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Wavelength Interleaving Based Dispersion Tolerant RoF System with Double Sideband Carrier Suppression

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Abstract: A Radio Over Fiber (RoF) system employing Wavelength Interleaving technique has been designed to enhance the overall efficiency of optical spectrum. In such a system, the spacing between the carrier and its sideband is fully utilized. The system performance and range of communication are still limited by dispersion caused by the optical link. This paper provides an insight into the design and performance analysis of dispersion compensated RoF system based on Wavelength Interleaving technique by employing optical double sideband suppressed carrier (ODSB-SC) scheme.

Keywords: Wavelength interleaving, MZI, optical double sideband suppressed carrier (ODSB-SC), Radio Over Fiber (RoF).

I. Introduction

Radio- over- Fiber (RoF) technology has been a field of immense research since it provides long haul high speed communication [2]. The few advantages of this technology are the reduction in complexity at the antenna site, the reduction in installation cost of access networks, the possibility of dynamic allocation of radio carriers to different antenna sites, transparency and scalability [6]. The high-frequency equipment is made simpler and the cost of the system is reduced to a great extent [9].To reduce the cost of system implementation, the high frequency radio carrier (tens of gigahertz) would be generated in a central station (CS) and then transmitted to a BS via optical fiber [12]. The above scenario brings about two problems, one of which is fading caused due to the dispersion of side bands which are equidistant from the optical carrier by the radio frequency (double side band – DSB) [2]. These side band components are affected by chromatic dispersion, which introduces a phase shift between them. If the phase shift is equal to 180L, the two side bands interfere destructively in the photodiode causing the fading of the output signal, occurring when the high frequency signals travel along the fiber. This is caused by the fact that the intensity modulation of the light generates two main side bands. Dispersion caused fading of these bands can be overcome by converting the DSB signal into a single side band (SSB) format [12]. The second problem is the inefficient utilization of the spectrum while using the standard channel spacing between WDM signals (spacing higher than twice the highest modulating frequency). To improve the spectral efficiency of such a system, an efficient new channel spacing technique called wavelength interleaving (WI) has been proposed [6]. For the systems employing WI, the spacing between adjacent channels is reduced to values less than twice the highest modulating frequency [12].

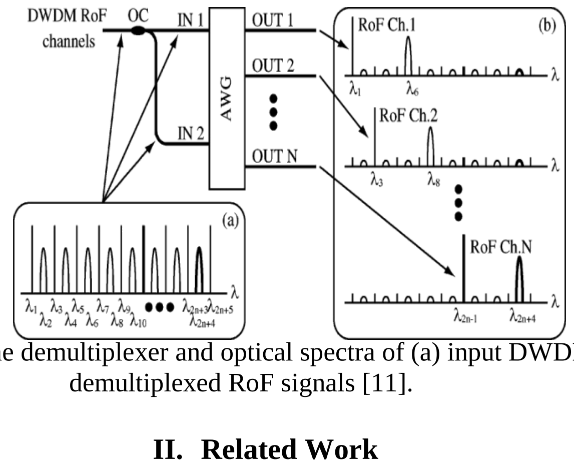

Fig.1. The Configuration of the demultiplexer and optical spectra of (a) input DWDM RoF signal and (b) demultiplexed RoF signals [11].

II. Related Work

Tian Y. et al. (2017) proposed and demonstrated an analog 60-GHz radio-over-fiber fronthaul link using two wavelength-tunable integrated microwave photonics filters for the first time. An integrated notch filter is cascaded with an integrated bandpass filter to offer the optical filtering function, resulting in a dual-passband filter profile with frequency separation of 60.25 GHz.

Wang D. et al. (2016) implemented a RoF system based on wavelength interleaving technique using double sideband carrier suppressed (ODSB-SC) based optical fiber transmission system. The author used Mach-Zehnder modulator (MZM) to realize the ODSB-CS modulation signal and two Mach-Zehnder interferometers (MZI) to separate the three optical RF signals. Using the photon simulation software, the author designed out an l0GHz, 15GHz and 25GHz three RF signal system through the wavelength interleaving RoF multiplexing ODSB-SC.

Guo Q. et al. (2015) proposed that time-interleaved multi-wavelength pseudo-random binary sequence (PRBS) optical pulses are utilized to significantly increase the instantaneous bandwidth of the modulated wideband converter (MWC). A four-channel MWC is proposed for the first time having a bandwidth of 20 GHz, where the four-wavelength optical pulse trains modulated by a 10.16Gb/s PRBS signals are interleaved temporally after passing through four sections of fibers with different lengths in parallel.

Kuri T. et al. (2015) investigated an optical frequency-interleaving based full-duplex multi-channel transmission of wide band (W-band) frequency-modulated signals with continuous-wave downlink and 10 Gbps on-off-keying uplink signals. The two-channel transmission with a flexible wavelength channel selector over a 10-km-class fiber-optic network was experimentally demonstrated.

Singh H. et al. (2014) investigated the impact of interferometer delay time in a 5 Gbps optical double sideband-suppressed carrier (ODSB-SC) RoF system transmitting two wavelength interleaved (WI) radio frequency (RF) signals at 10GHz and 15 GHz over an optical fiber. Here, an optical Mach–Zehnder modulator was used for both optical carrier suppression and signal modulation. At the receiver, delay interferometer was used for the separation of RF frequency signals.

Tripathi A. et al. (2012) investigated a spectrally efficient optical distribution system based on frequency interleaving. The proposed technique showed effective interleaving of three channels of baseband signals for the wired applications with a data rate of 2.5 Gbps and three channels of 62.5 GHz radio-over-fiber system for wireless services with a data rate of 1.25 Gbps, with complete spectrum occupying a bandwidth of 110 GHz. The interleaved signal thus contains six users, was transmitted over 60 km standard SMF without any dispersion compensation.

Yang X. et al. (2011) designed a frequency interleaved multiplexing DWDM-RoF based system to improve the optical spectral efficiency. In the proposed scheme, two chances of baseband signals and two carriers for wireless applications with a data rate of 2.5Gbps were used. The signals were distributed over 50-km single mode fiber without any compensation.

III. Wavelength Interleaving

The concept of frequency interleaving first mentioned by C. G. Schaffer, M. Sauer and C. Lim is applied to improve the efficiency of the spectrum [7]. Frequency interleaving means that the spacing between the adjacent optical carriers is less than the spacing between the carrier and sideband in a channel. The wideband optical spectrum cannot be fully utilized in a conventional DWDM-RoF system with large spacing because the bandwidth of the millimeter-wave signal is much narrower as compared to millimeter-wave carrier frequency [10].

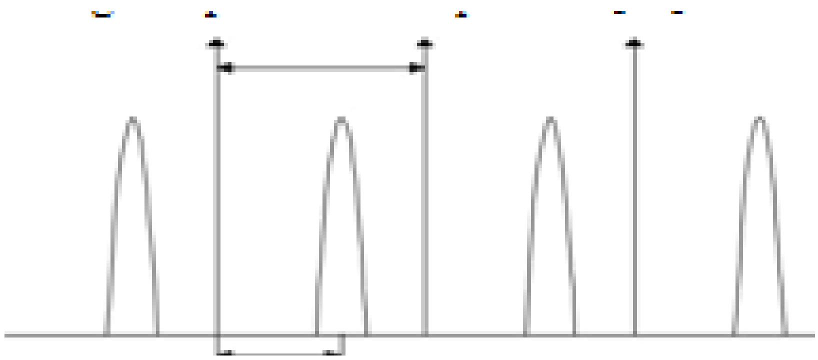

Fig. 1.2 Spectrum of conventional DWDM- RoF system [8]

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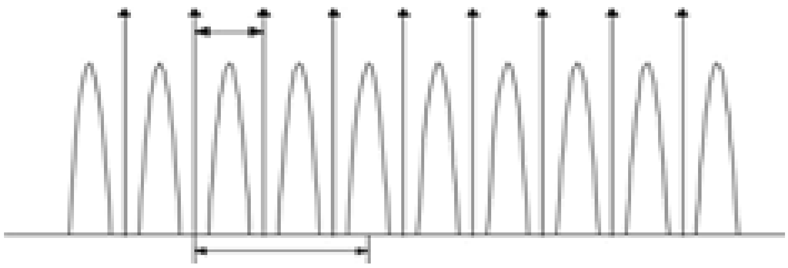

Fig. 1.3 The spectrum of Frequency Interleaved DWDM-RoF system[8]

Fig. 1.1 shows the spectrum of a conventional DWDM-ROF system. This short coming could be overcome simply by interleaving the optical frequency as shown in Fig 1.2. Wavelength interleaving technique has two possible configurations. In Scheme 1 (channel spacing larger than the radio frequency (RF) carrier), demultiplexing can be done using a simple optical band-pass filter. In this scheme, the side band of the neighbouring channel passes through the filter and will beat with the optical carrier producing an RF component at different a frequency than the desired signal. In Scheme 2 (channel spacing smaller than the RF carrier frequency) – spectral efficiency is better, but results in higher cost because it needs either two filters in cascade or a specially designed filter having two pass band frequencies [12].

IV. Simulation and Results

A. Simulation Model: Fig. 1.4 is the use of photon simulation software Optisystem to build a simulation system. In the center station, three RF signals at 10GHz, l5GHz, and 25GHz are generated. The signals are combined and fed to Mach Zender modulator to achieve optical carrier suppression modulation, an optical carrier for the output is generated from the laser continuous wave (CW), in which the frequency of 193.lTHz, the line width of l5MHz is kept.

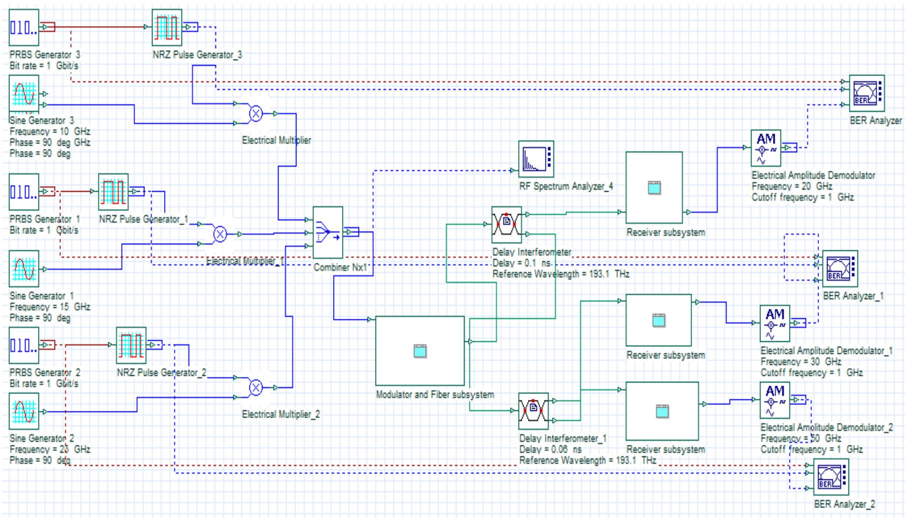

Fig 1.4- Simulation model of the proposed RoF system

The optical RF modulation signal is transmitted to the base station through a single mode fiber and dispersion compensated fiber. In the base station, the two cascaded MZI will demultiplex optical RF modulated signal to 10GHz, l5GHz and 25GHz optical RF signals, then they are fed into the corresponding receiver module consisting of an optical amplifier, the optical detector, filter and electric amplitude demodulator to lift the data signal modulation in RF. The modulator and fiber subsystem consists of Mach Zender modulator driven by a CW laser. The receiver subsystem consists of an optical filter, optical amplifier and photodetector in cascade. Fig. 1.5 shows the receiver subsystem of the simulated model.

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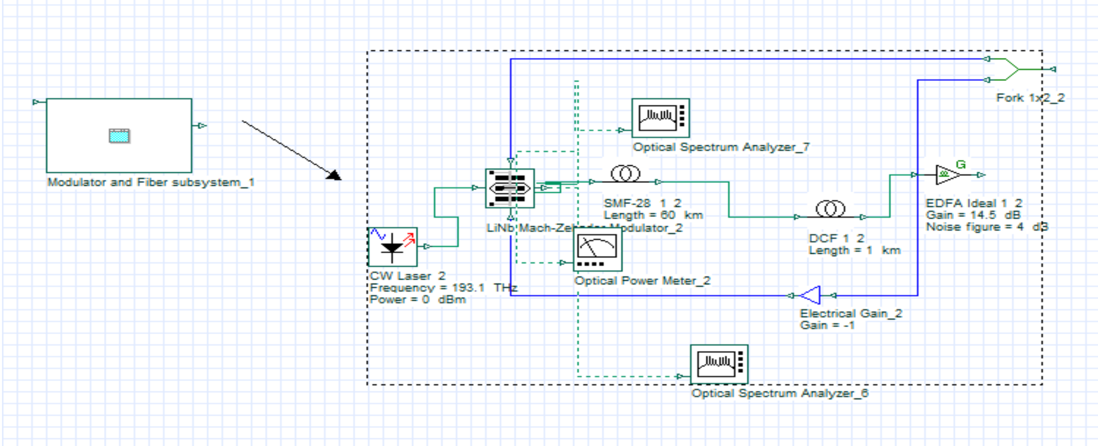

Fig 1.5- Modulator and Fiber subsystem

For l0GHz RF optical modulation signal and the upper band frequency 193.111THz and lower sideband 193.09THz, modulation bandwidth is 20GHz. For 15 GHz RF optical modulation signal and the upper sideband with frequency 193.ll5THz and lower sideband 193.085THz, modulation bandwidth is 30 GHz. For 25GHz optical RF modulation signal, the lower sideband and upper sideband frequency are 193.l25GHz and 193.3075GHz respectively, modulation bandwidth is 50GHz. Fig 1.6 shows the multiplexed spectrum of three RF signals at the output of Mach zender modulator.

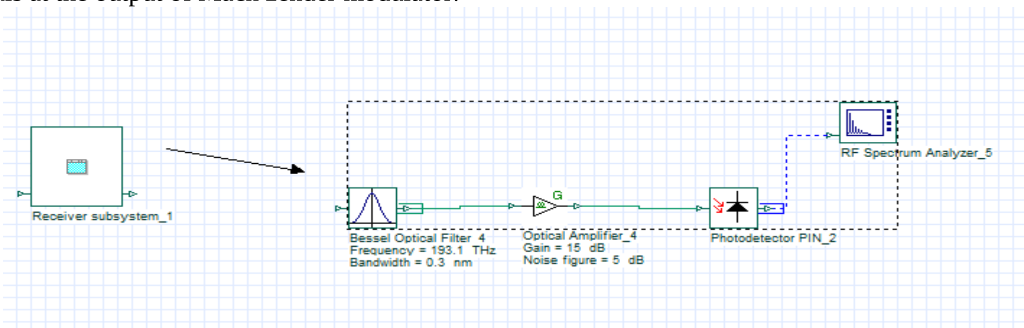

Fig. 1.6- Receiver subsystem

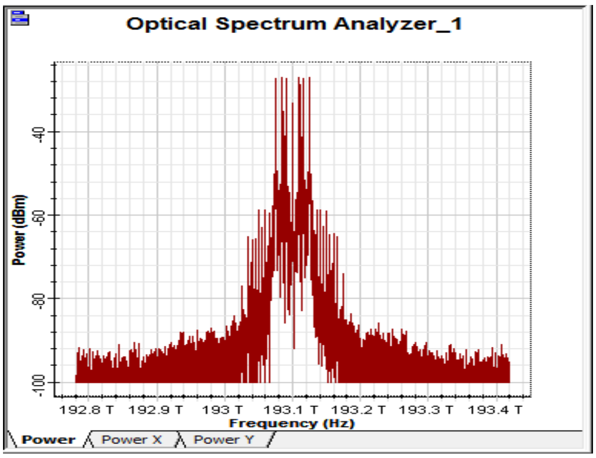

Fig 1.7 Demultiplexed spectrum

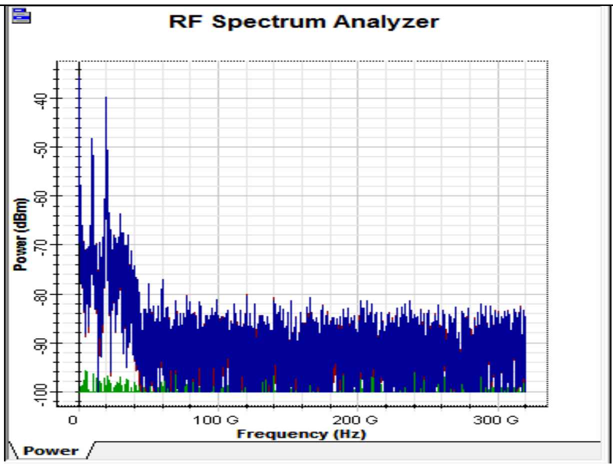

Fig 1.8 Mutiplexed spectrum of three RF spectrum of the 10GHz signal 10GHz, 15GHz and 25GHz.

For 10GHz RF signal the peak power of the demultiplexed spectrum is located at 20GHz.Fig 1.7 shows the demultiplexed spectrum of the 10GHz signal. For 15GHz and 25GHz RF signals the peak power is located at 30GHz and 50GHz respectively.

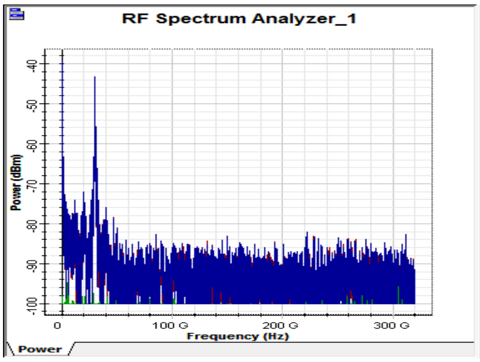

Fig 1.9 Demultiplexed spectrum of 15GHz RF signal

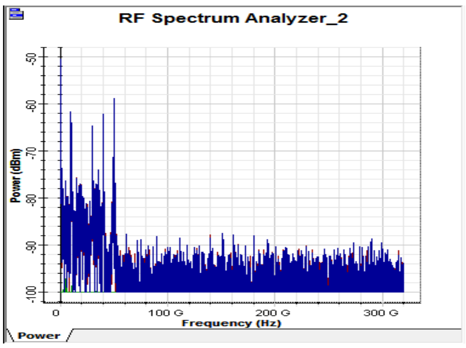

Fig. 1.10 Demultiplexed spectrum of 25GHz RF signal

Impact of fiber length on BER and Q value: Table 1 shows the variation of BER and Q Factor of three channels with a change in fiber length. It is observed that all the three channels have acceptable BER and Q Value even at length of 110 km. As seen from the table channel 1 has minimum BER of 4.03e-213, that of channel 2 is 1.23e-271 and channel 3 has minimum BER of 1.2e-141 at the fiber length of 20km.. The BER and Q Factor degrades with an increase in length. Due to dispersion compensation the the BER does not degrade too much with an increase in fiber length.

Table 1. Fiber length vs BER and Q value of three channels

Length(km)	Channel 1		Channel 2		Channel 3	
	Q Value	BER	Q Value	BER	Q Value	BER
20	31.13	4.03e-213	35.19	1.23e-271	25.30	1.2e-141
40	26.36	1.4e-153	19.9	1.6e-088	16.51	1.37e-062
60	17.23	7.6e-067	15.6	2.8e-055	16.50	9.8e-061
90	11.45	9.7e-031	14.48	7.7e-048	11.82	1.3e-032
110	9.35	3.8e-021	14.3	6.4e-046	6.06	6.4e-10

Impact of EDFA Noise Figure on BER: Erbium Doped Fiber Amplifier (EDFA) is used in cascade with DCF to boost the optical signal. However the Noise Figure of EDFA has a negative impact on system performance in terms of system BER. As the Noise Figure increases the BER degrades.

Table 2- Noise Figure vs BER

Noise Figure(dB)	BER Channel 1	BER Channel 2	BER Channel 3
4	7.2e-139	7.4e-187	17.5e-071
6	5.8e-119	6.18e-183	1.2e-070
12	8.2e-055	1.4e-153	1.1e-070
18	3.2e-017	1.2e-084	1.7e-036
22	1.4e-007	3.9e-034	1.13e-016

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V. Conclusion

The dispersion compensated Wavelength Interleaving based RoF employing Double Sideband Modulation with Carrier Suppressed (DSB-SC) system has greater range and Enhanced Bit Error Rate (BER) and Q Factor. The system BER degrades very slowly with length due to dispersion compensation in the fiber link. The system has acceptable BER at even 110km range. A cascade of Mach-Zender Interferometers (MZI) demultiplexes the signals while preserving the identity of each signal. The Noise Figure of EDFA has a negative impact on the system performance. The Q Factor and BER degrades for an increase in noise figure of the system. Further the delay time needs to be adjusted for proper demultiplexing of RF signals.

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