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PERFORMANCE ANALYSIS OF SCM TRANSMISSION LINK FOR DPSK DATA

Rajesh Goyal
Haryana State Board of Technical Education (HSBTE), Panchkula-134107, Haryana, India
Email- goelrajesh17@gmail.com

Abstract: Aim of this paper is to focus on the impact of different parameters on the performance of the Subcarrier Multiplexed Optical Transmission System for the application on radio link via optical fiber. Performance results were evaluated for DPSK data format for ODSB and OSSB modulation of Microwave subcarriers with digital NRZ coded random data patterns. The four sub-systems of DPSK modulators were kept at 400, 500, 600, 700 MHz subcarrier frequencies with a frequency spacing of 100 MHz. The power of subcarriers lowers with increase of the link distance due to dispersion and attenuation. With the use of dispersion compensation fiber, the link distance successfully enhanced from 120 km to 240 km. The impact of chromatic dispersion reduced in OSSB with the use of dual-electrode MZM. The constellation diagram also confirms that the phase of the signal after traveling through the link was changed due to dispersion. The impact of linewidth and responsivity on SNR was also analyzed. The maximum SNR decreased with increase in the linewidth of laser source and was increased with the increase in responsivity of PIN diode for the same fiber length in SCM transmission.
Keywords: Constellation Diagram, SCM, ODSB, OSSB, DPSK.

摘要：本文的目的是关注不同参数对副载波复用光传输系统性能的影响，以应用于通过光纤的无线电链路。对具有数字 NRZ 编码随机数据模式的微波副载波的 ODSB 和 OSSB 调制的 DPSK 数据格式的性能结果进行了评估。 DPSK 调制器的四个子系统保持在 400、500、600、700 MHz 子载波频率，频率间隔为 100 MHz。由于色散和衰减，子载波的功率随着链路距离的增加而降低。使用色散补偿光纤，链路距离成功从120公里提升到240公里。使用双电极 MZM 降低了 OSSB 中色散的影响。星座图也证实了信号通过链路后的相位由于色散而改变。还分析了线宽和响应度对 SNR 的影响。最大信噪比随着激光源线宽的增加而降低，并随着 PIN 二极管在 SCM 传输中对相同光纤长度的响应度的增加而增加。
关键词：星座图，SCM，ODSB，OSSB，DPSK。

Introduction

Bandwidth capacity of optical fiber communication system can be significantly enhanced by employing wavelength division multiplexing (WDM) and time division multiplexing (TDM). These high speed multiplexing techniques suffer from nonlinear crosstalk, chromatic and polarization-mode dispersion (PMD). Further, to enhance the efficiency of bandwidth utilization, subcarrier multiplexing can be used. SCM has better spectral efficiency because multiple RF channels

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About the authors: Rajesh Goyal, Haryana State Board of Technical Education (HSBTE), Panchkula-134107, Haryana, IndiaCorresponding author- e-mail: Rajesh Goyal

can be transmitted at a single optical channel wavelength. Optical subcarrier multiplexing (SCM) is a low frequency level multiplexing scheme where a number of signals at radio frequency (RF) range are multiplexed and resulting composite signal is further modulated on a high frequency optical carrier for transmission in a fiber. The RF signals are known as subcarriers and these can be modulated by information signals employing advanced modulation techniques due to availability of matured microwave technology. SCM has some advantages compared to other multiplexing WDM and TDM techniques. First of all, SCM is an inherent broadcasting technique and it is frequently employed for digital video broadcasting systems. It is very flexible and easily upgradable in the design of broadband networks as there is no need of synchronization between the channels. It is a very popular technique due to its simplicity and higher receiver sensitivity. The total usable bandwidth is restricted by large modulation bandwidth of semiconductor laser and high speed response of photodiodes. Subcarrier multiplexing (SCM) with wavelength division multiplexing (WDM) has been developed to increase the transmission capacity of existing optical communication system. With this technique, it is possible to increase number of subscribers, bit rate, transmission link length and enhancement in the system performance **[1]**. It has been analyzed that by employing optical single side band OSSB modulation PSK at subcarrier level gives comparatively good performance improvement as compared to ASK/FSK modulation in terms of higher spectral efficiency **[2]**. Improvement of BER can be done by using QAM modulation and components of ROF systems. The implementation of ROF technology and the WLAN of IEEE 802.11a standard using 64 QAM modulations provide more reliability by reducing BER as compared with IEEE 802.11a with wireless feeder network. This provides more flexibility in the case of future requirements such as other extension to the system to obtain more capacity and larger area coverage **[3]**. Moreover, it has been concluded that subcarrier multiplexing at various data rate provides high capacity transmissions at lower costs for Radio over Fiber (ROF) systems which enable fiber based wireless access system **[4]**. Researchers have find out that an optical beat Interference (OBI) limits the number of subcarriers that can be multiplexed in an optical channel while employing NRZ, Manchester line coding and Miller codes **[5]**. An analysis of comparative performance of the three line coding in an SCM-WDM system in which limitations of OBI can be reduced by employing miller codes. The bi-directional radio over fiber (RoF) communication system should be designed for different RF sub-carriers to observe impact of cross talk on system parameters i.e., bit error rate (BER), Q factor and signal to noise ratio (SNR). To reduce crosstalk among RF sub-carriers, the carrier frequency and channel frequency spacing are carefully chosen for simulative model of ROF system **[6]**. When numbers of channel are increased then level of crosstalk increases and degrades overall performance of simulative model and decreases the Q factor and increases the BER. In this paper SCM transmission link performance is investigated for DPSK data formats for both types of modulation techniques ODSB as well as OSSB for various parameters. Dispersion compensation technique is incorporated to reduce the signal degradation due to accumulated dispersion and to increase the link distance, further results are compared with results obtained in my previous study for QPSK data format [7].

Simulation Set up for DPSK SCM Transmission

The simulation set up used for Sub Carrier multiplexing for both types of modulation techniques ODSB and OSSB is as shown in Figure-1. Differential Phase Shift Keying (DPSK) data format was used as input. This data format at different subcarrier was modulated with the optical carrier. The DPSK is a modulation technique using three bits per symbol and one bit delay in the quadrature signal.

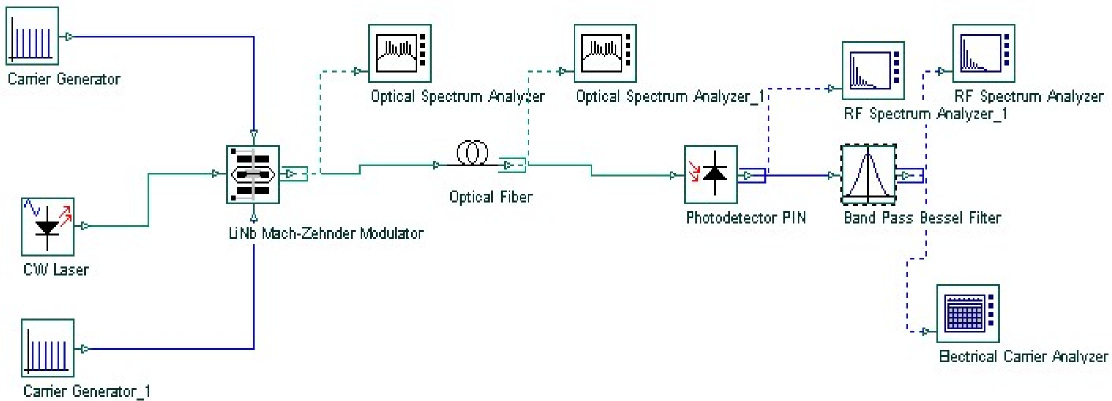


Figure -1 SCM Transmission Link

DPSK Modulator

For DPSK-SCM Transmission link, four subsystems at 400, 500, 600, 700 MHz carrier frequencies were used. The internal layout of the DPSK Modulator subsystem is shown in Figure-2.

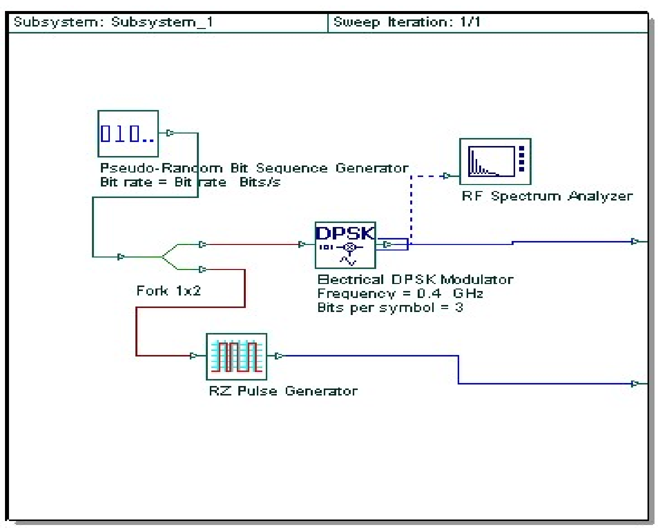


Figure-2 DPSK Modulator

The Pseudo Random Bit Sequence Generator (PRBS) generates the sequence of bits at the bit rate of 30.375 Mb/s. This bit sequence drives the PSK Sequence generator that uses three bits per symbol for generating the PSK sequence. This bit sequence drives the Electrical DPSK modulator, whose carrier frequency being set at 400, 500 600 and 700 MHz for each modulator in the four subsystems, and at the output of each modulator we got the DPSK modulated data for each subcarrier frequency. On the addition of the modulated signal of all the modulators a composite spectrum as shown in Figure - 4 (a) is obtained.

This frequency spectrum received at the output of DPSK modulator Figure-4(a) was given to the MZM modulator along with the laser source at 193.1 THz or 1550 nm with the Linewidth of 1MHz.The optical carrier modulates the RF composite spectrum according to the type of the modulator used. If the MZM is single electrode then there is ODSB and if MZM is dual electrode then OSSB is there, as shown in Figure - 4(c) and (d) respectively.

The optically modulated signal initially launched in the optical fiber of length 10 km with various parameters of the fiber being set as under:-

1	Fiber loss	$\alpha = 0.2$ dB/km
2	Reference wavelength	1550 nm
3	Fiber Length	10 Km (Intially)
4	Fiber Dispersion	16.75 ps/nm-km
5	Non linear refractive index	$n_2 = 2.6 \times 10^{-20} m^2 / W$
6	Effective Area	$A_{eff} = 60.31 \mu m^2$

DPSK Demodulator

The optical signal received by the Photo-detector converts into the electrical signal. The received RF spectrum is as shown in Figure -5(a) ODSB (b) OSSB. This spectrum consists of all the four subcarriers that were transmitted along with the optical carrier. These RF carriers carrying the data were first separated into individual carriers along with data by passing the RF spectrum through the Bandpass filter (BPF). So four BPF used to separate the RF carriers and the center frequency of each filter was set at the carrier frequency with a bandwidth of 50 MHz. After separating the RF carriers, the data was extracted from it with the help of DPSK demodulator.

The sub-systems at the output end of the link were DPSK demodulators as shown in Figure -3. The four demodulators were at different frequency to demodulate the baseband signal form the carrier. The RF carrier along with data drives the Quadrature demodulator which was set at the same carrier frequency as that of the input signal. This demodulates the signal and baseband signal was recovered. After passing the signal through M-ary's and PSK sequence generator using the three bits per symbol for generating the bit sequence, original bit sequence was obtained as seen by the oscilloscope visualizer.

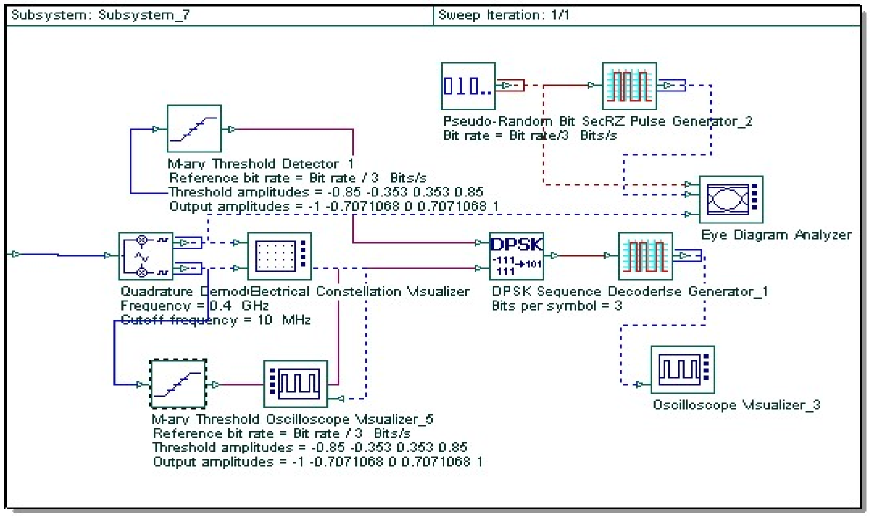


Figure-3 DPSK Demodulator

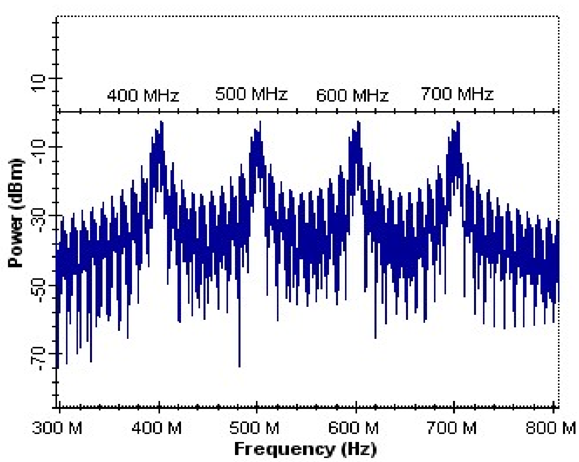
The eye pattern at the output was observed with eye diagram analyzer being driven by quadrature demodulator, PRBS with a bit rate equal to bit rate divided by 3 and RZ sequence generator. The eye patterns for all subcarrier frequencies were taken and the impact of variation of parameters was observed. Similarly the constellation diagram was observed at the output of quadrature demodulator with the help of Electrical Constellation Visualizer.

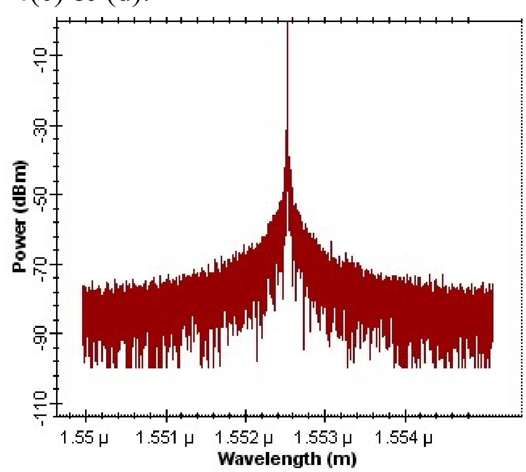
Results and Discussions

The results have been obtained with the initial fiber length of 10 km for DPSK-SCM Transmission link for ODSB and OSSB for various performance parameters.

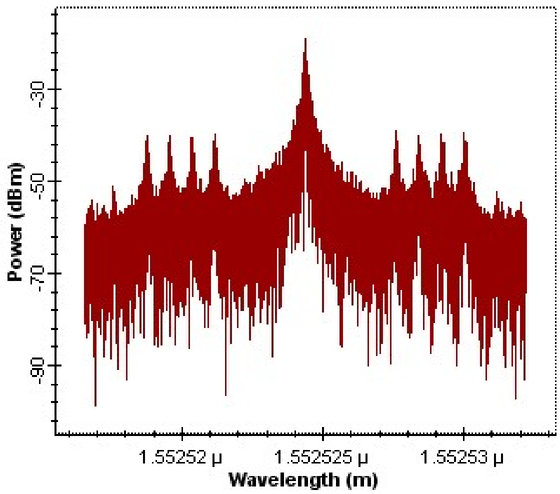
DPSK SCM Modulation and Detection

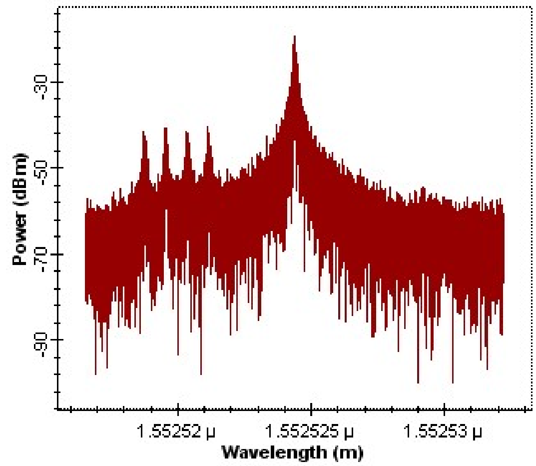
Figure -4(a) demonstrate the modulation of PRBS data at 30.37 MB/s with the RF carriers at 400, 500,600,700 MHz. This composite signal was given to the MZM modulator along with the optical carrier to get the modulated signal. Depending upon the type of MZM used SE-MZM or DE-MZM, ODSB & OSSB signals had been received respectively as shown in Figure-4(c) & (d).





(a) (b)

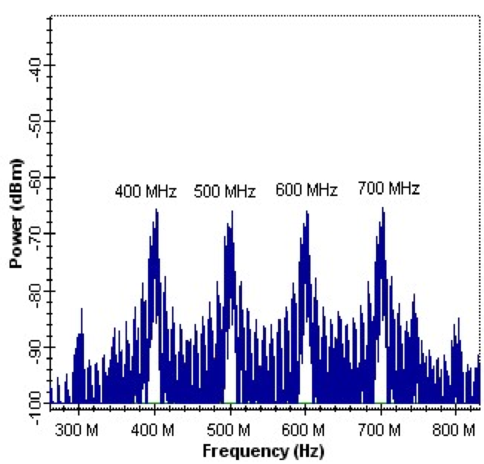


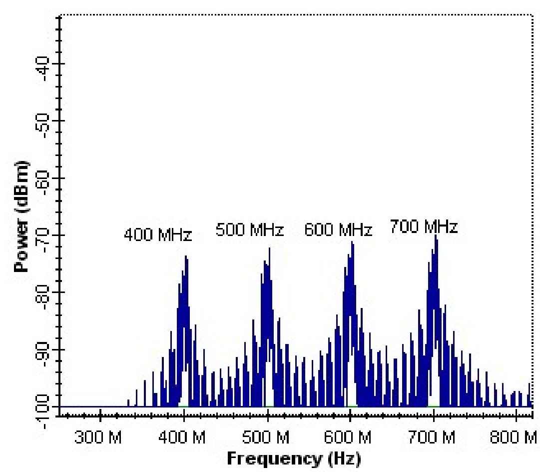


(c) (d)

Figure- 4 (a) QPSK Modulation with four RF carriers at 400, 500, 600, 700 MHz (b)Optical Carrier at 193.1 GHz (c) ODSB (d) OSSB.

The DPSK-SCM modulated signal was passed through the optical filter of length 10 km and the optical signal was detected which was converted to electrical signal by the photodetector. The four detected RF carriers were then separated by using the BPF at the center frequency as that of subcarrier.





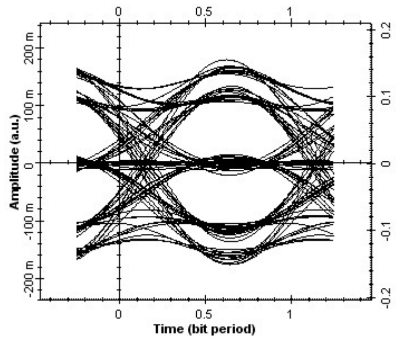
(a) (b)

Figure -5 Detected RF carriers at Photodetector (a) ODSB (b) OSSB

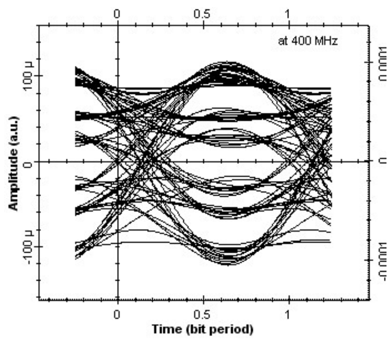
The individual RF carrier after the BPF filter was given to the corresponding DPSK demodulator that was at the same carrier frequency. Here the detected signal was demodulated and the baseband signal was recovered.

Eye Diagrams

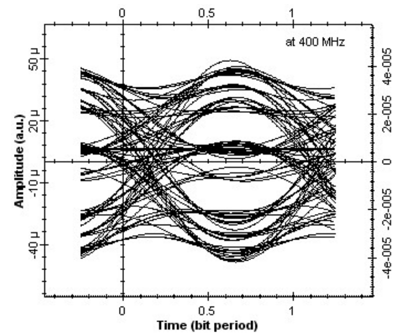
Back- to- Back **ODSB** **OSSB**



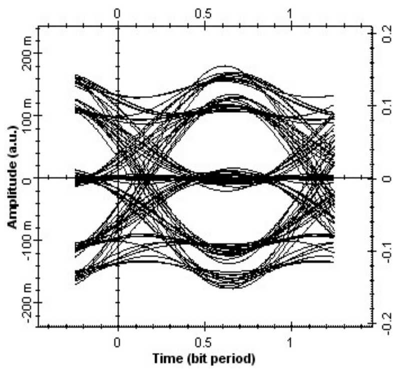
(a)



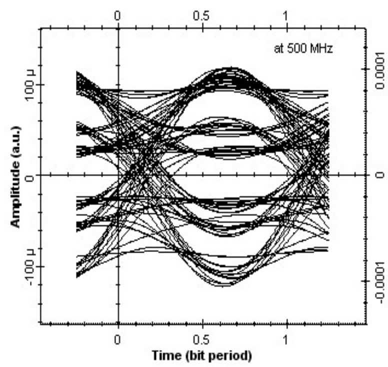
(e)



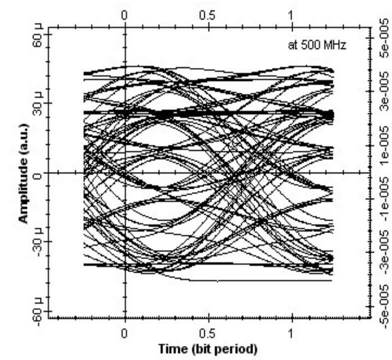
(i)



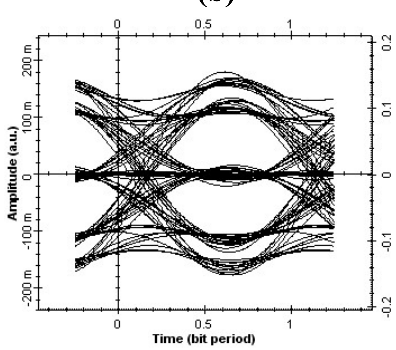
(b)



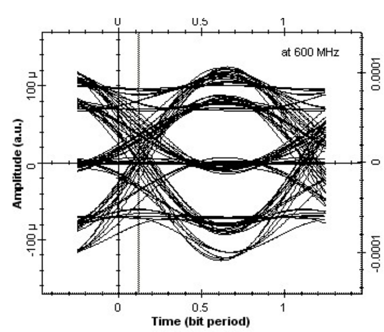
(f)



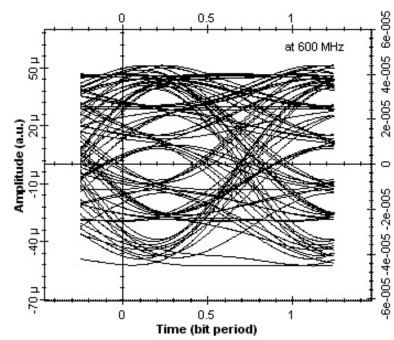
(j)



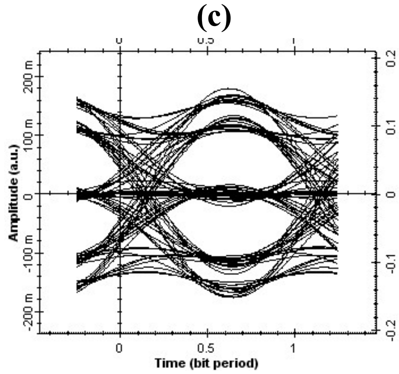
(c)



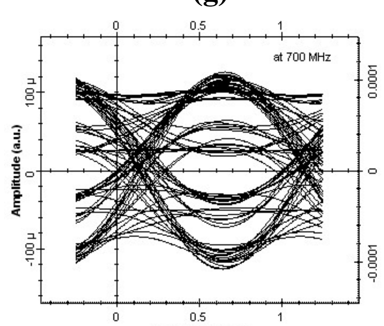
(g)



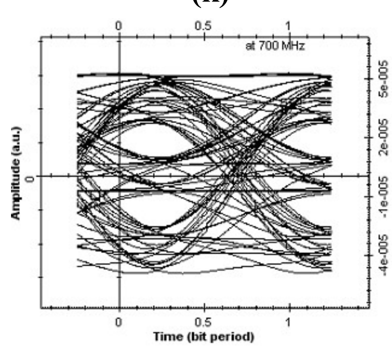
(k)



(d)



(h)

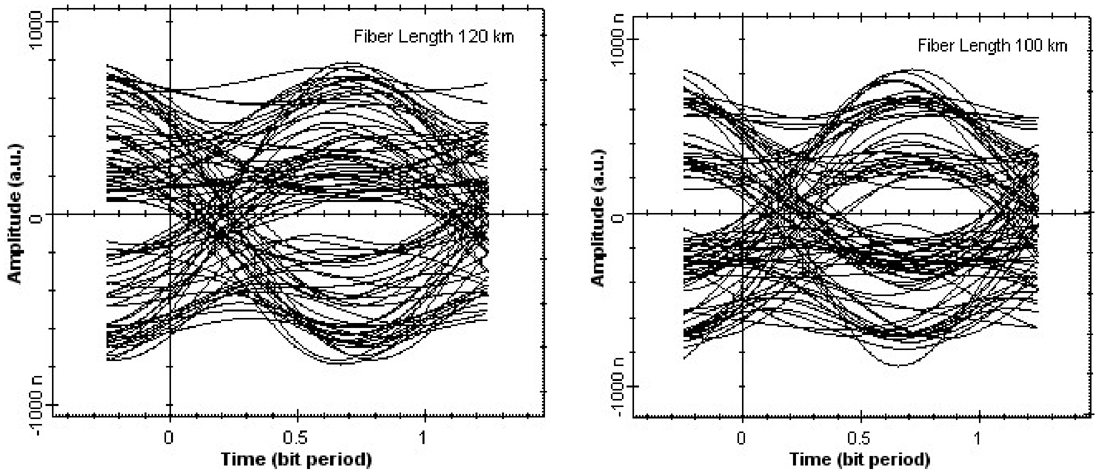


(l)

Figure -6 The Eye Patterns DPSK SCM Transmission Link (a)-(d) Back-to-Back (e)-(h) ODSB (i)-(l) OSSB

The eye diagrams at the output were observed with the BER analyzer. The Figure - 6(a)-(d) shows the eye diagrams of the back-to-back transmission link for exact data recovery at 400, 500, 600, 700 MHz respectively. Eye opening in the back-to-back link was maximum. Figure - 6 (e)-(h) & (i)-(l) shows eye opening patterns for the use of ODSB and OSSB transmission between the modulator and demodulator.

Similarly eye diagrams were taken at the same frequencies as in back to back, for ODSB and OSSB. The fiber length considered in each case was 10 km. As the transmission distance was increased the degradation in the eye pattern was also increased due to dispersion and span loss. It was also observed that the opening of the eye was clearer for frequencies of 600 MHz for ODSB and at 400MHz for OSSB as compared to other as shown in Figure - 6. Figure – 7(a) illustrates the pattern of ODSB at length of 120 km at 600 MHz and 7(b) pattern for OSSB at length of 100 km for sub-carrier at 400 MHz, beyond these distances the eye pattern is totally degraded because of the accumulated dispersion and attenuation of the fiber length. So it can be concluded that this is the maximum link distance without any dispersion compensation technique.



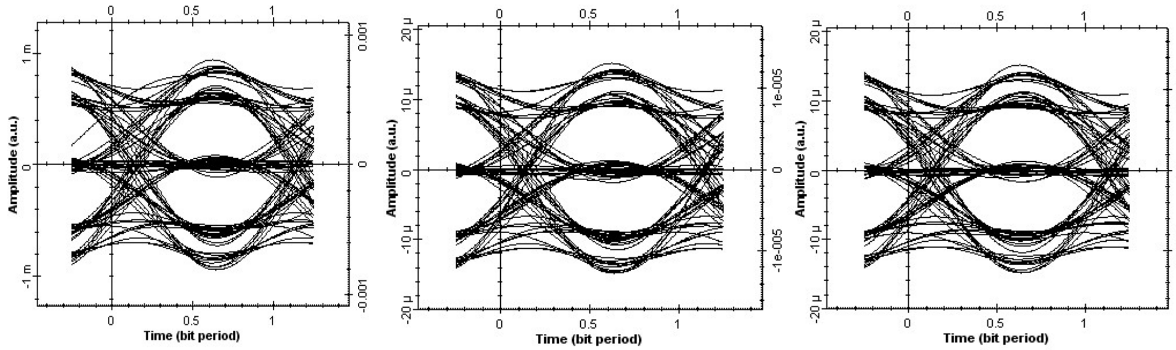
(a) **(b)**

Figure-7 Degradation of the Eye Pattern with increase in fiber length, Carrier at 400 MHz. (a) ODSB (b) OSSB

Dispersion compensation Fiber

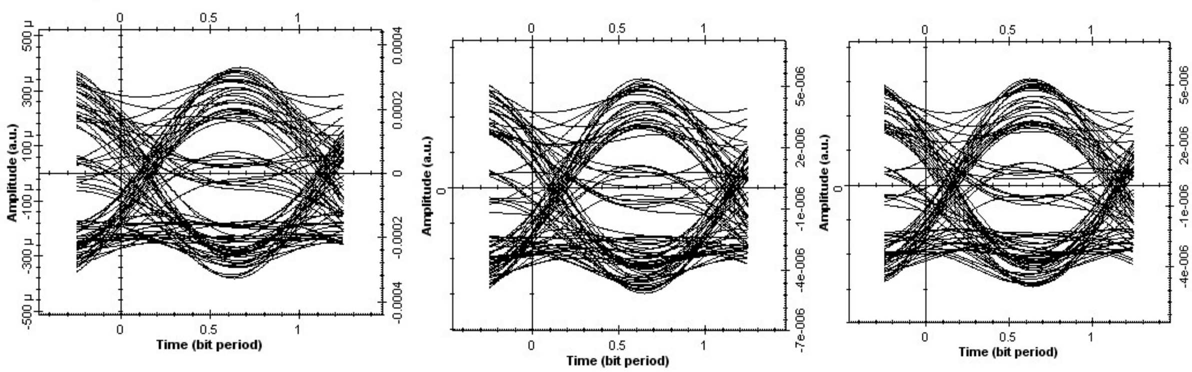
Figure - 8 shows the eye diagrams taken for the sub-carrier at frequency of 400 MHz for both ODSB and OSSB transmission with Pre, Post and Symmetric dispersion compensation fiber. By incorporating the DCF the link distance was increased up to 240 Km and the opening of the eye pattern was improved.

ODSB



(a) **(b)** **(c)**

OSSB



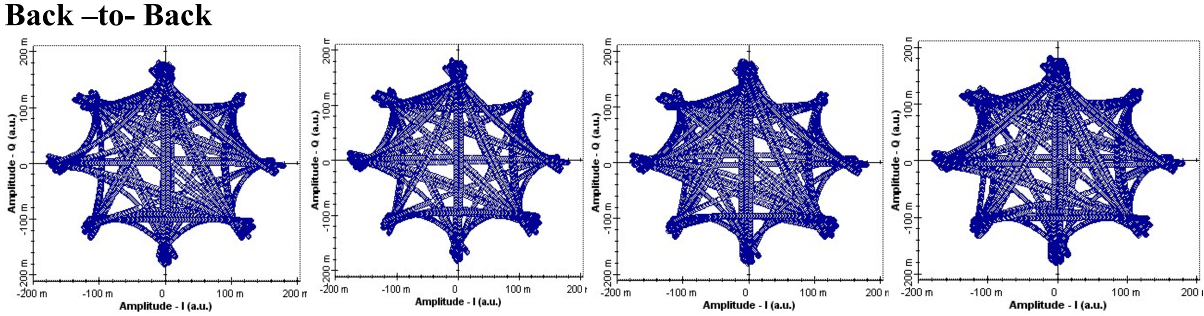
(d) **(e)** **(f)**

Figure -8 Eye Pattern with Dispersion compensation fiber of length 240 km, sub-carrier at 400 MHz (a)-(c) ODSB (d)-(g)OSSB (a) &(d) Pre (b)&(e) Post (C)&(g) Symmetric

Constellation Diagram

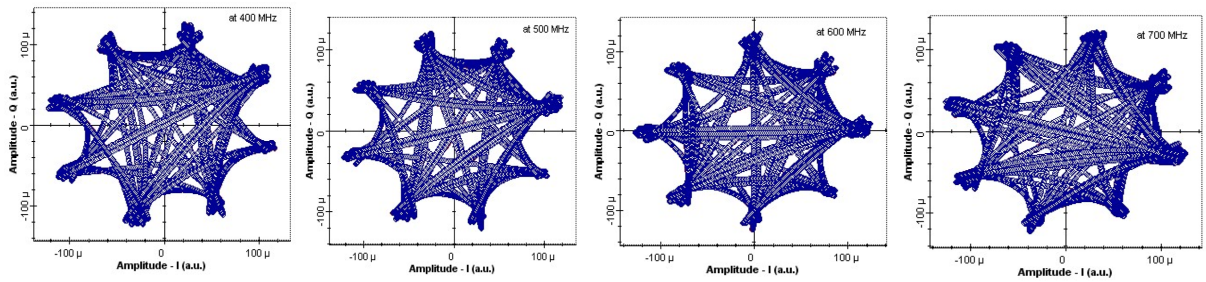
The Figure - 9 demonstrates the constellation diagram at the output of the modulator. Figure – 9(a) to (d) shows the constellation diagram for back-to-back link, 9(e) to (h) for ODSB

Back –to- Back



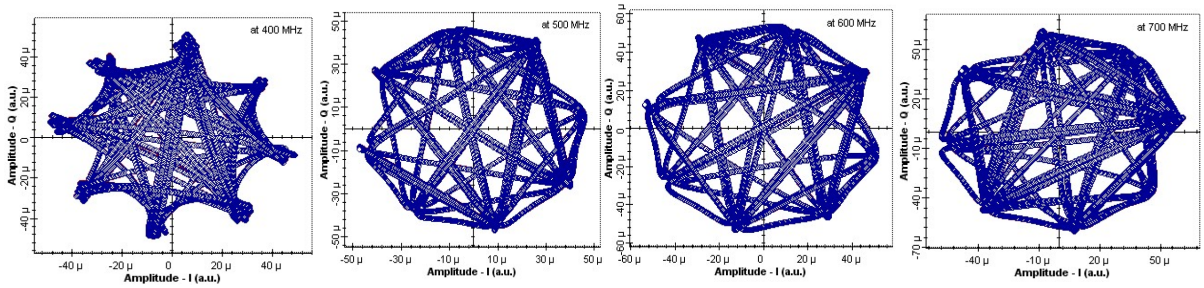
(a) **(b)** **(c)** **(d)**

ODSB



(e) **(f)** **(g)** **(h)**

OSSB



(i) **(j)** **(k)** **(l)**

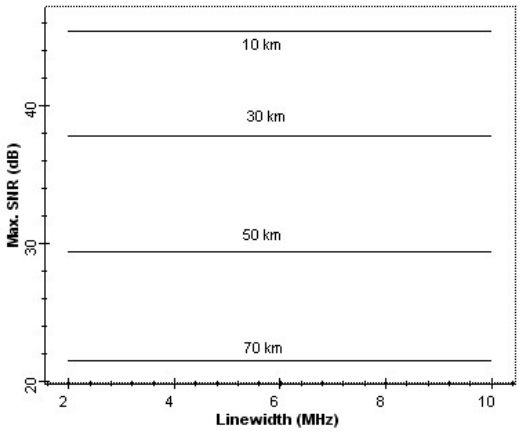
Figure -9 Constellation Diagrams DPSK Transmission Link (a)-(d) Back-to-Back (e)-(h) ODSB (i)-(l) OSSB

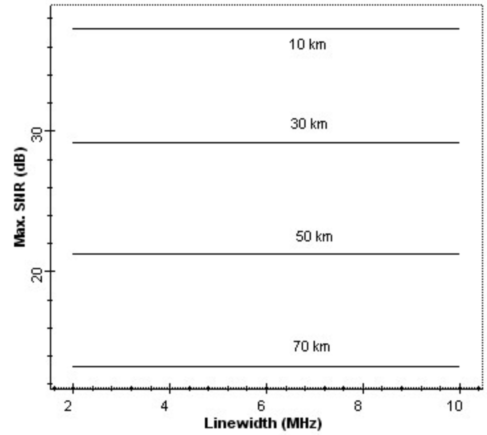
and 9(i) to (l) for OSSB respectively at 400, 500, 600, 700 MHz sub-carrier in each case. It was observed that the constellation diagram shift in single sideband and double sideband transmission. This is due to change in phase of the signal along the fiber length with dispersion and span loss.

Linewidth vs Max. SNR

With the increase in the Linewidth of the Laser source the SNR deceases. The Max. SNR (dB) was observed for the one sub-carrier at 400 MHz with electrical carrier analyzer at the output of the Photodetector. By varying Linewidth from 2 to 10 MHz, Max SNR was observed for different values of fiber length. Figure - 10 & Table -1 shows that the Max. SNR decreases in ODSB and OSSB with DPSK Transmission.

ODSB **OSSB**





(a) **(b)**

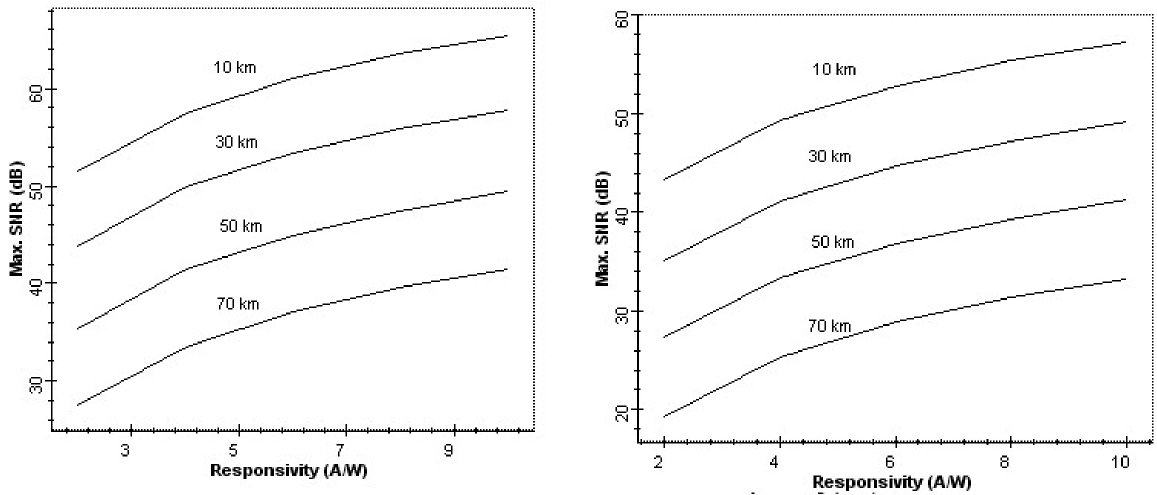
Figure-10 Linewidth vs Max. SNR (a) ODSB (b) OSSB

Table -1 The comparison of Max. SNR with different Linewidth and fiber length for ODSB and OSSB

Linewidth (MHz)	Max. SNR (dB)							
	10 km		30 km		50km		70 km	
	ODSB	OSSB	ODSB	OSSB	ODSB	OSSB	ODSB	OSSB
2	45.44	37.28	37.85	29.19	29.39	21.29	21.51	13.28
10	45.40	37.21	37.81	29.14	29.32	21.22	21.45	13.23

Responsivity vs. Max. SNR

In both the transmission links the responsivity of the PIN diode was varied from 2 to 10 A/W and Max. SNR was measured at the output of the photodetector with electrical carrier analyzer for different fiber lengths.

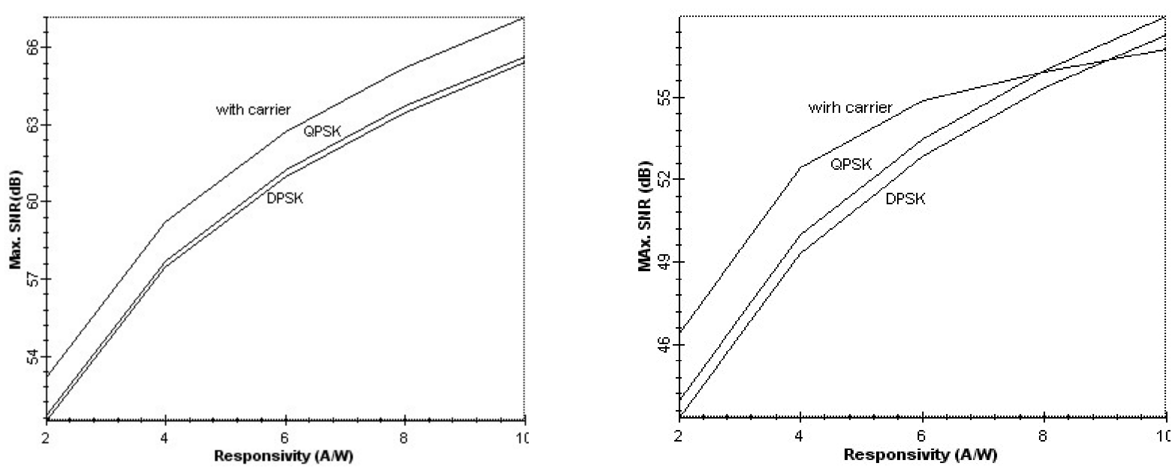


(a) **(b)**

Figure -11 Responsivity vs. Max. SNR (a) ODSB (e) OSSB

It has been observed that the Max SNR increases with increase in responsivity for different fiber lengths for ODSB and OSSB in the same manner as shown in Figure - 11. So the change in fiber length is immaterial. This seems that more responsivity is required for better SNR at any fiber length

Comparison of ODSB and OSSB for different Data Formats



(a) **(b)**

Figure -12 Comparison of Responsivity vs. Max. SNR for different data formats (a) ODSB (b) OSSB

Figure -12 shows the comparison between the responsivity vs Max SNR with carrier, QPSK and DPSK data formats for ODSB and OSSB. The plots were taken for 10 km fiber length. It has been observed that with carriers only, the SNR is more as compared to when the data format is sent and it increases from 53.5 dB to 66.5 dB and 46.0 db to 56.5 dB for ODSB and OSSB respectively. For DPSK data format, the SNR is increased from 51.5 dB to 63 dB and 43dB to 57 dB for ODSB and OSSB respectively. For QPSK data format the SNR increases from between 53 dB to 64 dB and from 43.5 dB to 58 dB for ODSB and OSSB respectively which is slightly more than that of DPSK. But the increase in Max SNR with responsivity is in the same fashion for all data formats in ODSB and OSSB.

Conclusions

The performance of the SCM transmission link has been investigated with QPSK and DPSK data formats for ODSB and OSSB. The power of subcarriers is decreasing through link –60dBm as against input power level at about –5dBm due to dispersion and span loss. The eye opening is more at 600 MHz and 400 MHz for ODSB and OSSB in DPSK SCM transmission as compared to other carrier frequencies. Using dispersion compensation fiber the link distance can be enhanced up to 240Km as compared to 120Km. The phase is same for sub-carrier at 600MHz for ODSB in DPSK-SCM. Similarly the constellation diagram of both data formats for all four carriers were observed for single and double sideband. The phase of the signal shifts as it propagates along the length of the fiber. The analysis of the system performance with variation in Linewidth and responsivity from 2 to 10 MHz and 2 to 10 A/W respectively for different fiber lengths shows that the SNR decreases with increase in Linewidth and increases with increase in responsivity. So the change in fiber length is immaterial. This seems that more responsivity is required for better SNR at any fiber length. The results confirm that with only single optical wavelength we can transmit multiple analog channels and data channels without any interference. The optimum value for frequency spacing is 4.7 GHz. To reduce the chromatic dispersion and to increase bandwidth efficiency optical single side band (OSSB) may be used.

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