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Analysis of Power in Optical Single Side Band Technique for Radio over Fiber Transmission System

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Abstract**—In this paper, we have analyzed the impact of laser-spectral width and differential delay due to chromatic dispersion, incorporating dual-electrode Mach–Zehnder modulator (DEMZM), in radio-over-fiber(RoF) transmission system and results have been obtained. The results are calculated for 10 to 30 Km optical single side band (OSSB)–RoF transmission system by varying the laser line width. RoF system with OSSB has been used as it is tolerable for power degradation due to a chromatic fiber- dispersion, through a standard single-mode fiber (SSMF) carried by a continuous wave (CW) laser at 1550 nm of laser-spectral width varying from 100MHz to 650 MHz with CW power of 10mW that modulates a single RF channel of 30GHz. It has been found that deployment of lasers with lower spectral width will help the telecom industry to reduce the designing cost of RoF communication systems.**

Keywords: **RoF, DEMZM, OSSB**

I. INTRODUCTION

The great expansion of wireless networks worldwide and the increasing demand for applications requiring large bandwidth such as VoIP, IPTV and peer-to-peer have encouraged the appearance of new technologies that lead to more efficient wireless networks at low cost. Radio-over-Fiber (RoF) technology has been suggested as one of the most promising solution to integration of wired and wireless networks as well as to increase the availability of bandwidth and to reduce deployment costs. Radio-over-Fiber technology is based on the usage of optical links for the distribution of radio-frequency (RF) signals between a Base Station (BS) and several Remote Antenna Units (RAUs). In such system almost all RF components are kept centralized and the RAUs can be extremely simple and cheap, since all RF processing is carried out at the BS. The fiber links work as transparent signal medium and the RAUs are responsible only for the electro optical conversion. The performance of RoF systems depends on the method used to generate the optically modulated radio frequency (RF) signal, power degradation due to fiber chromatic dispersion, nonlinearity due to an optical power level, and phase noises from a laser and an RF oscillator [1–6]. There are two techniques to generate the optically modulated RF signal: direct and external modulation. The direct modulation scheme is simple but suffers from a laser-frequency chirp effect, and this chirp effect results in severe degradation of the system performance. However, this can be eliminated by using the external-modulation scheme instead of the direct modulation scheme [2]. Although the external-modulation scheme is employed, the conventional optical double sideband (ODSB) signal can degrade the received RF signal power due to fiber chromatic dispersion drastically. For overcoming the power degradation, an optical single sideband (OSSB) signal, generated by using a phase shifter and a dual-electrode (DE) Mach–Zehnder modulator (MZM), is employed [2]. In addition to these two effects, then nonlinearity of an optical fiber can give a large penalty on the long-haul transmission and multi channel system using a high-power signal. For the high- power transmission, then nonlinear effect should be managed by utilizing a modulation format [3], and by controlling the launched power level [4]. Then nonlinear effect ,however, can be negligible in short and low optical power(0dBm), especially for a single channel transmission.

Unlike these parameters, phase noise is one of the practical and decisive factors in high-quality services that require high signal- to-noise ratio (SNR) [6]. This phenomenon is serious to RoF systems because the purpose of RoF systems is to provide a service of high data rate and high quality, which require a large SNR. Thus, the system performance can be more sensitive to the phase noise in these services. The influence of the phase noise on optical communication systems has been investigated [5–10]. The system performance for an ODSB signal including laser phase noise has also been analyzed and suggestions are given how to compensate the differential delay by using a dispersion-compen- sating fiber (DCF) [ ]. The performance of coherent optical systems with laser phase noise by utilizing a Wiener process, since coherent detection provides better sensitivity than that of direct detection, while direct detection has a simple structure [6-7]. An autocorrelation function and a PSD function for evaluating the effect of the laser line width and fiber chromatic dispersion on the system performance [8-9]. RoF systems transmit an optically modulated radio frequency

(RF) signal from a central station (CS) to a base station (BS) via an optical fiber. The RF signal recovered using a photo detector (PD) at the BS arrives at a mobile station (MS) through a wireless channel as shown in Fig. 1. This architecture provides a cost-effective system since any RF oscillator is not required at the BS. However, the performance of RoF systems depends on the method used to generate the optically modulated RF signal, power degradation due to fiber chromatic dispersion, nonlinearity due to an optical power level, and phase noises from a laser and an RF oscillator. Therefore, it has been a matter of concern and interest to investigate parameters that degrade the performance of RoF systems.

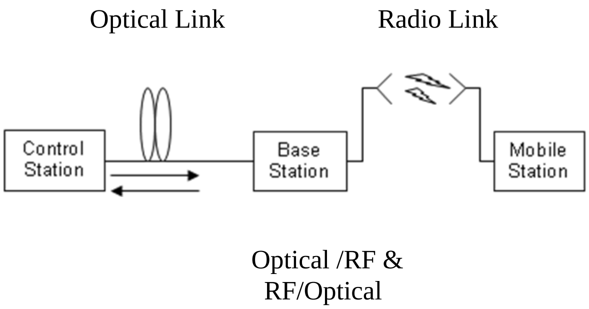

Figure 1: Optical Link in Radio over Fiber System

Single sideband (SSB) modulation scheme is an effective way to eliminate the dispersion effects in RoF system. The power degradation due to fiber dispersion can be overcome by employing an optical single sideband modulation scheme [2].The nonlinear effect of an optical fiber can be managed by the modulation format and control of a launched optical power [3] [4].Unlike those parameters, a phase noise is one of practical and decisive factors in high quality services which require high signal to noise ratio (SNR) because it result in the bit error rate (BER) floor at high signal to noise ratio (SNR) values [5].This phenomenon is serious to RoF systems because the purpose of RoF systems is to provide high data rate and high quality service requiring a large signal to noise ratio. Thus the system performance can be much sensitive to the phase noise in such services. Here we investigate the received RF power due to fiber chromatic dispersion and phase noises due to laser line width using an Optical Single Side Band (OSSB) signal and a direct-detection scheme. For the analysis, the autocorrelation and the power spectral density function of a received photocurrent are evaluated. It is shown that the phase noise due to the laser line width is the dominant parameter in a large optical distance.

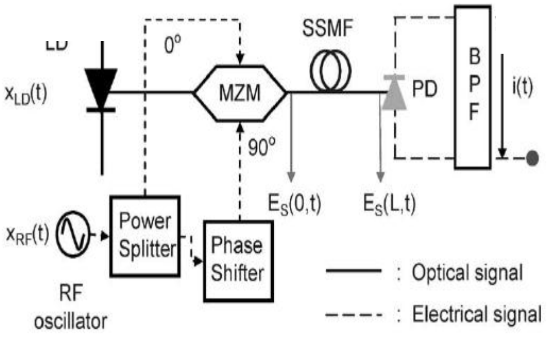

Figure. 2: RoF system using OSSB modulation and direct detection

II. RoF SYSTEM BASED ON OPTICAL SINGLE SIDE BAND & DIRECT DETECTION

An optical single side band (OSSB) signal is generated by using dual electrode Mach Zehender modulator (MZM) and a phase shifter. An RF signal from an oscillator is split by a power splitter and a 90◦ phase shifter. This RF signal is optically modulated by the laser diode (LD) with an MZM. The optically modulated signal is transmitted to the Photo detector and the photocurrent corresponding to the transmitted RF signal is extracted by the band pass filter as in Fig. 2. First, the optical signals from the optical source, laser diode and the RF oscillator are modeled as:

$$x_d(t) = A^d.\exp j(w_d t + \Phi_d(t)) \qquad (1.1)$$

$$x_o(t) = V_o.\cos(w_o t + \Phi_o(t)) \qquad (1.2)$$

Where A^d and V_o define amplitudes from the optical source and the RF oscillator signal, ω_d and ω_o define angular frequencies of the signals from the LD and the RF oscillator, and $\Phi_d(t)$ and $\Phi_o(t)$ are phase-noise processes.
The OSSB signal generated using Dual electrode MZM is modeled in equation (1.3).

$$E_{SS}(0,t) \cong A^d.L_{MZM}\begin{Bmatrix} J_0(\alpha\pi)\exp j\left[w_d t + \Phi_d(t) + \dfrac{\pi}{4}\right] - \sqrt{2}J_1(\alpha\pi) \\ \exp j\left[w_d t + \Phi_d(t) + w_o t + \Phi_o(t)\right] \end{Bmatrix}$$

(1.3)

After the transmission of signal over L Km fiber, the signal can be represented as equation (1.4) & in this equation L_{add} denotes an additional loss in the optical link, α_{fiber} is the

SSMF loss, L_{fiber} is the transmission distance of the SSMF, and $\tau 0$ and $\tau +$ define group delays for a center angular frequency of ω_{d} and an upper sideband frequency of $\omega_{\text{d}} + \omega\text{o}$. $\varphi 1$ and $\varphi 2$ are phase-shift parameters for specific frequencies due to the fiber chromatic dispersion.

$$E_{SS}(L,t) \cong \left[\begin{array}{l} A^{d}.L_{MZM}.L_{add}.10^{\frac{\alpha_{fiber}L_{fiber}}{20}} J_0(\alpha\pi) \\ \left\{\begin{array}{l} \exp j\left[w_d t + \Phi_d(t-\tau_0) - \phi_1 + \dfrac{\pi}{4}\right] - \dfrac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)} \\ \exp j\left[w_d t + \Phi_d(t-\tau_+) + w_o t + \Phi_o(t-\tau_+) - \Phi_2\right] \end{array}\right\} \end{array}\right] \tag{1.4}$$

To evaluate the R, we utilize the autocorrelation function and the PSD of the photocurrent.

$$i(t) \cong \eta \left|E_{SS}(L,t)\right|^2 \tag{1.5}$$

Where η defines the responsivity of the PD and $|\,.|^2$ is the square-law detection.

$$i(t) \cong \eta \left|A_1^d\right|^2 \left\{B + 2\alpha_1 \cos\left[\begin{array}{l} \Phi_d(t-\tau_+) - \Phi_d(t-\tau_0) \\ +w_o t + \Phi_o(t-\tau_+) - \Phi_2 + \Phi_1 \end{array}\right]\right\}$$

$$A_1^d = A^d.L_{MZM}.L_{add}.10^{\frac{\alpha_{fiber}L_{fiber}}{20}} J_0(\alpha\pi)$$

Where, $B = 1 + \alpha_1^2$

(1.6)

The autocorrelation function $R_I(\tau)$ is obtained as

$$R_1(\tau) = \left\langle i(t).i(t+\tau)\right\rangle \tag{1.7}$$

Now we will evaluate PSD function which is Fourier transform of $R_I(\tau)$

Where,

$$S_1(f) = F\left\langle R_1(\tau)\right\rangle \tag{1.8}$$

$$S_1(f) = R_1(\tau)\int_{-\infty}^{\infty} R_1(\tau)d\tau * \exp(-j\tau w)$$

$$\alpha_1 = \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)}$$

$$P(f+f_o) = \left[\begin{array}{l} \dfrac{2\Upsilon_o\alpha_1^2.\exp(-2\Upsilon_t|\tau|).\cos\left[2\pi(f+f_o)\tau\right]}{\Upsilon_o^2 + \left[2\pi(f+f_o)\right]^2} + \dfrac{4\alpha_1^2.\exp(-2\Upsilon_t|\tau|)}{(2\Upsilon_t)^2 + [2\pi(f+f_o)]^2} \\ .\{\Upsilon_t.\exp(-2\Upsilon_t|\tau|) - \Upsilon_t\cos\left[2\pi(f+f_o)\tau\right] - \dfrac{4\pi\Upsilon_d(\Upsilon_d+\Upsilon_o)(f+f_o)}{\Upsilon_o^2 + \left[2\pi(f+f_o)\right]^2} \\ .\sin\left[2\pi(f+f_o)\tau\right]\} \end{array}\right]$$

$$\frac{S_1(f)}{\eta^2.A_1^{d4}} = \left[\begin{array}{l} B^2\delta(f) + \dfrac{2\Upsilon_o\alpha_1^2.\exp(-2\Upsilon_t|\tau|).\cos\left[2\pi(f-f_o)\tau\right]}{\Upsilon_o^2 + \left[2\pi(f-f_o)\right]^2} \\ + \dfrac{4\alpha_1^2.\exp(-2\Upsilon_t|\tau|)}{(2\Upsilon_t)^2 + [2\pi(f-f_o)]^2}.\{\Upsilon_t.\exp(-2\Upsilon_t|\tau|) - \Upsilon_t\cos\left[2\pi(f-f_o)\tau\right] \\ - \dfrac{4\pi\Upsilon_d(\Upsilon_d+\Upsilon_o)(f-f_o)}{\Upsilon_o^2 + \left[2\pi(f-f_o)\right]^2}.\sin\left[2\pi(f-f_o)\tau\right]\} + P(f+f_o) \end{array}\right]$$

………. (1.9)

In equation, the first term represents a dc component, the second and third is the broadening effects due to the fiber chromatic dispersion and the line widths of the laser and the RF oscillator. The second term was only a Signal to noise penalty due to the fiber chromatic dispersion.Now the received RF carrier Power P1 is approximately represented as follows

$$P_1 = 2\int_{f_o - \frac{B_o}{2}}^{f_o + \frac{B_o}{2}} S_1(f)df \tag{1.10}$$

By using (1.9), received RF carrier power P_1 *as*

$$P_1 \cong \frac{4\eta^2 A_1^{d4} \alpha_1^2}{\pi} \exp(-2\Upsilon_t |\tau|) \tan^{-1}\left(\frac{\pi.B_o}{2\Upsilon_o}\right) \tag{1.11}$$

III. RESULT AND DISCUSSIONS

Received RF power on ROF link has been investigated by varying the RF oscillator and Laser linewidth. Firstly the effect of laser linewidth and optical fiber length has been investigated on the received RF power under a 10 Km fiber, 30 GHz RF carrier, dispersion of 17ps/nm-Km and 1550 nm laser with varying linewidth . Result of laser linewidth is described in figure 3. In this figure, linewidth is swept from 0 to 650 MHz. Received RF power decreases exponentially with increase in laser linewidth. Therefor ROF system suffers from reduction in power in large distance such as 30 Km.While for shorter distances it is less,confirming the use of Fabrey-Perot Laser in the cell boundary.

Another parameter , that is the effect of RF oscillator linewidth has also been investigated on received RF power under a 10 Km fiber, 30 GHz RF carrier, dispersion of 17ps/nm-Km and 1550 nm under varying RF oscillator linewidth which is swept from 1 to 10 Hz. Results show that the phase noise from RF oscillator gives a contant effect as shown in figure 4.While he received power decreases exponentially due to laser linewidth as the product of laser linewidth and differential delay. For a shorter distance the phase noise from the RF oscillator is dominant but for laser linewidth the decrement is exponential. Therefore the laser linewidth should be chosen carefully in long haul transmission since the large differential delay and large laser linewidth cause a serious power reduction.

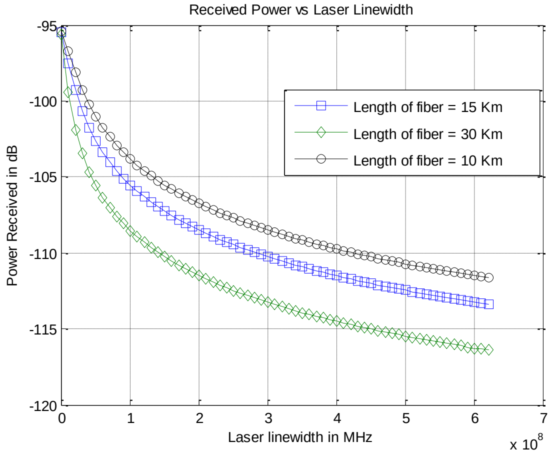

Figure. 3: Received power vs. Laser linewidth

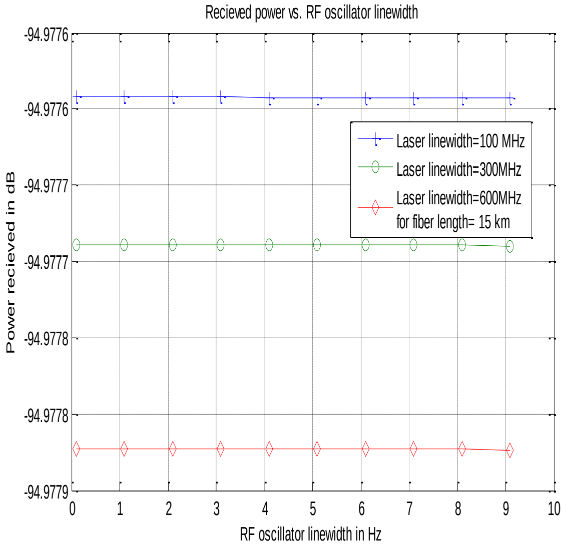

Figure. 4: Received power vs. RF oscillator linewidth

IV. CONCLUSION

From our simulative results obtained for 10 to 30 Km OSSB-RoF transmission system through a standard single mode fiber carried by 1550 nm laser , we have concluded that better RF power can br received by reducing the laser spectral width. Our results are calculated for Our 10 to 30KmOSSB–RoF transmission system requires less bandwidth than DSSB–RoF system and is tolerable for power degradation due to a chromatic fiber-dispersion, through a standard single-mode fiber carried. By reducing the laser-spectral width, we can also reduce the impact of chromatic fiber- dispersion [13]. Hence ,by deploying lasers like VSCEL, Fabry perot having small spectral width in OSSB–RoF transmission system ,we can reduce designing-cost of the central office(CO) comprises of transmitting section and information can be transmitted to a longer distance with minimum number of intermediate optical and RF amplifiers.

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