# EFFECT OF RF LINEWIDTH ON BER PERFORMANCE OF 64-QAM ROF

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## Abstract

The optical and wireless communication systems integration will activate the potential capacity of photonic technology for providing the expected growth in interactive video, voice communication and data traffic services that are cost effective and a green communication service. The last decade growth of the broadband internet projects the number of active users will grow to over 2 billion globally by the end of 2014. Enabling the abandoned capacity of photonic signal processing is the promising solution for seamless transportation of the future consumer traffic demand. One emerging technology applicable in high capacity, broadband millimeter-wave access systems is Radio over Fiber also called Fiber To The Air (FTTA). 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 BER (bit error rate) is evaluated in terms of RF line width and percentage of received power.
*Keywords*: RoF, BER, MZM, OSSB, Power degradation.

## Introduction

The Indian telecommunication industry is one of the world's fastest growing industries, with 914.59 million telephone (landlines and mobile) subscribers and 881.40 million mobile phone connections as on October 2011[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 wire-less 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 BER(bit error rate) and phase noises from an RF oscillator and laser linewidth using an Optical Single Side Band (OSSB) signal. For the analysis of the BER it is expressed in terms of CNR for which the autocorrelation and the PSD (power spectral density) function of a received photocurrent at photo detector (PD) are evaluated[8],and [9]. It is shown that the phase noise from the RF oscillator is the dominant parameter in a short optical distance.

## 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 Zehender Modulator and a phase shifter. An RF signal from an oscillator is split by a power splitter and a 90◦ phase shifter.

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

$$x_d(t) = A^d \exp j(w_d t + \Phi_d(t)) \text{.......} (1)$$

$$x_o(t) = V_o.Cos(w_o t + \Phi_o(t)) \text{........} (2)$$

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

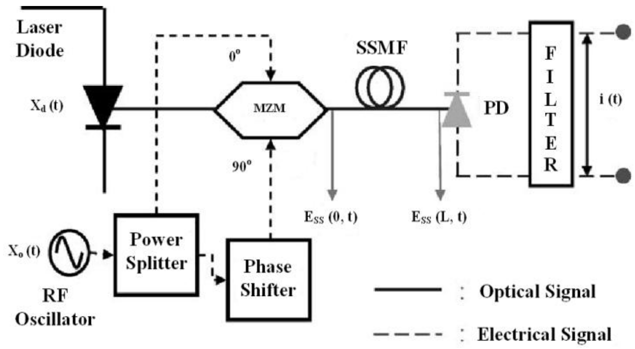


**Figure 1. RoF system signal model**

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

$$E_{SS}(0,t) = \frac{L_{MZM}\, x_d(t)}{\sqrt{2}} \begin{Bmatrix} \exp j\left[\gamma\pi + \frac{\pi}{V_\pi}.\frac{x_0(t)}{\sqrt{2}}\right] \\ + \exp j\left[\frac{\pi}{V_\pi}.\frac{x_0(t)}{\sqrt{2}}\right] \end{Bmatrix}$$

$$E_{SS}(0,t) = \frac{A^d.L_{MZM}}{\sqrt{2}} \begin{Bmatrix} \exp j\begin{bmatrix} \gamma\pi + w_d t + \Phi_d(t) \\ +\alpha\pi\cos(w_0 t + \Phi_0(t)) \end{bmatrix} \\ + \exp j\begin{bmatrix} w_d t + \Phi_d(t) + \alpha\pi \\ \cos(w_0 t + \Phi_0(t) + \theta) \end{bmatrix} \end{Bmatrix}$$

where $\tilde{x}_o(t)$ denotes the phase-shift version of $x_o(t)$, $\gamma(= Vdc/V\pi)$ and $\alpha(= V_o/\sqrt{2}V\pi)$ define a normalized dc and ac value, $V\pi$ is the switching voltage of the DE MZM, $L_{MZM}$ is the insertion loss of the DE MZM, and $\theta$ 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, $\theta$ and $\gamma$ are set to $\pi/2$ and 1/2, respectively. By using (4) and the OSSB signal becomes

$$E_{SS}(0,t) = \frac{A^d.L_{MZM}}{\sqrt{2}} \begin{Bmatrix} \exp j\begin{bmatrix} \frac{\pi}{2} + w_d t + \Phi_d(t) \\ +\alpha\pi\cos(w_0 t + \Phi_0(t)) \end{bmatrix} \\ + \exp j\begin{bmatrix} w_d t + \Phi_d(t) \\ +\alpha\pi\cos(w_0 t + \Phi_0(t) + 90^o) \end{bmatrix} \end{Bmatrix} \text{....} (5)$$

$$E_{SS}(0,t) = \frac{A^d.L_{MZM}}{\sqrt{2}} \begin{Bmatrix} J_0(\alpha\pi)\exp j\left[w_d t + \Phi_d(t) + \frac{\pi}{4}\right] \\ -\sqrt{2}J_1(\alpha\pi)\exp j\begin{bmatrix} w_d t + \Phi_d(t) \\ +w_0 t + \Phi_0(t) \end{bmatrix} \end{Bmatrix} \text{....} (6)$$

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

$$E_{SS}(0,t) \cong \begin{bmatrix} A^d.L_{MZM}.L_{add}.10^{\frac{\alpha_{fibre}\,L_{fibre}}{20}} J_0(\alpha\pi) \\ \begin{Bmatrix} \exp j\begin{bmatrix} w_d t + \Phi_d(t-\tau_0) \\ -\emptyset_1 + \frac{\pi}{4} \end{bmatrix} - \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)} \\ \exp j\begin{bmatrix} w_d t + \Phi_d(t-\tau_+) + w_0 t \\ +\Phi_0(t-\tau_+) - \Phi_2 \end{bmatrix} \end{Bmatrix} \end{bmatrix} \text{...}(7)$$

# CNR Evaluation

To evaluate the CNR we utilize the autocorrelation function and the PSD of the photocurrent [9]. By using a square-law model, the photocurrent $i(t)$ can be found from (7) as follows:

$$i(t) \cong \eta\left|E_{SS}(L,t)\right|^2 \text{....} (8)$$

$$i(t) \cong \eta|A_1^d|^2 \begin{Bmatrix} B + 2\alpha_1 \cos \\ \begin{bmatrix} \Phi_d(t-\tau_+) - \Phi_d(t-\tau_0) \\ +w_0 t + \Phi_0(t-\tau_+) - \Phi_2 + \Phi_1 \end{bmatrix} \end{Bmatrix} \text{.....} (9)$$

Where

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

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

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

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

$$R_1(\tau) = \langle i(t).i(t+\tau)\rangle \text{.....} (10)$$

. The PSD function $S_I(f)$ can be written as

$$S_1(f) = F\left\langle R_1(\tau)\right\rangle \text{.....} \quad (11)$$

$$S_1(f) = R_1(\tau)\int_{-\infty}^{\infty} R_1(\tau)d\tau * \exp(-j\tau w) \text{ ....} \quad (12)$$

Next 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.

$$\frac{S_1(f)}{\eta^2.A_1^{d4}} = \begin{bmatrix} B^2\delta(f) + \\ \dfrac{2\Upsilon_o\alpha_1^2.\exp(-2\Upsilon_t|\tau|).\cos\left[2\pi(f-f_o)\tau\right]}{\Upsilon_o^2+\left[2\pi(f-f_o)\right]^2} \\ +\dfrac{4\alpha_1^2.\exp(-2\Upsilon_t|\tau|)}{(2\Upsilon_t)^2+[2\pi(f-f_o)]^2} \\ .\{\Upsilon_t.\exp(-2\Upsilon_t|\tau|)-\Upsilon_t\cos\left[2\pi(f-f_o)\tau\right] \\ -\dfrac{4\pi\Upsilon_d(\Upsilon_d+\Upsilon_o)(f-f_o)}{\Upsilon_o^2+\left[2\pi(f-f_o)\right]^2} \\ .\sin\left[2\pi(f-f_o)\tau\right]\} + P(f+f_o) \end{bmatrix} \ldots (13)$$

Where

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

Now the received RF carrier Power $P_I$ is approximately represented as follows

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

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

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

$$p \cong \frac{2}{\pi}\left\{\exp(-2\Upsilon_t|\tau|)\tan^{-1}\left(\frac{\pi.B_o}{2\Upsilon_o}\right)\right\} \text{ ....} \quad (15)$$

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

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

$$CNR \cong \frac{2\eta^2A_1^{d4}\alpha_1^2 p}{N_o.\left(\frac{\Upsilon_o}{\pi}\right)\tan\left(\frac{\pi.p\exp(-2\Upsilon_t|\tau|)}{2}\right)} \text{ ....} \quad (16)$$

# Result and Discussion

Now, we investigate effect on BER due to RF Oscillatror Linewidth and percentage of received power as follows:

$$BER = \frac{\left(\sqrt{M}-1\right)}{\left(\log\sqrt{M}\right)\sqrt{M}}\,erfc\sqrt{\frac{3CNR(\log M)}{2(M-1)}}$$

For M=64 it can be modified as:

$$BER = \left(\frac{7}{24}\right)erfc\left(\sqrt{\frac{CNR}{7}}\right)$$

$$BER = \left(\frac{7}{24}\right)erfc\sqrt{\frac{2\eta^2A_1^{d4}\alpha_1^2 p}{7.N_o.\left(\frac{\Upsilon_o}{\pi}\right)\tan\left(\frac{\pi.p\exp(-2\Upsilon_t|\tau|)}{2}\right)}} \text{....} (17)$$

Figure 2 where the effect of RF oscillator line width is plotted at different values of p, that the effect of Bandwidth is also equally pronounced.

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

| **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 |
| RF Oscillator linewidth | 1Hz to 10 Hz |

| | |
|---|---|
| Percentage of received power | 0.3,0.5,0.8,0.99 |

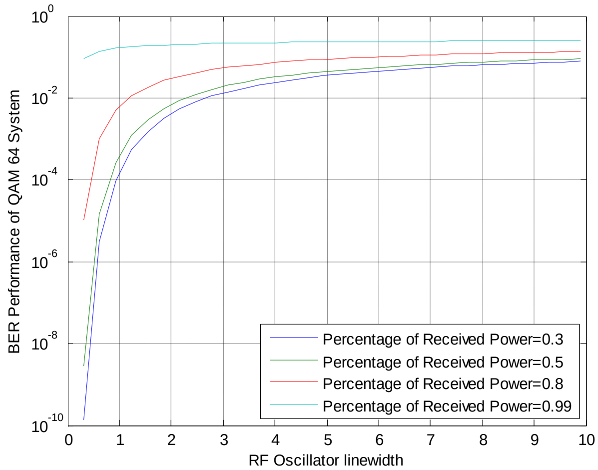


**Figure 2. BER as a function of the RF oscillator linewidth and percentage of received power**

Now, the result BER is sketched in Fig. 2 with simulation parameters in Table 1. represents the function of the RF Oscillator line width and percentage of received power. It is found that BER deteriorates as the value of p is increased. It is noticed that BER due to RF Oscillator linewidth from 1 to 10 Hz are different for different percentage of power received.

And we have to make a considerable trade of between the bandwidth requirement and the RF oscillator linewidth. As it can be seen that the BER deteriorates rapidly as value of p is increased. For values of p above 0.8, there is hardly any meaningful communication possible in the channel for the RF oscillator linewidths of above 1 Hz. Thus we need to employ highly stable local oscillators if higher bandwidth is required .

# Conclusion

We have shown that the BER has been investigated due to RF Oscillator for various line widths over different percentage of received power. It is evident that the BER deteriorates rapidly as the as the value of p is increased. 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.

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