SNR Analysis of RoF Systems based on 64-QAM Including the Impact of Dispersion and Phase Noise

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ABSTRACT
In this paper, the performance of radio-over-fiber (RoF) links employing intensity modulation has been investigated in terms of signal to noise ratio (SNR). An analytical model including dispersion, laser and radio frequency (RF) oscillator phase noise is constructed to estimate the SNR performance for 64- quadrature amplitude modulation (QAM) based RoF systems. It has been observed that the RF oscillator line-width and laser line-width affect the SNR significantly. SNR decreases monotonously as the value of laser line width increases but for increased RF oscillator line widths specifically above 1Hz, the SNR degrades to a great extent [20 dB] which is not desirable for efficient communication system.

Keywords
RoF, SNR, QAM, Phase noise, Dispersion.

1. INTRODUCTION
Radio over fiber is becoming an increasingly attractive technology for implementing broadband in building wireless access coverage, such as in corporate office buildings, shopping malls and airports [1]. The direct modulation based scheme of generation is simple but suffers from a laser-frequency chirp effect leading to the performance degradation. External modulation scheme can be used to improve the system performance [2]. The conventional double sideband transmission technique is affected by fiber chromatic dispersion severely. Single side band (SSB) modulation can be used to overcome the deteriorating effects caused by chromatic dispersion. In a radio-over-fiber system which carries millimeter-wave (MM) signals, the chromatic dispersion limited transmission distance also gets extended by the use of SSB technique [3], whereas the radio-spectrum-limited capacity can be overcome by using multilevel modulation techniques such as *M*-ary quadrature amplitude modulation (M-QAM) techniques [4]–[6]. Regardless of the number of constellation points, all quadrature-amplitude modulation (QAM) signals can be generated using a single dual-drive Mach–Zehnder modulator [7]. The QAM signal generation is greatly simplified with the usage of only one dual-drive modulator. Multilevel modulation signals like QAM improve the spectral efficiency of a optical communication system. Here, an analytical model for the signal to noise ratio (SNR) for 64-QAM based RoF system has been developed including the impact of dispersion, phase noise from laser and RF oscillator.

2. THEORETICAL MODELING AND SNR ANALYSIS
The QAM signal consists of two phase quadrature carriers each of which is modulated by a set of discrete amplitudes. An M-array QAM signal can be generated using dual electrode Mach–Zehnder modulators (DE-MZM). The M-array QAM signal generated using dual electrode MZM is given as [7]:

$$\mathrm{E_{QAM}} = \frac{\mathrm{E_{in}}}{2}\left[\mathrm{e}^{\mathrm{j}\varphi_1} - \mathrm{e}^{\mathrm{j}\varphi_2}\right] \tag{1}$$

Where $\varphi_1 = \pi\frac{V_1}{V_\pi}, \varphi_2 = \pi\frac{V_2}{V_\pi} + \pi,$

Here, V_1 and V_2 are the signals from RF oscillator. The phase of V_1 and V_2 are carefully chosen to generate quadrature signal in the output. The RF signal is optically modulated by the laser source with an MZM. The optical signals from the laser and the RF oscillator are modeled as [8]:

$$\mathrm{x_{LD}}(\mathrm{t}) = A.\,\mathrm{e}^{\mathrm{j}[\mathrm{w_d t} + \emptyset_\mathrm{d}(\mathrm{t})]} \tag{1}$$

and

$$x_0(t) = V_0.\cos\ [w_0 t + \emptyset_0(t)] \tag{2}$$

where A_d , V_o are amplitudes from the laser source and the RF oscillator signal, ω_d is angular frequency of the laser signal, w_0 is the RF oscillator signal, $\emptyset_d(t)$, $\emptyset_0(t)$ are phase-noise processes. The electrical output of QAM signal generated using dual electrode MZM is modeled as [9]:

$$\mathrm{E_{QAM}}(0,\mathrm{t}) = A_d \mathrm{L_{MZM}}\left[\mathrm{J_0}(\beta\pi)\mathrm{e}^{\mathrm{j}[\mathrm{w_d t}+\emptyset_\mathrm{d}(\mathrm{t})+\frac{\pi}{4}]} - \sqrt{2}\,\mathrm{J_1}(\beta\pi)\mathrm{e}^{\mathrm{j}[\mathrm{w_d t}+\emptyset_\mathrm{d}(\mathrm{t})+\mathrm{w_0 t}+\emptyset_0(\mathrm{t})]}\right] \tag{3}$$

Where β is $\frac{V_0}{\sqrt{2}V_\pi}$, and

V_π is switching voltage of MZM, $\mathrm{L_{MZM}}$ is insertion loss

After the transmission of signal over a length of L km, the signal can be represented as:

$$\mathrm{E_{QAM}}\,(\mathrm{L,t}) = A_d \mathrm{L_{MZM}}\, \mathrm{L_{add}}\, 10^{\frac{\alpha L}{20}}\, \mathrm{J_0}(\beta\pi) \left[\mathrm{e}^{\mathrm{j}\left(\mathrm{w_d t} + \emptyset_\mathrm{d}(\mathrm{t}-\tau_0) - \emptyset_1 + \frac{\pi}{4}\right)} - \frac{\sqrt{2\mathrm{J_1}(\beta\pi)}}{\mathrm{J_0}(\beta\pi)} \mathrm{e}^{\mathrm{j}(\mathrm{w_d t} + \emptyset_\mathrm{d}(\mathrm{t}-\tau_+) + \mathrm{w_0 t} + \emptyset_0(\mathrm{t}-\tau_+) - \emptyset_2)} \right] \tag{4}$$

where L_{add} is additional loss in the optical link, α is standard single mode fiber loss, L is transmission distance, τ_0 and τ_+ are group delays for center angular frequency $(\mathrm{W_d})$ and upper sideband frequency $(\mathrm{W_d}+\mathrm{W_0})$, $\emptyset_1$ and $\emptyset_2$ are phase-shift parameters for specific frequencies due to the chromatic dispersion.

The power signal received at the receiver based on power spectral density function is given as :

$$P_{rcd} \cong \frac{4r^2{\alpha_1}^2{A_D}^4}{\pi} e^{-2\gamma_t\tau}.\tan^{-1}\left(\frac{\pi B_0}{2\gamma_0}\right) \tag{5}$$

Where r is the resposivity, γ_t is total line-width, $2\gamma_t = 2\gamma_d + 2\gamma_o$, γ_d *is* $\pi\Delta_d$, $\gamma_o/2$ is $\pi\Delta_o$, Δ_d is laser line-width, Δ_o is RF oscillator line-width, α_1 is the loss due to normalized RF voltage, A_D is a constant dependent on laser source amplitude and losses, B_0 is electrical filter bandwidth and τ is the differential delay due to the chromatic dispersion which is given as:

$$\tau = DL\lambda^2(f_o/c) \tag{6}$$

Where D is dispersion parameter, L is the transmission distance, λ is the operation wavelength and f_o is the carrier frequency.

Signal to noise ratio (SNR) of the system can be given as:

$$SNR = \frac{Signal\ \ Power}{Noise\ \ Power}$$

$$SNR = \frac{2r^2{A_D}^4{\alpha_1}^2 p}{N_a \frac{\gamma_{RF}}{\pi} \tan\ \left[\frac{\pi}{2}.p.\exp\left(2\gamma_t\tau\right)\right]} \tag{7}$$

Where p is the percentage of power received, N_a is the additive white gaussian noise power spectral density.

3. RESULTS AND DISCUSSION

The impact of phase noise due to laser line-width and RF oscillator line-width on SNR has been studied in the presence of dispersion. Simulations have been carried out for 64-QAM signal generated through DE-MZM. Table 1 summarises various simulation parameters selected to study the impact of dispersion and phase noise on SNR.

Table 1: Simulation Parameters for obtaining SNR

Responsivity (r)	0.7 A/W
Switching Voltage (V_π)	2.5 V
AWGN Noise	10^{-11}
Dispersion Parameter (D)	17 ps/km.nm
Fiber Loss (α)	0.2 dB/km

Fig. 1 shows the variation of the SNR with laser line-width for 64-QAM signal. The SNR is plotted against laser line-width varying from 0 to 600 MHz for four different values of RF oscillator line-width i.e. 0.5 Hz, 0.8 Hz, 1 Hz and 1.2 Hz. The graph has been drawn for a 10 km transmission distance including the impact of dispersion of 17 ps/km.nm. It can be seen that SNR decreases monotonously with increase in the laser line-width at defferent values of RF line-width. SNR decreases from 15.1 dB to 13.9 dB when laser line-width is varied from 0 to 600 MHz for 0.5 Hz RF line-width. It can be seen from the graph that laser possessing line-width upto 10 MHz and RF oscillator upto 1 Hz are desirable for a 10 km transmission distance.

The effect of the RF line-width on the SNR of the system is shown in Fig. 2. The results obtained show an exponential decrement in SNR with the increase in RF line-width. Plots have been drawn for different values of laser line-width i.e. 100 MHz, 300 MHz and 600MHz including the impact of dispersion 17 ps/km.nm. It can be found from the results that good quality communication is achievable upto RF line-width value of 1 Hz. After this SNR performance degrades very badly. For the 5 Hz RF line-width, the SNR decreases further.

4. CONCLUSION

The effect of the phase noise induced from the laser line-width and the RF oscillator line-width on the SNR of the 64-Ary QAM RoF systems has been studied. In most of the light wave communication systems, the lower threshold for the SNR is less than 10 dB. If the SNR decreases below this value, the link does not support high quality multimedia services. Greater the phase noise, the more is noise penetration into the system and hence poorer is the SNR. The effect of the RF oscillator line-width on the system SNR is also studied. To achieve better SNR performance, the RF oscillator line-width should be below 1 Hz. This means we need to use highly stable RF oscillators. It can also be depicted that for RoF links, the effect of the RF oscillator line-width on the system SNR is more pronounced than that of the laser line width.

5. REFERENCES

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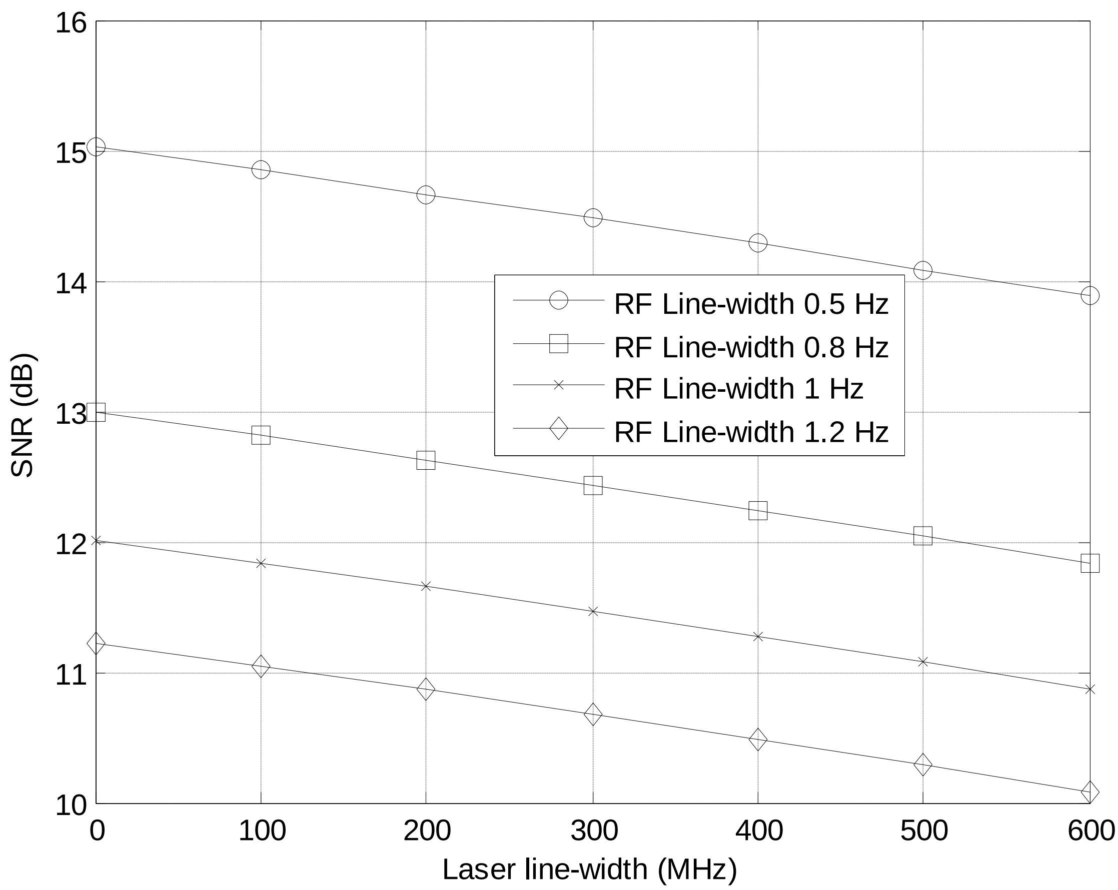

Fig 1: SNR as a function of laser line-width for varying RF line-width

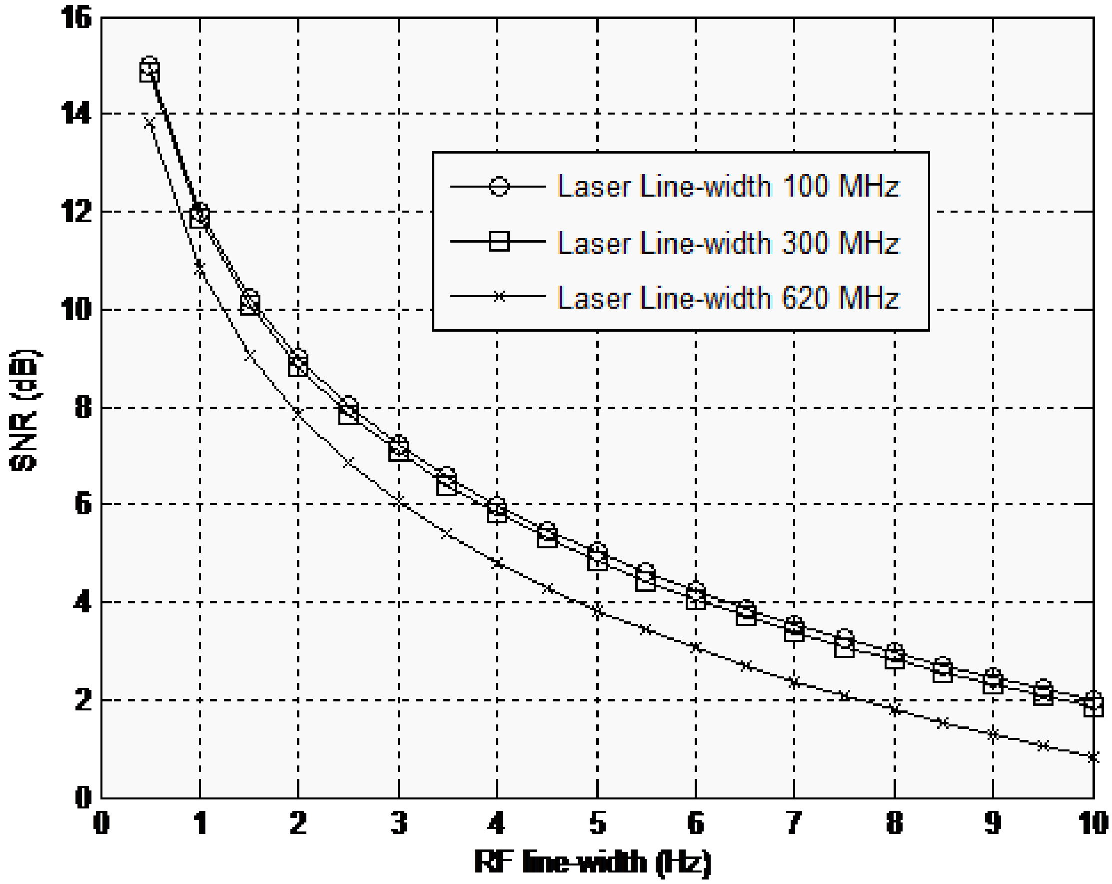

Fig 2: SNR as a function of RF Line-width varying laser line-width