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Received Power performance in downlink architecture of Radio-over-Fiber Transmission system using OSSB Techniquedue to chromatic dispersion and laser linewidth

Rohit Khattar[1], Dinesh Arora[2]

[1](Deptt. of Electronics and Communication Engineering, SDDIET Barwala/ Kurukshetra university, India)
[2](Deptt. of Electronics and Communication Engineering, SDDIET Barwala/ Kurukshetra university, India)

Abstract : *The In this paper, we studied the RoF system and analyzed the received power performance in downlink architecture of RoF system. The RoF system employs a Mach–Zehnder modulator (MZM) and a phase shifter to externally generate an optical single sideband (OSSB) signal since the OSSB signal is tolerable for power degradation due to a chromatic fiber-dispersion effect. The received power performance is analyzed by calculating a factor called Power Penalty. It is shown that Power penalty is increased exponentially as the differential delay increased with the distance due to chromatic dispersion with the change in laser linewidth (γ_{RF}) from 10MHz to 1000MHz. The results are calculated for various transmission distances (L_{FIBER}) 1km to 40km for optical distances. The frequency of laser taken is 30-GHz RF carrier (f_{RF}) and wavelength 1550-nm laser (λ) with zero line width, fiber dispersion parameter (D) 17 ps/nm·km.*

Keywords: *Chromatic dispersion, DEMZM, Laser line width, Power penalty and Received power.*

I. INTRODUCTION

Wireless operators are increasingly challenged to accommodate a great diversity of data oriented mobile services and the growing number of end users. To meet the higher data rate [1] communication systems are necessary in both wired link and wireless link.Radio over fiber (RoF) systems have been potential candidates for broadband services since an optical fiber provides low loss and large bandwidth and a radio signal covers up the mobility and the easy accessibility.This is a technology, which modulates light into radio frequency and transmits it via optical fiber to facilitate wireless access. Radio signals are carried over fiber utilising distributed antenna systems in fiber-optic cellular and micro-cellular radio networks. Radio signals in each cell are transmitted and received to and from mobile users by applying a separate little box that is connected to the base station via optical fiber. Cells are divided into microcells to enhance the frequency re-use and support a growing number of mobile users.

RoF technology has various advantages when it applies to wireless systems, especially for mobile communication radio networks. NTT DoCoMo, one of the cellular system operators in Japan, was employed the RoF technology for radio links of micro and Pico cell layouts. Very small base stations (access units) are equipped on the ceiling of rooms in a building and are connected to a master base station (base unit) by optical fiber cables [2] The introduction of microcells has the following advantages Firstly, the microcell is able to meet increasing bandwidth demands; secondly, reduces the power consumption also the size of the handset devices. The high-power radiating base station antenna is replaced by a divided antenna system connected to the base station via optical fiber [3]. However, 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 [4-10][12-18].There are two techniques to generate the optically modulatedRF 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 [5]. 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 [5].

In addition to these two effects, the nonlinearity of an optical fiber can give a large penalty on the long-haul transmission and multichannel system using a high-power signal. For the high-power transmission, the nonlinear effect should be managed by utilizing a modulation format [6], and by controlling the launched power level [7]. The nonlinear effect, however, can be negligible in short and low optical power less than 0dBm, especially for a single channel transmission. Unlike those parameters, phase noise isone of the practical and decisive factors in high-quality servicesthat require high signal-to-noise ratio (SNR), because it resultsin a bit error rate (BER) floor in a high SNR value [9]. This phenomenonis serious to RoF systems because the purpose of RoFsystems is to provide a service of high data rate and high quality, which require a large SNR. Thus, the system performance canbe more sensitive to the phase noise in these services. The influence of the phase noise on optical communicationsystems has been investigated [8-13]. Kitayama et al. analyzedthe system performance for an ODSB signal includinglaser phase noise and suggested how to compensate the differentialdelay by using a dispersion-compensating fiber (DCF).He focused on how to compensate fiber chromatic dispersionfor the ODSB signal experimentally and analytically. Barry and Lee [9] and Salz [10] analyzed the performanceof coherent optical systems with laser phase noise by utilizinga Wiener process, since coherent detection provides better sensitivity than that of direct detection, while direct detection has a simple structure [11]. Gallion and Debarge [12] andTkach [13] used an autocorrelation function and a PSD functionfor evaluating the effect of the laser line width and fiber chromaticdispersion on the system performance. Gallionanalyzedthe power spectral density (PSD) function of a photocurrentincorporating the laser phase noise in detail. Gliese applied theresult in [12] to study the influence of chromatic fiber dispersion on the transmission distance of fiber optic microwave and millimeter wave links [14]. For the tolerance to fiber chromaticdispersion, dual correlated lasers were employed to generatean OSSB signal in [14]. In this paper, we will analyze the Power penalty due to fiberchromatic dispersion using an OSSB signal and a direct-detection scheme. For the analysis of the Power penalty, the autocorrelation and the PSD function of a received photocurrent are evaluated. The bandwidth of an electrical filter is dealt in the Penalty since the phase noises result in an increase of the required bandwidth and the increased bandwidth causes an additional Power penalty.

II. R-O-F ARCHITECTURE

The overall downlink architecture of the RoF system is shown in Fig. 1. In the RoF system an optically modulated radio Frequency signal is generated from a Control Station (CS) to a base station (BS) via an optical fiber. An OSSB signal is produced by using a Dual-Electrode Mach–Zehnder modulator (DEMZM) and a 90° phase shifter, and optically modulated by LASER diode at Control Station. The optically modulated signal is transmitted to BS via Single mode Fiber where the received RF signal is recovered by using a photo detector (PD) and a BPF. The Mobile Station is connected to Base Station via wireless channel.

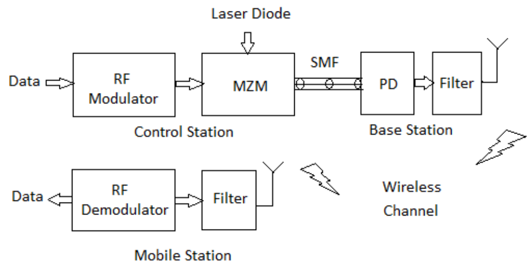

Fig.1

The optical signals generated from the laser and the RF oscillator are represented mathematically as

$$:x_{LD}(t) = A\,.\,expj\big(w_{LD}(t) + \Phi_{LD}(t)\big) \qquad (1)$$
$$: x_{RF}(t) = V_{RF}\,.\cos\big(w_{RF}(t) + \Phi_{RF}(t)\big) \qquad (2)$$

Where A and$V_{RF}$are amplitudes of signals from the LD and the RF oscillator respectively,w_{RF} andw_{LD} are angular frequencies of the signals from the LD and the RF oscillator, Φ_{LD} and Φ_{RF} are phase-noise processes and Φ_{LD} is characterized by a Wiener process [9] as

$$: \Phi_{LD}(t) = \int_0^t \Phi'_{LD}(\tau)d\tau \qquad (3)$$

The time derivative$\Phi_{LD}(t)$ is not flat at low frequencies due to 1/f noise [9]. The white phase noise, however, is the principal cause for line broadening and is associated with quantum fluctuations [10]. Thus, $\Phi_{LD}(t)$can be modeled as a zero-mean white Gaussian process with a PSD [9]

$$:S_{\Phi'_{LD}}(w) = 2\pi\Delta v_{LD} \qquad (4)$$

Wherev_{LD} is Laser linewidth

After optically modulating $x_{LD}(t)$by$x_{RF}(t)$ with a DEMZM and by controlling the phase shifter, the OSSB signal is generated by setting θ (phase shift) and γ (normalized dc value of LD) to 90° and 0.5, respectively, and this OSSB signal at the output of DEMZM is represented as

:$E(0,t) = A.L_{MZM}\left[J_0(\alpha\pi).expj\left(w_{LD}(t) + \Phi_{LD}(t) + \frac{\pi}{4}\right)\right] - \sqrt{2}J_1(\alpha\pi).expj(w_{LD}(t) + \Phi_{LD}(t) + w_{RF}(t) + \Phi_{RF}(t))$ (5)

Where $\alpha = V_{RF}/\sqrt{2}V_\pi$is the normalized ac value,$V_\pi$is the switching voltage of the DEMZM. $L_{MZM}$is the insertion loss of the DEMZM, and θ is the phase shift by the phase shifter. Generally, $V_\pi \gg V_{RF}$, thus, the high-order components of the Bessel function are neglected.

III. RECEIVED POWER ANALYSIS

After transmitting the OSSB at the output of DEMZM through standard single-mode fiber (SSMF) ofL_{FIBER}Km is represented as

: $E(L,t) =$
$A.L_{MZM}.L_{LOSS}.10^{-\frac{\alpha_{FIBER}\cdot L_{FIBER}}{20}}.J_0(\alpha\pi)\left[expj\left(w_{LD}(t) + \Phi_{LD}(t-\tau_0) - \Phi_1 + \frac{\pi}{4}\right) - \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)}.expj(w_{LD}(t) +\right.$
$\Phi LDt-\tau++wRFt+\Phi RFt-\tau+-\Phi 2$ (6)

Where L_{LOSS} denotes an additional loss in the optical link line, $\alpha_{FIBER}$is the SSMF loss,L_{FIBER} is the transmission distance of the SSMF, and τ_0 and τ_+ define group delays for a center angular frequency of$w_{LD}(t)$, and an upper side band frequency of $w_{LD}(t) + w_{RF}(t)$, Φ_1 and $\Phi_2$are phase-shift parameters for specific frequencies due to the fiber chromatic dispersion. By using a square-law model, the photocurrent i(t) can be obtained from (6) as follows

: $i(t) = R|E(L,t)|^2 = RA_1^2[B + 2\alpha_1\cos(w_{RF}(t) + \Phi_{LD}(t-\tau_+) - \Phi_{LD}(t-\tau_0) + \Phi_{RF}(t-\tau_+) - \Phi_2 + \Phi_1)]$ (7)

Where $A_1 = A.L_{MZM}.L_{LOSS}.10^{-\frac{\alpha_{FIBER}\cdot L_{FIBER}}{20}}.J_0(\alpha\pi)$

$\alpha_1 = \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)}, B = 1 + \alpha_1^2, R = Responsivity of PD$

From (7), the autocorrelation function $R_{AF}(\tau)$is obtained as

: $R_{AF}(\tau) = < i(t).i(t+\tau) >$ (8)

: $\frac{R_{AF}(\tau)}{R^2.A_1^4} = B^2.\begin{cases} 2.\alpha_1^2.\cos(w_{RF}\tau)\exp(-2\gamma_1|\tau|), & |\tau| \le \tau_1 \\ 2.\alpha_1^2.\cos(w_{RF}\tau)\exp(-2\gamma_{LD}\tau_1 - \gamma_{RF}|\tau|), & |\tau| > \tau_1 \end{cases}$ (9)

Where Δv_{LD} and $\Delta v_{RF}$are the line widths for the laser and the RF oscillator, respectively, $2\gamma_{LD}$(=$2\pi\Delta v_{LD}$) and $2\gamma_{RF}$ (=$2\pi\Delta v_{RF}$) are the angular full-line width at half-maximum (FWHM) of the Lorentzian shape for the laser and the RF oscillator, respectively, and $2\gamma_t$ is related to the total line width. Note that the$2\gamma_t$is given not as $2\pi\Delta v_{LD} + 2\pi\Delta v_{RF}but2\pi\Delta v_{LD} + \pi\Delta v_{RF}$. Now τ_1 (=$\tau_+ - \tau_0$) is the differential delay due to the fiber chromatic dispersion and is dependent on the wavelength λ, the carrier frequencyf_{RF} , the fiber chromatic dispersion D, and the optical transmission distanceL_{FIBER}. It is given by [10]

: $\tau_1 = D\ .\ L_{FIBER}\ .\lambda^2\ .\ \frac{f_{RF}}{c}$ (10)

Wherec is the light velocity.
The shot noise term at the PD is omitted here since the noise power can be evaluated by the product of bandwidth and noise density level. The PSD function of the photocurrent is given by the Fourier transform of Autocorrelation Function.

: $S(f) = F < R_{AF}(\tau) >$

: $\frac{S(f)}{R^2A_1^4} = B_2\ .\delta(f) + G(f - f_{RF}) + G(f + f_{RF})$

Where
: $G(f - f_{RF}) = S_1 + S_2 + S_3$

After getting the three terms, S_1 and S_2 defines the broadening effects due to the fiber chromatic dispersion and the line width of the laser and the RF oscillator. By using Fourier Transform the received RF carrier power $P_{RECIEVED}$ is approximately represented as follows

$$: P_{RECIEVED} = \frac{4R^2A_1^4\alpha_1^2}{\pi} e^{-2\gamma_t\tau_1} . \tan^{-1}\left(\frac{\pi . B_{RF}}{\gamma_{RF}}\right) \qquad (11)$$

Where $2\gamma_t\tau_1 \ll 1$and $\gamma_t \ll \gamma_{RF}$. This is because the laser linewidth is much greater than the RF oscillator linewidth. The received RF carrier power is a function of the differential delayτ_1, the laser and the RF oscillator linewidths, and the Bandwidth of the electrical filterB_{RF}. The ratio between the bandwidth and the linewidth of the RF oscillator is one of the dominant parameters for the carrier power. Practical systems employ various types of bandwidth as the required power, such as half-power bandwidth, fractional-power containment bandwidth (99% of signal power), and so on [19].For evaluating the total RF power excluding dc power, we utilize the Autocorrelation Function.

$$: P_{TOTAL} = R_{AF}(0) - R^2A_1^4B^2$$

$$: P_{TOTAL} = 2R^2A_1^4\alpha_1^2 \qquad (12)$$

By using (12), we define the ratio p between the total carrierPower and the required power as follows

$$: p = \frac{P_{RECIEVED}}{P_{TOTAL}} for \ 2\gamma_t\tau_1 \ll 1 \ and \gamma_t \ll \gamma_{RF}$$

$$: p \cong \frac{2}{\pi} e^{-2\gamma_t\tau_1} . \tan^{-1}\left(\frac{\pi . B_{RF}}{\gamma_{RF}}\right) \qquad (13)$$

Required bandwidth for ratio p is

$$: B_{RF} = \frac{\gamma_{RF}}{\pi} . \tan\left(\frac{\pi}{2} e^{2\gamma_t\tau_1} p\right) \qquad (14)$$

It shows that when we need more received signal power the required bandwidth increases. Now for analyzing the variation in received power a Power penalty factor is calculated by a factor p from (13). The Power penalty induced by the Differential delay from the fiber chromatic dispersion by varying laser linewidth is as

$$: PowerPenalty = \frac{1}{p} = 1/\left(\frac{2}{\pi} e^{-2\gamma_t\tau_1} . \tan^{-1}\left(\frac{\pi . B_{RF}}{\gamma_{RF}}\right)\right) \qquad (15)$$

For calculation we set 30-GHz RF carrier (f_{RF}) and wavelength 1550-nm laser (λ),B_{RF} = 25GHz,$\gamma_{RF_0} = \pi$, Dispersion parameter D=17 ps/nm · km.

IV. RESULTS

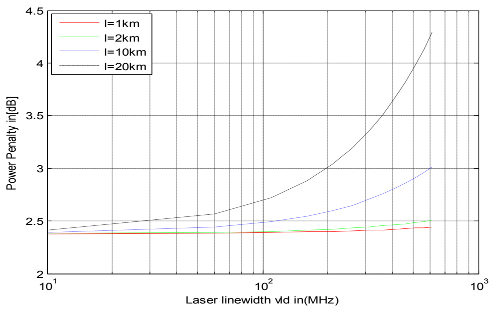

Fig.1

The result is shown in the Fig.2, Power penalty induced by the Differential delay from the fiber chromatic dispersion by varying laser linewidth at various optical distances increases exponentially. The Penalty are observed for laser line width from 10 to 624 MHz since 10 and 624 MHz are typical line width values of a distributed-feedback (DFB) laser and a Fabry–Pérot (FP) laser [20].Therefore, the RoF system relatively suffers from Power penalty for a long transmission, such as 30 km, while both are almost unchanged for the FP laser in the short-transmission case (=2 km). We can say 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 [21].

V. CONCLUSION & DISCUSSION

We can see that the Power Penalty due to the limits of the fiber chromatic dispersion in the standardsingle-mode fiber (SSMF) by the laser in the radio-over-fiber (RoF)system. In order to investigate the Power penalty we evaluate thepower spectral density (PSD) function, and the PSD function isidentical with the previous result in [12], when the phase noiseof the RF oscillator is 0.A practical laser having nonzero linewidthinduces penalty by the multiplication with nonzero differential delayin the RoF system that uses external modulation with a(DEMZM) dual-electrode Mach–Zehnder modulator and directdetection. However, the penalty due to the laser linewidthis much less than the penalty due to the RF-oscillatorlinewidth at short distance.The penalty comes from the power degradation due todifferential delay caused by fiber chromaticdispersion. The filter bandwidth at an electrical receivershould be selected carefully considering tradeoff between the penalty and required signal power ratio p, especially forp greater than 0.9, since the increase of bandwidth causes the increase ofnoise power. The penalty for the use of a 99% bandwidthfilter is 15.1 dB, as compared to the case using the half-power bandwidth.The penalty due to the FP laser linewidth is very small 2.4 dB in a microcell (2 km) even though it becomes relatively severe in a long distance (40 km).The long-haul transmission is different because the initial phase difference is not maintained at the end of the optical fiber anymore. The observed linewidth due to the laser at the PD will be twice that of an initial laser linewidth Φ_{LD} since the differential delay due to chromatic dispersion is much greater than the coherence time. Therefore, the phase noise processes of Φ_{LD} and $\Phi_{LD}(t+\tau_1)$ are completely uncorrelated [13]. In that case, the system performance will suffer from the laser linewidth in a long-haul case seriously while the laser-linewidth effect can be ignored in a short transmission.In conclusion, the bandwidth of an electrical filter at the receiver should be carefully chosen considering minimum required signal power ratio p at the same time.

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