybrid WDM/SCM system with two WDM channels, each of which carries two SCM channels simulated in Optisystem is shown in Figure 6. Each WDM channel have two SCM channels of bit rate 1 Gbps each which are electrically modulated into two RF sub carriers of frequency 2 and 5 GHz and is then combined by a 2×1 power combiner. This composite SCM signals are then modulated into two optical carriers of frequency 193.1 and 193.2 THz which is then multiplexed by a 2×1 WDM multiplexer and is transmitted through an optical fiber. The received signal is then demultiplexed by a 1×2 demultiplexer, detected by photo detector and then two SCM channels in each wavelength channel is detected by means of optical band pass filters which filters out the two sub carrier frequencies. The baseband data from each RF sub carriers is recovered by low pass filters.

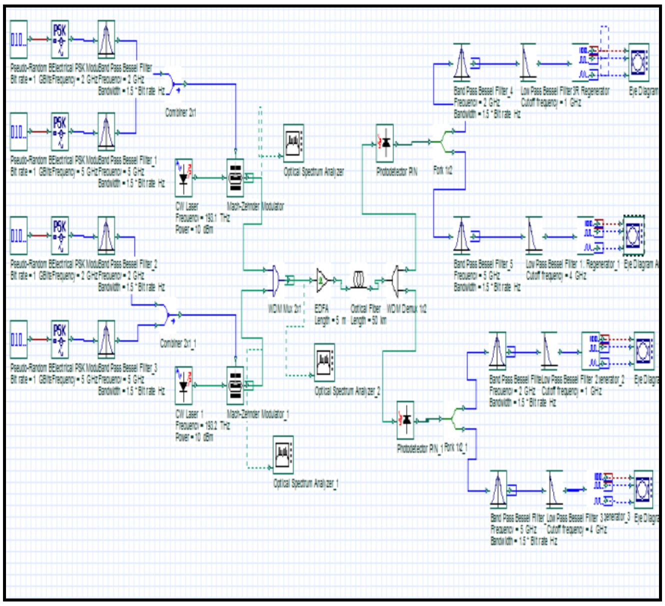

Figure 6: Simulation layout of a hybrid WDM/SCM system

3. Results and Discussions

The Figure 7 shows the spectrum of wavelength division multiplexed signal for four data streams. As shown in figure the four data streams of bit rate 1 Gbps are modulated into four optical carriers of frequencies 193.1 THz, 193.2 THz, 193.3 THz and 193.4 THz.

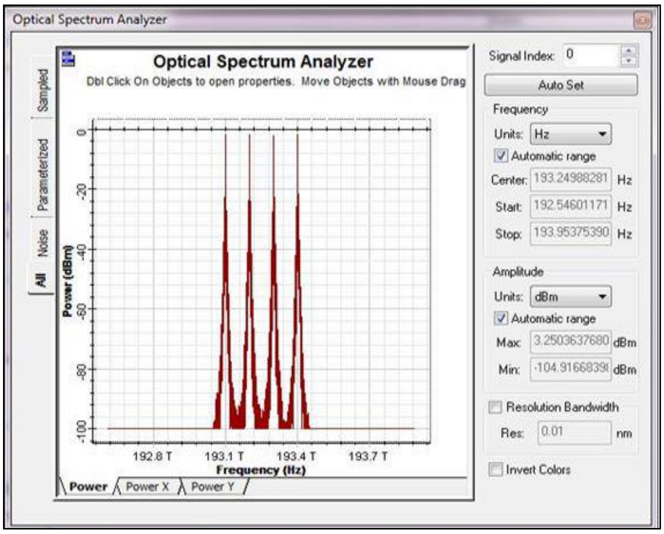

Figure 7: Spectrum of 4 channel wavelength division multiplexed signal

The Figure 8 shows the spectrum of sub carrier multiplexed signal for four data streams. As shown above the four data streams of bit rate 1 Gbps are modulated into four RF subcarriers of frequencies 10 GHz, 15 GHz, 20 GHz and 25 GHz which are multiplexed in RF domain. This SCM composite signal is then modulated on to a single optical carrier of frequency 193.1 THz.

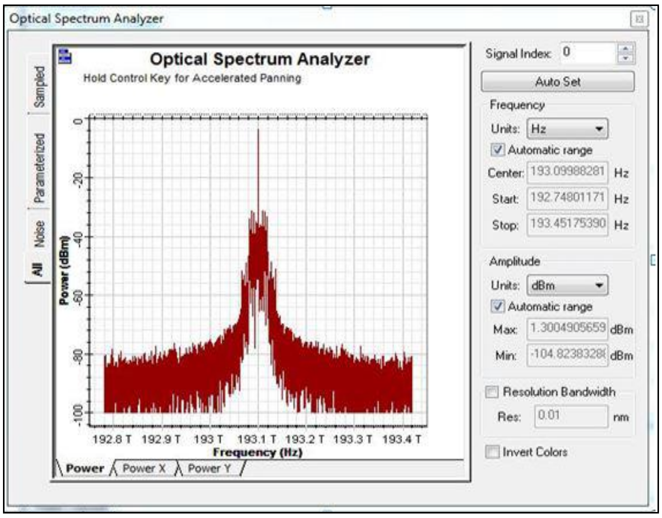

Figure 8: Spectrum of 4 channel sub carrier multiplexed signal.

The Figure 9 shows the spectrum of a hybrid WDM/SCM signal in two WDM channels each of which carries two SCM channels. As shown above there are two WDM channels centered at frequency of 193.1 and 193.2 THz, each of which carries two RF sub carriers of frequencies 2 and 5 GHz modulated with two data streams of bit rate 1 Gbps each.

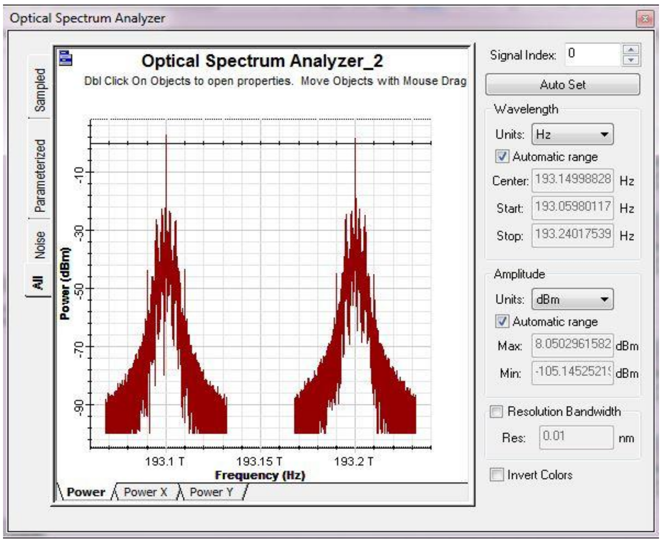

Figure 8: Spectrum of a hybrid WDM/SCM signal.

4. Conclusion

A WDM system allows multiple connections over a single fiber by assigning different wavelength channels for different connections, each which can operate at arbitrary data rates. In an SCM infrastructure, the baseband data is first modulated on a Gigahertz wide sub carrier that is subsequently modulated in the Terahertz optical carrier. SCM makes better use of available bandwidth and increases the spectral efficiency compared to WDM. Hence SCM is spectrally more efficient than WDM. But a hybrid WDM/SCM system in which each WDM channel carries an SCM composite signal provides more efficient utilization of optical bandwidth.

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