A Time-Domain Analysis for Radio over Fiber System Considering the Phase Noise Effect due to RF Oscillator Linewidth

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ABSTRACT
With the aim of distribution of millimeter wave signals while merging of radio frequency and optical fiber technologies, A Radio over Fiber (RoF) system is taking under research and its time-domain analysis is used while considering the phase noise effect with a power spectral density (PSD) and autocorrelation function to its performance improvements. This analysis uses a dual-drive Mach-Zehnder modulator (DD-MZM) and photodetector (PD) for transmitted single sideband (OSSB) signal as the OSSB signal is tolerable for power degradation due to a chromatic fiber-dispersion effect. In time domain, we have shown the output current of PD is the function of Phase Noise from Laser linewidth and RF Oscillator linewidth. In this paper, we have calculate the received signal power with respect to the power spectral density (PSD), derive a closed-form of signal to noise ratio and shall analyse the bit error rate (BER) performance using different modulation scheme. In simulation results, we have illustrated the variation of signal to noise ratio with respect to RF Oscillator linewidth under different values of percentage of received power. Also, we shall observe the BER performance using different modulation scheme variation with RF Oscillator linewidth. Finally, we suggest the condition for choosing RF Oscillator linewidth for better performance of RoF system for its future implementation.

KEYWORDS
RF Oscillator, laser, linewidth, dual-drive Mach-Zehnder modulator (DD-MZM), optical single sideband (OSSB), oscillator, phase noise and power spectral density (PSD).

1. INTRODUCTION
It is predicted in future that the data traffic in Mobile and telecommunication networks will be growing from today three Exabyte a year to ninety Exabyte per year by 2015, where an Exabyte is equal to one million terabytes [1] -[3]. For the future provision of broadband, interactive and multimedia services over wireless media, current trends in cellular networks, both mobile and fixed are to reduce cell size to accommodate more users and to operate in the millimeter wave frequency and the radio frequency bands for wireless communication systems are shown in Table 1.1. In order to meet these explosive demands of users, Radio-over-Fiber system (RoF) will be considered and found to be the most promising solution to achieve effective delivery of wireless and baseband signals.

Table 1. Radio Frequency Bands for Wireless Communication Systems

Band No.	Frequency Subdivision	Frequency Range	Wavelength
4	VLF (very low frequency)	Below 30kHz	Greater than 10 km
5	LF (low frequency)	30 to 300kHz	10km to 1km
6	MF(medium frequency)	300 to 3000kHz	1km to 100m
7	HF(high frequency)	3 to 30MHz	100m to 10m
8	VHF(very high frequency)	30 to 300MHz	10m to 1m
9	UHF(ultra high frequency)	300 to 3000MHz	1m to 10cm
10	SHF(super high frequency)	3 to 30GHz	10cm to 1cm
11	EHF(extremely high frequency)	30 to 300GHz	1cm to 1mm

However, the main challenge of the signal transmission via RoF for a long distance is the phase noise effect due to laser linewidth and RF oscillator and chromatic dispersion in SMF at wavelength 1550nm that can limit the signal transmission. Therefore, it has been a matter of concern and interest to investigate the performance of RoF systems by using time domain analysis and find out how to enhance the performance cost effectively. In this paper, the Phase noise effect is considered due to RF oscillator linewidth.

2. ROF SYSTEM SIGNAL MODEL
RoF system is a technology that essentially integrates two worlds the radio and the optics. We proposed a RoF system signal model. This RoF systems model distribute an optically modulated radio frequency (RF) signal from a central station (CS) to a base station (BS) via an optical fiber link and the photocurrent corresponding to the transmitted RF signal is produced by the filter and this signal arrives at a mobile station (MS) through a wireless channel. An OSSB signal at base station (BS) is generated by using a Dual electrode Mach Zehender Modulator and a phase shifter [4], [6]-[7]. 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 LD with an DEMZM. The optically modulated signal is transmitted to the photodetector and the photocurrent corresponding to the

transmitted RF signal is extracted by the filter at the BS of RoF system. Figure 1 describes the overall architecture of an external modulator with OSSB modultion scheme based RoF system while considering control station, base station and mobile station [5], [8] and [9].

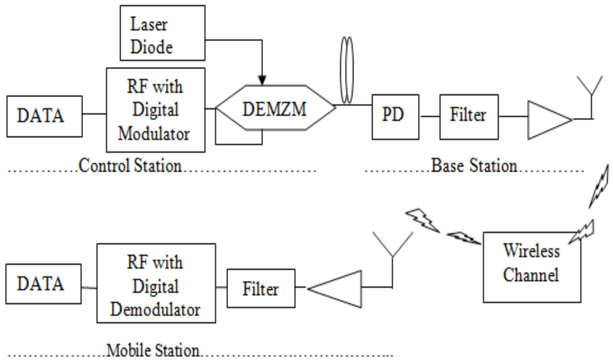

Fig. 1. The overall architecture of an external modulator based RoF system

3. ANALYTICAL TIME DOMAIN MODEL FOR ROF SYSTEM

Here, the optical signals from the optical source (laser diode) $x_o(t)$ and the RF oscillator signal, $x_d(t)$ operating at millimeter wave are modeled as follows:

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

$$x_0(t) = V_0 \exp j(w_0 t + \Phi_0 t)$$

Where A^d and V_o define amplitudes from the laser diode and the RF oscillator, w_d and w_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 transmitted from CS.

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

Where L_{MZM} is the insertion loss of the DEMZM. After the transmission of L_{fiber} in km standard single m ode fiber (SSMF), the signal is received at BS. By using a square-law model, the photocurrent $i(t)$ is as

$$i(t) \cong \eta \left[\begin{array}{l} A^d L_{MZM}.L_{add}.10^{\frac{\alpha_{fiber}.L_{fiber}}{20}}.J_0(\alpha\pi) \\ \left\{ \begin{array}{l} \exp j\left[w_d t + \Phi_d(t-\tau_0) - \phi_1 + \frac{\pi}{4} \right] - \\ \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)} \exp j \left[\begin{array}{l} w_d t + \Phi_d(t-\tau_0) \\ + w_0 t + \Phi_0(t-\tau_+) \\ -\phi_2 \end{array} \right] \end{array} \right\} \end{array} \right]$$

Where η defines the responsivity of the PD, 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 τ_0 and τ_+ define group delays for a center angular frequency of w_d and an upper sideband frequency of w_d + w_0. ϕ_1 and ϕ_2 are phase-shift parameters for specific frequencies due to the fiber chromatic dispersion. Now, we use the autocorrelation function and the PSD of the photocurrent and percentage of received power p between the total signal power and the required power is

$$p \cong \frac{2}{\pi}\left\{ \exp(-2\Upsilon_t|\tau|) \tan^{-1}\left(\frac{\pi B_0}{2\Upsilon_0} \right) \right\}$$

Where B_0 is the bandwidth of the electrical filter. Δv_d and Δv_0 are the linewidths for the laser and the RF oscillator, respectively, $2\Upsilon_d(2\pi\Delta v_d)$ and $2\Upsilon_0(\cong 2\pi\Delta v_0)$ define the angular full-linewidth at half maximum (FWHM) of the Lorentzian shape for the laser and the RF oscillator, respectively, and $2\Upsilon_t$ is related to the total linewidth (laser + RF oscillator). Note that the $2\Upsilon_t \equiv 2\pi\Delta v_d + \pi\Delta v_0$ and $\tau \approx (\tau_+ - \tau_0)$ is the differential delay due to the fiber chromatic dispersion and is dependent on the wavelength λ, the signal frequency f_o, the fiber chromatic dispersion D, and the optical transmission distance L_{fiber}.

Now, we evaluate the Signal to Noise (SNR) ratio considering signal power and noise power.

$$SNRratio \cong \frac{2\eta^2 A_1^d \alpha_1^2 p}{N_0.\left(\frac{\Upsilon_0}{\pi}\right)\tan\left(\frac{\pi.p\exp(-2\Upsilon_t|\tau|)}{2}\right)} \text{ W}$$

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

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

Finally, the BER performance is evaluted for BPSK/QPSK//4-QAM, DPSK and FSK using basic equation in terms of error function and signal to noise ratio.

4. ROF SYSTEM SIMULATION PARAMETERS

S.No.	Parameters	Value
1.	Fiber dispersion	17 ps/nm-km
2.	Optical transmission distance	1Km to 40 km
3.	RF signal frequency	30 GHz
4.	Wavelength of LD	1550 nm
5.	Half power bandwidth filter	0.5
6.	RF oscillator linewidth	0.1 to 20 Hz
7.	Laser linewidth	10 to 700 MHz
8.	Percentage of received power	0.5, 0.7, 0.9

5. NUMERICAL RESULTS AND DISCUSSION

The figure 2 illustates SNR ratio with respect to RF oscillator linewidth with laser linewidth 700MHz for diifferent percentage of received power range from 0.5 to 0.9. It is obseved that signal to noise ratio is having exponential decrement as per the RF oscillator linewidth varried from 0.5 to 5Hz. The signal to noise ratio are 70dB, 50 dB, 42 dB and 38 dB with value of percentage of received power 0.5, 0.7, 0.8 and 0.9 respectively. Thus, approximately 30 dB decrement in SNR is found out as per increment in percentage of received power from 0.5 to 0.9.

Therefore, the bandwidth on which percentage of received power depends should be selected carefully in a RoF system. The bit error rate (BER) performance of Radio over Fiber (RoF) system is illustrated in figures 3 and 4. The BER varies from 10^{-34} to 10^{-2} as RF Oscillator linewidth from 0.5 Hz to 5 Hz percentage of received power 0.5 and BER varies from 10^{-10} to 10^{-1} as RF Oscillator linewidth from 0.5 Hz to 5 Hz percentage of received power 0.9.

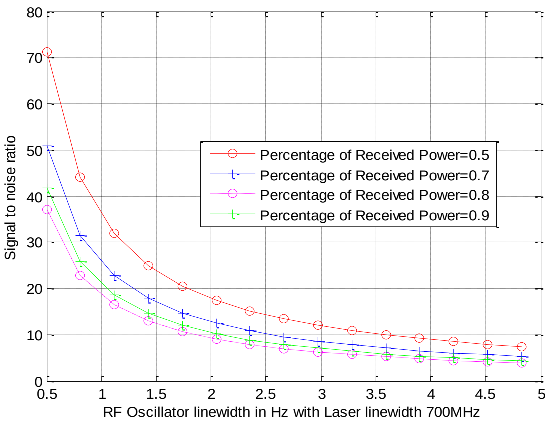

Fig. 2. Signal to Noise ratio with respect to RF oscillator linewidth with laser linewidth 700 MHz.

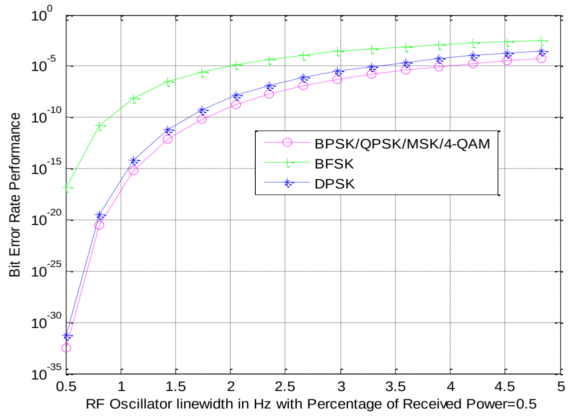

Fig. 3. Bit Error Performance with respect to RF oscillator linewidth with percentage of received power 0.5 and laser linewidth 700MHz.

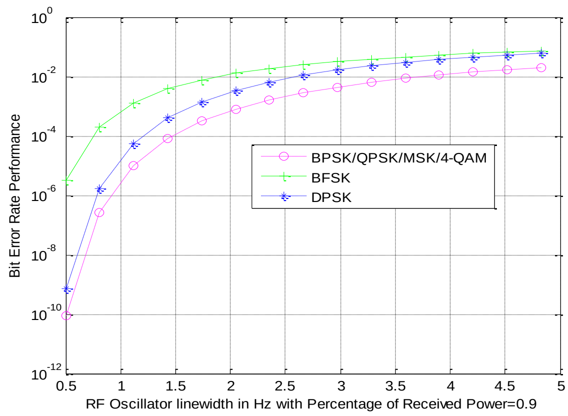

Fig. 4. Bit Error Performance with respect to RF oscillator linewidth with percentage of received power 0.9.

Thus, BER increases as per increment in RF Oscillator linewidth as well as percentage of received power. Also, it is found that BER is minimum for modulation scheme BPSK/QPSK/MSK/4-QAM in comparison with other modulation scheme.

6. CONCLUSION

In this paper, A time domain analysis for signal to noise ratio and bit error rate (BER) are investigate while considering the phase noise effect dur to RF oscillator linewidth. With simulation results and time domain analysis, we conclude that the signal to noise ratio is more sensitive to the phase noise from the RF oscillator and there is need for careful selection of electric bandwidth of filter that provides minimum percentage of signal power. Further, we investigate a BER performance of RoF system considering RF Oscillator linewidth under different modulation techniques. We have shown that BER performance of RoF system is increased as increment in the RF Oscillator linewidth. Also, it is also found that BER increases with the increment of percentage of Received power. In comparative analysis, modulation scheme BPSK/QPSK//4-QAM provides minimum BER rate. Finally, it is suggested that RoF system provides desired signal to noise ratio and better BER performance for RF Oscillator linewidth of 0.5 to 1Hz and percentage of received power 0.5. It may be predicted that RoF system part of future broadband system with better performance and successfully meet the explosive demand of users.

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