

Phase Noise Analysis of optical SSB Signal in Radio over Fiber System

Prof. Rahul Jain , Prof. Swati Juneja, Prof. Vishal Jain, Dr.K.M.Singh

ECE Department, BMIET, Sonapat, India

ECE Department, DRCET, Panipat, India
rj8134@gmail.com

Abstract: Radio over Fiber refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access. In RoF system, wireless signals are transported in optical form between a central station and a set of base stations before being radiated through the air. Each base station is adapted to communicate over a radio link with at least one user's mobile station located within the radio range of said base station. In this paper, Optical SSB signal is specifically selected as it has tolerance for power degradation due to dispersion effects over a length of fiber and phase noise from RF oscillator linewidth and laser linewidth is evaluated by using parameter CNR (carrier to noise ratio). Signal degradation is studied for various lengths of fibers in the presence of fiber chromatic dispersion

Keywords: RoF, CNR, MZM, OSSB, Power degradation.

I. INTRODUCTION

The Indian telecommunication industry is one of the world's fastest growing industries, with 653.92 million telephone (landlines and mobile) subscribers and 617.53 million mobile phone connections as on May 2010[1]. It stands the second largest telecommunication network in the world in terms of number of wireless connections after China. As the fastest growing telecommunications industry in the world, it is projected that India will have 1.159 billion mobile subscribers by 2013[1]. To meet the explosive demands of high-capacity and broadband wireless access, modern cell-based wireless networks have trends, projecting continuous increase in the number of cells and utilization of higher frequency bands which leads to a large amount of base stations (BSs) to be deployed; therefore, cost-effective BS development is a key to success in the market [2]. In order to reduce the system cost, radio over fiber (RoF) technology has been proposed. 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. This architecture provides a cost-effective system since any RF oscillator is not required at the BS [3], and [4]. 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. Several techniques have been found for the optical generation of mm-waves wireless signals, including optical self-heterodyning, up- and down conversion, and external modulation[5], and [6]. The external modulation generates mm-wave optical double sideband (DSB) by using an external optical modulator. It is attractive because of the

simplicity, and it can offer the most cost-effective base station (BS) without adding any active millimeter wave components to it. However, optical DSB signal suffers a severe fiber dispersion effect in an optical fiber link, resulting in the fading[7]. This problem has been solved in various ways; via either optical filtering of one of the sideband or single sideband modulation, and via compensation of the dispersion using either a fiber Bragg grating (FBG) or optical phase conjugator (OPC). So, Optical Single Side Band (OSSB) modulation scheme is an effective way to eliminate the dispersion effects in RoF system. Here, we investigate the CNR (carrier to noise ratio) penalty due to fiber chromatic dispersion and phase noises from an RF oscillator and laser linewidth using an Optical Single Side Band (OSSB) signal. For the analysis of the CNR penalty, the autocorrelation and the PSD (power spectral density) function of a received photocurrent at photo detector (PD) are evaluated [8]. The bandwidth of an electrical filter is dealt in the CNR penalty since the phase noises result in an increase of the required bandwidth and the increased bandwidth causes an additional CNR penalty. It is shown that the phase noise from the RF oscillator is the dominant parameter in a short optical distance.

II. ROF SYSTEM MODEL

Generally, RoF systems transmit an optically modulated radio frequency (RF) signal from a central station (CS) to a base station (BS) via an optical fiber and the photocurrent corresponding to the transmitted RF signal is extracted by the filter and this signal arrives at a mobile station (MS) through a wireless channel which is shown in Fig.1. An OSSB signal at base station (BS) is generated by using a Mach Zehnder Modulator and a phase shifter. An RF signal from an oscillator is split by a power splitter and a 90° phase shifter.

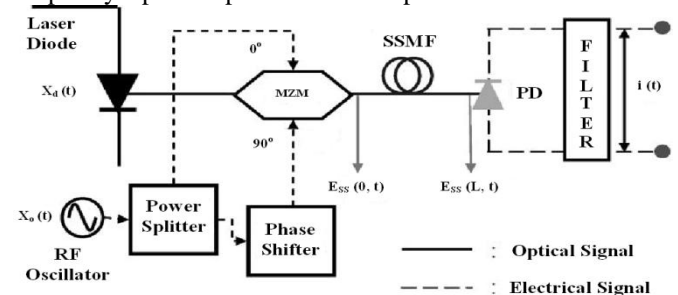


Fig.1. RoF system signal model

First, the optical signals from the optical source (laser diode) and the RF oscillator are modeled as follows:

$$x_d(t) = A^d \exp j(\omega_d t + \Phi_d(t)) \dots\dots\dots (1)$$

$$x_o(t) = V_o \cdot \text{Cos}(\omega_o t + \Phi_o(t)) \dots\dots\dots (2)$$

III. CNR PENALTY EVALUATION

Where A^c and V_o define amplitudes from the laser diode and the RF oscillator, 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.

After optically modulating $x_o(t)$ by $x_d(t)$ with a Dual Electrode MZM, the output signal is represented as

$$E_{ss}(0,t) = \frac{L_{MZM} \cdot x_d(t)}{\sqrt{2}} \left\{ \begin{array}{l} \exp j \left[\gamma\pi + \frac{\pi}{V_\pi} \cdot \frac{x_o(t)}{\sqrt{2}} \right] \\ + \exp j \left[\frac{\pi}{V_\pi} \cdot \frac{x_o(t)}{\sqrt{2}} \right] \end{array} \right\} \dots (3)$$

$$E_{ss}(0,t) = \frac{A^d \cdot L_{MZM}}{\sqrt{2}} \left\{ \begin{array}{l} \exp j \left[\gamma\pi + w_d t + \Phi_d(t) \right. \\ \left. + \alpha\pi \cos(w_o t + \Phi_o(t)) \right] \\ + \exp j \left[w_d t + \Phi_d(t) + \alpha\pi \right. \\ \left. \cos(w_o t + \Phi_o(t) + \theta) \right] \end{array} \right\} \dots (4)$$

where $\tilde{x}_o(t)$ denotes the phase-shift version of $x_o(t)$, $\gamma(= V_{dc}/V_\pi)$ and $\alpha(= V_o/\sqrt{2}V_\pi)$ define a normalized dc and ac value, V_π is the switching voltage of the DE MZM, L_{MZM} is the insertion loss of the DE MZM, and θ is the phase shift by the phase shifter. The output signal can be the OSSB or the ODSB signal by controlling the phase shifter. Since the ODSB signal suffers from fiber chromatic dispersion severely and requires double bandwidth than that of the OSSB signals. Due to that reasons, the OSSB signal will be generated. For generating the OSSB signal, θ and γ are set to $\pi/2$ and $1/2$, respectively. By using (4) and the OSSB signal becomes

$$E_{SS}(0,t) = \frac{A^d \cdot L_{MZM}}{\sqrt{2}} \left\{ \begin{array}{l} \exp j \left[\frac{\pi}{2} + w_d t + \Phi_d(t) \right. \\ \left. + \alpha\pi \cos(w_o t + \Phi_o(t)) \right] \\ + \exp j \left[w_d t + \Phi_d(t) \right. \\ \left. + \alpha\pi \cos(w_o t + \Phi_o(t) + 90^\circ) \right] \end{array} \right\} \dots (5)$$

$$E_{SS}(0,t) \cong A^d \cdot L_{MZM} \left\{ \begin{array}{l} J_0(\alpha\pi) \exp j \left[w_d t + \Phi_d(t) + \frac{\pi}{4} \right] \\ - \sqrt{2} J_1(\alpha\pi) \exp j \left[w_d t + \Phi_d(t) \right. \\ \left. + w_o t + \Phi_o(t) \right] \end{array} \right\} \dots (6)$$

After the transmission of L_{fiber} in km standard single mode fiber (SSMF), the signal at the end of the SSMF becomes

$$E_{SS}(L,t) \cong \left\{ \begin{array}{l} A^d \cdot L_{MZM} \cdot L_{add} \cdot 10^{\frac{\alpha_{fiber} L_{fiber}}{20}} J_0(\alpha\pi) \\ \exp j \left[w_d t + \Phi_d(t - \tau_0) \right. \\ \left. - \phi_1 + \frac{\pi}{4} \right] - \frac{\sqrt{2} J_1(\alpha\pi)}{J_0(\alpha\pi)} \\ \exp j \left[w_d t + \Phi_d(t - \tau_+) + w_o t \right. \\ \left. + \Phi_o(t - \tau_+) - \Phi_2 \right] \end{array} \right\} \dots (7)$$

To evaluate the CNR and the CNR penalty, we utilize the autocorrelation function and the PSD of the photocurrent [8]. By using a square-law model, the photocurrent $i(t)$ can be found from (7) as follows:

$$i(t) \cong \eta |E_{SS}(L,t)|^2 \dots (8)$$

$$i(t) \cong \eta |A_1^d|^2 \left\{ \begin{array}{l} B + 2\alpha_1 \cos \\ \left[\Phi_d(t - \tau_+) - \Phi_d(t - \tau_0) \right. \\ \left. + w_o t + \Phi_o(t - \tau_+) - \Phi_2 + \Phi_1 \right] \end{array} \right\} \dots (9)$$

Where

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

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

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

where η defines the responsivity of the PD and $| \cdot |^2$ is the square-law detection. From (9), the autocorrelation function $R_i(\tau)$ is obtained as

$$R_i(\tau) = \langle i(t) \cdot i(t + \tau) \rangle \dots (10)$$

The PSD function $S_i(f)$ can be written as

$$S_i(f) = F \langle R_i(\tau) \rangle \dots (11)$$

$$S_i(f) = R_i(\tau) \int_{-\infty}^{\infty} R_i(\tau) d\tau \cdot \exp(-j\tau\omega) \dots (12)$$

In equation (13), the first term represents a dc component, second and third is the broadening effects due to the fiber dispersion and the linewidths of the RF oscillator.

$$\frac{S_i(f)}{\eta^2 \cdot A_1^{d4}} = \left[\begin{array}{l} B^2 \delta(f) + \\ \frac{2\gamma_o \alpha_1^2 \cdot \exp(-2\gamma_t |\tau|) \cdot \cos[2\pi(f - f_o)\tau]}{\gamma_o^2 + [2\pi(f - f_o)]^2} \\ + \frac{4\alpha_1^2 \cdot \exp(-2\gamma_t |\tau|)}{(2\gamma_t)^2 + [2\pi(f - f_o)]^2} \\ \cdot \{ \gamma_t \cdot \exp(-2\gamma_t |\tau|) - \gamma_t \cos[2\pi(f - f_o)\tau] \} \\ - \frac{4\pi\gamma_d (\gamma_d + \gamma_o)(f - f_o)}{\gamma_o^2 + [2\pi(f - f_o)]^2} \\ \cdot \sin[2\pi(f - f_o)\tau] + P(f + f_o) \end{array} \right] \dots (13)$$

Where

$$P(f + f_o) = \left[\frac{2\gamma_o \alpha_1^2 \cdot \exp(-2\gamma_i |\tau|) \cdot \cos[2\pi(f + f_o)\tau]}{\gamma_o^2 + [2\pi(f + f_o)]^2} + \frac{4\alpha_1^2 \cdot \exp(-2\gamma_i |\tau|)}{(2\gamma_i)^2 + [2\pi(f + f_o)]^2} \cdot \{ \gamma_i \cdot \exp(-2\gamma_i |\tau|) - \gamma_i \cos[2\pi(f + f_o)\tau] - \frac{4\pi\gamma_d(\gamma_d + \gamma_o)(f + f_o)}{\gamma_o^2 + [2\pi(f + f_o)]^2} \cdot \sin[2\pi(f + f_o)\tau] \} \right]$$

$$\Delta CNR = 10 \log_{10} \left(\frac{p_o \cdot \gamma_o \tan\left(\frac{\pi p_o}{2} \exp(2\gamma_i |\tau|)\right)}{p \cdot \gamma_o \tan\left(\frac{\pi p_o}{2} \exp(2\gamma_o |\tau|)\right)} \right) \dots (17)$$

For calculating the CNR_o , we set p_o to 0.5 as a half-power bandwidth filter, γ_o to π , which means a 1-Hz linewidth of the RF oscillator, and zero laser linewidth. The CNR penalty

ΔCNR depends on p , the linewidths, and the differential delay. Firstly, we investigate the effect of p and γ_o on the CNR penalty for a 10-km fiber, 30-GHz RF carrier, fiber dispersion parameter D ($= 17$ ps/nm.km), and 1550-nm.

Now the received RF carrier Power P_1 is approximately represented as follows

$$P_1 = 2 \int_{f_o - \frac{B_o}{2}}^{f_o + \frac{B_o}{2}} PSD(f) df \dots (14)$$

Table 1 the Simulation Parameters for CNR penalty as a function of the RF oscillator linewidth and percentage of received power

Parameters	Value
Fiber dispersion	17 ps/nm-km
Optical transmission distance	10 km
RF carrier frequency	30 GHz
Wavelength of LD	1550 nm
Half power bandwidth filter	0.5
RF oscillator linewidth	0.1 to 20 Hz
Percentage of received power	0.1 to 0.99

And by using (14), we find ratio p between the total carrier power and the required power as follows:

$$p = \frac{P_1}{P_t}$$

$$p \cong \frac{2}{\pi} \left\{ \exp(-2\gamma_i |\tau|) \tan^{-1} \left(\frac{\pi B_o}{2\gamma_o} \right) \right\} \dots (15)$$

The CNR penalty induced by the differential delay from the fiber chromatic dispersion and the linewidths from the laser and the RF oscillator is found as

$$CNR \cong \frac{P_1}{2B_o \cdot \left(\frac{N_o}{2} \right)}$$

$$CNR \cong \frac{2\eta^2 A_1^{d4} \alpha_1^2 p}{N_o \cdot \left(\frac{\gamma_o}{\pi} \right) \tan\left(\frac{\pi \cdot p \exp(-2\gamma_i |\tau|)}{2}\right)} \dots (16)$$

IV. RESULT AND DISCUSSION

Now, we investigate the CNR penalty due to the differential delay, and the filter type. If CNR_o is defined as a reference CNR, the CNR penalty ΔCNR is represented as

$$\Delta CNR = 10 \log_{10} \left(\frac{CNR_o}{CNR} \right)$$

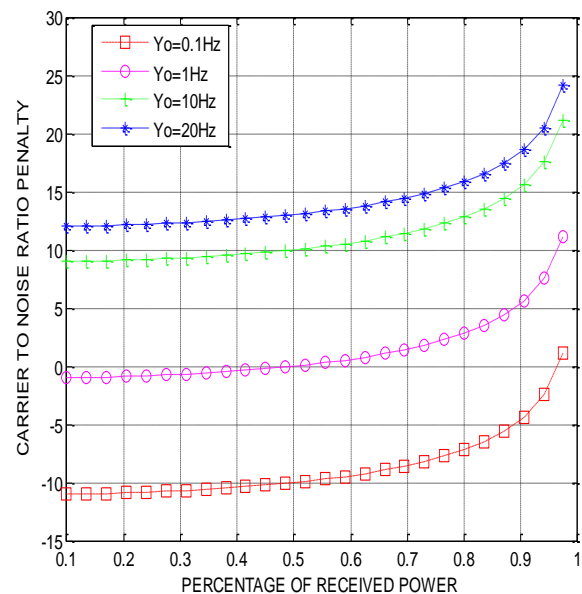


Fig.2. ΔCNR as a function of the RF oscillator linewidth and percentage of received power

The First result sketched in Fig.2 with simulation parameters in Table 1 represents the CNR penalty as a function of the RF oscillator linewidth and percentage of received power. The linewidth of the RF oscillator has been swept from 0.1 to 20 Hz and the CNR penalty of the RF oscillator due to the increment of the phase noise from 0.1 to 20 Hz is around 23 dB. Also the

effect of γ_0 is linearly proportional to ΔCNR and Fig. 2. The linear proportion means that ΔCNR increases 10 dB, which is equivalent to ten times the increment of γ_0 . ΔCNR also increases as p becomes large since the increment of the noise power is greater than that of the received signal power as the bandwidth increases. For example, the CNR penalty of $p = 0.99$ is 12.2 dB as compared to $p = 0.1$ [9]. Thus, the minimum required power to detect the signal should be carefully considered before we consider the filter bandwidth.

Table 2 the Simulation Parameters for CNR penalty as a function of the laser linewidth and length of fiber

Parameters	Value
Fiber dispersion	17 ps/nm-km
Optical transmission distance	1 km to 40 km
RF carrier frequency	30 GHz
Wavelength of LD	1550 nm
Half power bandwidth filter	0.5
Laser linewidth	10 to 624 MHz
Percentage of received power	0.5

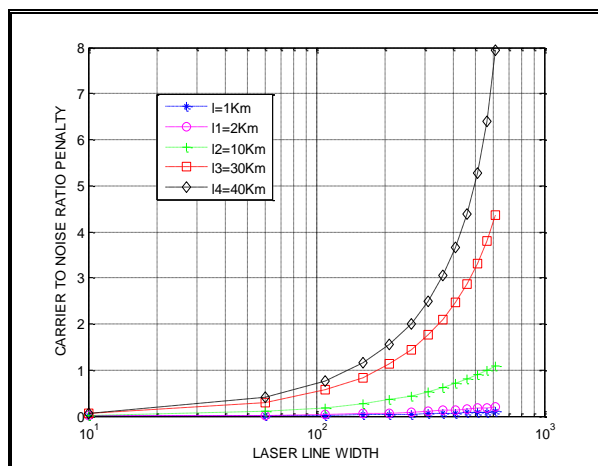


Fig.3. ΔCNR as a function of the laser line width and fiber transmission distance.

Now, The Second result ΔCNR is sketched in Fig. 3 with simulation parameters in Table 2. It represents the function of the laser line width and fiber transmission distance. It is found that ΔCNR exponentially increases as the laser linewidth (Y_d). It is noticed that CNR penalty due to laser linewidth from 10 to 624 MHz are 0.22, 1.2, 4.9, and 8 dB in 2, 10, 30, and 40 km SSMFs. Further, it is found that CNR penalty increases around 8 dB with respect to fiber length from 1 km to 40 km. So, the RoF system relatively suffers from ΔCNR for a long transmission, such as 40 km, while ΔCNR is almost not changed (≈ 0.22 dB) even for the FP laser in the short-transmission case (≈ 2 km). It is confirmed that the FP laser can be used in a practical microcell boundary because the radius of the microcell is from 0.2 to 1 km.

The CNR penalty due to the laser linewidth increases dramatically over a specific distance. Therefore, the laser linewidth should be selected carefully in a long-haul

transmission since the large differential delay and large laser linewidth cause a serious CNR penalty. For a short distance, the phase noise from the RF oscillator is the dominant factor of the CNR penalty. For consideration, the CNR penalty due to RF oscillator linewidth from 0.1 to 20 Hz is around 23 dB in any case, while the CNR penalties due to the laser linewidth for 624 MHz are 0.22, 1.2, 4.9 and 8 dB in 2-, 10-, 30- and 40-km SSMFs. This means that we can employ a cheap laser such as the FP laser in the RoF system in picocell, microcell and macrocell without a severe CNR penalty.

V. CONCLUSION

We have shown that the phase noise from RF oscillator Linewidth and laser linewidth is analyzed by using parameter CNR (carrier to noise ratio) for various line widths over different lengths of fiber. It is evident that the CNR penalty increases as the length of the fiber increases following the exponential increment. We also conclude that the bandwidth of an electrical filter at the receiver should be carefully chosen after considering minimum required signal power ratio p .

REFERENCES

- [1] http://en.wikipedia.org/wiki/Communications_in_India.
- [2] Y. Kim *et al.*, "Beyond 3G: Vision, requirements, and enabling technologies," *IEEE Commun. Mag.*, vol. 41, no. 3, pp. 120–124, 2003.
- [3] A. Alphones, "Double-spread radio-over-fiber system for next-generation Wireless technologies," *OSA J. Opt. Netw.*, vol. 8, no. 2, pp. 225–234, Feb. 2009.
- [4] T. Koonen, "Fiber to the Home/Fiber to the Premises: What, Where, and When?," *Proceedings of the IEEE*, Vol. 94, No. 5, May 2006.
- [5] P. Kaur, and R.S.Kaler, "Radio over Fiber Networks," *Proceedings of National Conference on Challenges & Opportunities in Information Technology (COIT-2007) RIMT-IET, Mandi Gobindgarh, March 23, 2007.*
- [6] N. Mohamed, S.M. Idrus, and A.B. Mohammad, "Review on System Architectures for the Millimeter-Wave Generation Techniques for RoF Communication Link," *IEEE International RF and Microwave Conference Proceedings*, December 2-4, 2008.
- [7] N. Pleros, K. Vyrsoinos, K. Tsagkaris, and N. D. Tselikas, "A 60 GHz Radio-Over-Fiber Network Architecture for Seamless Communication With High Mobility," *Journal of Lightwave Technology*, Vol. 27, No. 12, June 15, 2009.
- [8] H. K. Dass, *Advanced Engineering Mathematics*, 1st Edition, S. Chand, 2009.