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Abstract: The optical and wireless communication systems convergence 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 CNR (carrier to noise ratio) performance is evaluated in terms of phase noise from RF oscillator Linewidth and laser linewidth. 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 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 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 Zehender Modulator and a phase shifter. An RF signal from an oscillator is split by a power splitter and a 90◦ phase shifter.

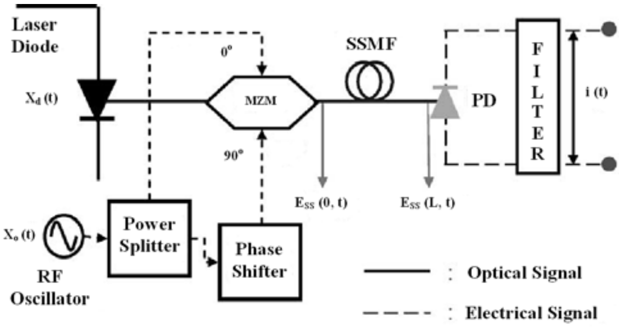

Fig.1. RoF system signal model

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

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

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

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

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

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

where $\tilde{x}_o(t)$ denotes the phase-shift version of $x_o(t)$, γ(= Vdc/$V\pi$) and α(= V_o/ $\sqrt{}$ $2V\pi$) 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 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

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

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

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

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

III. CNR PENALTY EVALUATION

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:

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

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

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

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

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

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

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

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.

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

Where

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

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

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

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

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

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

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

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

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

IV. RESULT AND DISCUSSION

Now, we investigate the CNR penalty due to the differential delay, and the filter type. If CNR_0 is defined as a reference CNR, the CNR penalty ΔCNR is represented as

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

$$\Delta CNR=10\log_{10}\left(\frac{p_0.\Upsilon_o\tan\left(\frac{\pi p.}{2}\exp(2\Upsilon_t|\tau|)\right)}{p.\Upsilon_{oo}\tan\left(\frac{\pi p_o.}{2}\exp(2\Upsilon_{oo}|\tau|)\right)}\right)\ ..(17)$$

For calculating the CNR_o, we set p_0 to 0.5 as a half-power bandwidth filter, γ_{oo} 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.

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

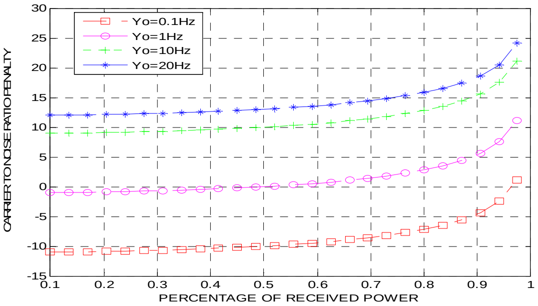

Fig.2. ΔCNR as a function of the RF oscillator linewidth and percentage of received power

The First result sketched in Fig.2 with simulation parameters in Table 1represents the CNR penalty as a function of the RF oscillator linewidth and percentage of received power is. 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_o 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_o. 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

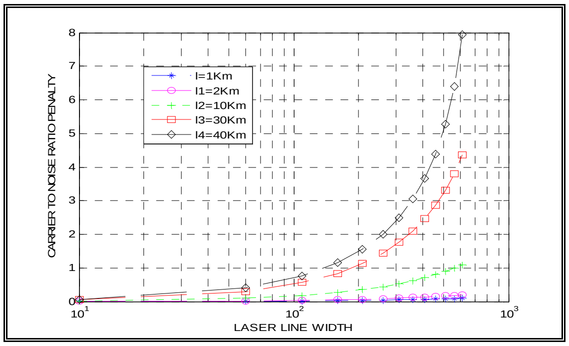

Fig.3. ΔCNR as a function of the laser line width and fiber transmission distance.

Now, The Second result ΔCNR is sketched in Fig. 3 with simulation parameters in Table 2. 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 notice 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 1km 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 8m 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 CNR Penalty has been investigated due to the phase noise from RF oscillator as well as laser 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 exponentially 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.

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