

# Performance Evaluation of Radio-over-Fibre Systems Using Mach-Zehnder Modulator

A. Bahrami<sup>1</sup>, *Student member, IEEE*, T. Kanesan<sup>1</sup>, *Student member, IEEE*, W. P. Ng<sup>1</sup>, *Senior member, IEEE*,  
Z. Ghassemlooy<sup>1</sup>, *Senior member, IEEE*, C. Qiao<sup>2</sup>, *Senior member, IEEE*

<sup>1</sup> Optical Communications Research Group, NCRLab, Northumbria University, Newcastle upon Tyne, UK, <sup>2</sup> University at Buffalo The State University of New York, USA

**Abstract:** This paper investigates the bit error rate (BER) performance of a radio-over-fibre (RoF) system utilizing the binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) at a radio frequency (RF) of 5 GHz. The RF signal is externally modulated using the Mach-Zehnder modulator (MZM). The effects of noise sources and channels for the RoF link at distances of 30, 60, 90, 120 and 200 km are investigated. We shown that the RoF system offers lower BER performance compared to the RF wireless communication system employing the same modulation schemes.

## 1. Introduction

RoF refers to a technique where light is modulated by a radio signal and transmitted over an optical fibre link to facilitate wireless access. RoF system has been designed to improve the performance of a radio system by providing higher bandwidth for mobile communications. RoF systems have several advantages including lower attenuation compared to the coaxial cable [1], higher bandwidth [2], immunity to the RF interference, and durability [3].

In this paper the BER performance of a RoF system at a carrier frequency of 5 GHz employing BPSK and QPSK modulation schemes and the external Mach-Zehnder modulator (MZM) [4] over the distances of 30, 60, 90, 120 and 200 km have been modelled to investigate the effect of noise, attenuation and the chromatic dispersion. The results have been compared to a RF wireless communication system with the Rayleigh fading channel and the additive white Gaussian noise (AWGN).

## 2. RoF System

Figure 1 illustrates the block diagram of the RoF system investigated in this paper. It consists of a central office (CO) connected to a base station (BS) via a single mode fibre (SMF). At the CO the modulating electrical signal,  $x_{RF}(t)$  (1) is split into its in-phase and quadrature-phase components,  $x_i(t)$  and  $x_q(t)$ , respectively via a 3 dB splitter.

$$x_{RF}(t) = V_{RF} \cos(\omega_{RF}(t) + \theta(t)) \quad (1)$$

where  $V_{RF}$  is the electrical signal amplitude in volts,  $\omega_{RF}(t)$  is the electrical carrier frequency defined as  $2\pi f_{RF}$ , and  $\theta(t)$  is the signal phase in radians. The output of MZM which is denoted as  $y_R(t)$  as shown in (2) [4]:

$$y_R(t) = \frac{V_{LD}}{\sqrt{2} \times 10^{L_M/20}} \times \left( \exp \left( j \left( \omega_c(t) + \gamma\pi + \Phi_{in}(t) + \frac{x_i(t)}{\sqrt{2}} \right) \right) + \exp \left( j \left( \omega_c(t) + \Phi_{in}(t) + \frac{x_q(t)}{\sqrt{2}} \right) \right) \right), \quad (2)$$

where  $V_{LD}$  is the laser source voltage in mV,  $L_M$  is the insertion loss of MZM,  $\omega_c(t)$  is the optical carrier frequency,  $\gamma = V_{dc}/\sqrt{2} \times V_\pi$ , is defined as the normalized direct current (dc) voltage,  $V_{dc}$  and  $V_\pi$  is the threshold voltage and switching voltage for MZM in volts respectively. In order to obtain an optical single sideband (OSSB) signal from the MZM output, the value of  $\gamma$  should be 0.5.  $\Phi_{in}(t)$  is the phase difference of optical carrier within MZM in radian.

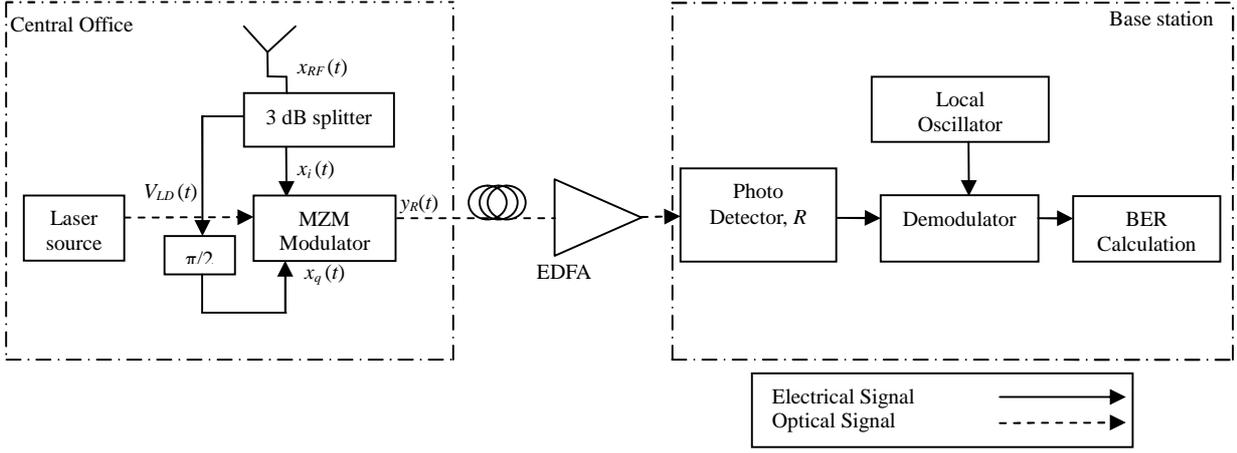


Figure 1: RoF system block diagram using MZM.

The received signal is amplified using an erbium doped fibre amplifier (EDFA) preamplifier prior to being converted back into electrical format using a photodetector (PD).

The photocurrent generated at PD is given by [4]:

$$i(t) = R |y_R(t)|^2 + n_{th}(t), \quad (3)$$

where  $R$  is the responsivity [5] and  $n_{th}(t)$  is the total noise current due to the thermal noise, shot noise, signal-to-spontaneous beat noise, and spontaneous-to-spontaneous beat noise [6].

All system noise sources have been represented with Gaussian probability density functions as the stochastic process of the noise [7],[8]. Thermal noise and shot noise could affect the performance of communication systems significantly. In this paper, thermal noise, shot noise, signal-to-spontaneous beat noise and spontaneous-to-spontaneous beat noise are taken into account [9].

### 3. RF Wireless Communication Channel

Higher data rate transmission in wireless communication systems is limited by multipath fading [10]. Increasing the quality of the system or reducing the BER in a multipath fading channel is extremely complex in mobile communication systems [11]. In the presence of the AWGN channel, using typical modulation schemes and coding, the BER performance can be improved (i.e. from  $10^{-2}$  to  $10^{-3}$ ) by increasing the signal-to-noise ratio (SNR) (i.e. 1 or 2 dB). However in fading environment the same improvement may require additional 10 dB of SNR [11]. The Rayleigh channel represents the fading effect when there is no line-of-side (LOS) between the CO and BS [10]. In this paper the propagation loss has been modelled with the free space propagation loss model (FSPL) between the CO and BS [10].

### 4. Results and Discussions.

Table 1: Parameter definition

Parameter	Symbol	Value	Unit	Parameter	Symbol	Value	Unit
Electrical signal amplitude	$V_{RF}$	1	V	Normalized direct current	$\gamma$	0.5	
Electrical carrier frequency	$f_{RF}$	5	GHz	Threshold voltage	$V_{dc}$	1.7677	V
Signal phase	$\theta(t)$	0	rad	Switching voltage	$V_{\pi}$	2.5	V
Laser source voltage	$V_{LD}$	3.2	mV	Phase difference of optical carrier	$\Phi_{in}$	0	rad
Insertion loss	$L_M$	6	dB	Responsivity	$R$	0.9	A/W
Optical carrier frequency	$\omega_c$	193	THz				

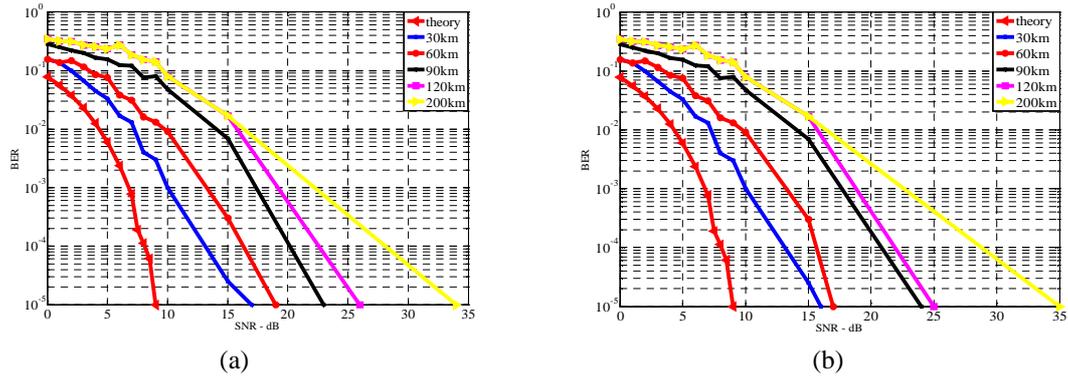


Figure 2: BER performance against the SNR for RoF system for a range of link range over the Rayleigh channel (a) BPSK and (b) QPSK

As it has been illustrated in figure 2, the BER performance degraded from  $10^{-3}$  to  $10^{-1}$  when the distance increases from 30 to 200 km. As shown in the figure, the simulated BER performance for all link range values are higher than the predicted curve due to the multipath fading effect occurs in wireless communication systems and depicted as Rayleigh fading effect. In wireless communication systems for uncoded data the required BER is  $10^{-5}$  [12]. In order to achieve the BER of  $10^{-5}$ , the minimum SNR value is 15 dB and for 200 km it increases to 34 dB.

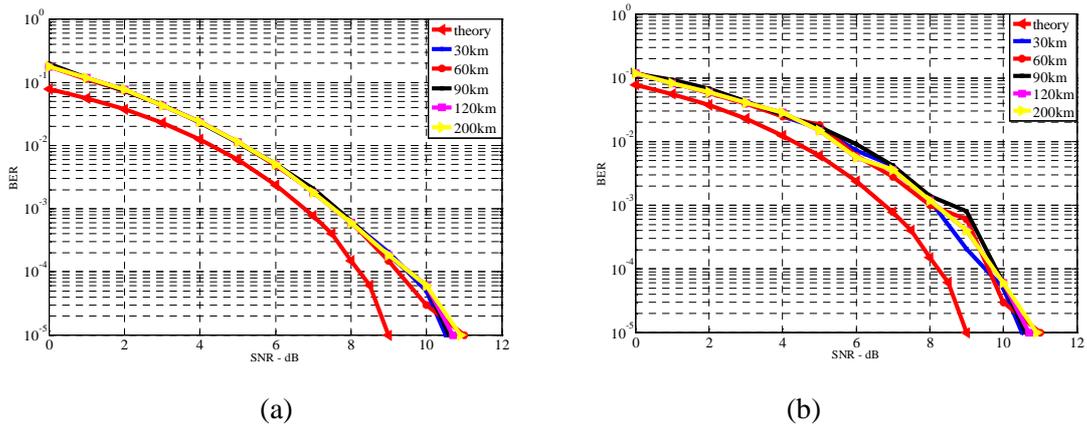


Figure 3: BER performance against the SNR for RoF system for a range of link over fibre for (a) BPSK and (b) QPSK

In figure 3, the BER plot is almost the same for all link range values for BPSK and QPSK. The two simulated curves plotted in figure 3 are above the theoretical curve due to the noise effects which have been taken into the consideration. Although the noise in the system degrades the performance of the RoF link, the degradation level is far less than the degradation of RF wireless communication systems.

For the RoF system, the SNR required to achieve the BER of  $10^{-5}$  at a distance of 200 km is 10.9 dB. The SNR penalty for the RF wireless communication system to achieve the same BER of  $10^{-5}$  is 25 dB compared 1.9 dB for the RoF system.

## 5. Conclusions

In this paper the performance of RoF system using BPSK and QPSK modulation schemes have been evaluated in terms of the BER and are compared to the RF wireless communication systems. We have shown that the effect of the fading channel in the RF wireless communication system is more severe compared to degradation of optical fibre in the RoF system. In the RoF system the SNR penalty is less than 2 dB for BER of  $10^{-5}$  for both modulation schemes. By comparing the results of BER values in RF wireless communication system with RoF communication system using theoretical curve as the reference point, RoF has far less degradation in BER values by  $10^{-3}$  in average. In order for RF wireless communication systems to achieve the BER value of  $10^{-5}$ , the SNR penalty is 25 dB for the distance of 200 km. Therefore, RoF communication systems are better alternative compared to RF wireless communication systems.

## References

- [1] N. Uesugi, T. Horiguchi, M. Nakazawa, and Y. Murakami, "Optical Fiber Cable Measurements in the Field," *IEEE Journal on Selected Areas in Communications*, vol. 4, pp. 732-736, 1986.
- [2] M. Sauer, A. Kobaykov, J. E. Hurley, and J. George, "Experimental Study of Radio Frequency Transmission over Standard and High-Bandwidth Multimode Optical Fibers," in *International Topical Meeting on Microwave Photonics*, pp. 99-102, 2005.
- [3] R. J. Green, "Secure Communications: The Infrared Alternative," in *ICTON Mediterranean Winter Conference, 2007. ICTON-MW 2007*, pp. 1-4, 2007.
- [4] C. Tae-Sik, Y. Changho, S. Jong-In, and K. Kiseon, "Analysis of CNR Penalty of Radio-over-Fiber Systems Including the Effects of Phase Noise from Laser and RF Oscillator," *Journal of Lightwave Technology*, vol. 23, pp. 4093-4100, 2005.
- [5] G. Wang, Y. Yoneda, I. Hanawa, H. Aono, K. Araki, M. Takechi, Y. Momma, T. Odagawa, T. Fujii, K. Sato, and M. Kobayashi, "Highly Reliable High Performance Waveguide-Integrated InP/InGaAs PIN Photodiodes for 40 Gbit/s Fibre-Optical Communication Application," *Electronics Letters*, vol. 39, pp. 1147-1149, 2003.
- [6] I. Keigo, "Elements of Photonics, For Fibre and Integrated Optics". New York: John Wiley & Sons, Ins. 2002.
- [7] H. Nyquist, "Thermal Agitation of Electric Charge in Conductors," *Physical Review*, vol. 32, p. 110, 1928.
- [8] G. Keiser, "Optical Fibre Communication". McGraw-Hill Education (India) Pvt Ltd, 2008.
- [9] M. S. Ab-Rahman, M. F. Ibrahim, and A. A. A. Rahni, "Thermal Noise Effect in FTTH Communication Systems," in *Telecommunications, 2008. AICT '08. Fourth Advanced International Conference on*, pp. 364-370, 2008.
- [10] T. K. Sarkar, J. Zhong, K. Kyungjung, A. Medouri, and M. Salazar-Palma, "A Survey of Various Propagation Models for Mobile Communication," *Antennas and Propagation Magazine, IEEE*, vol. 45, pp. 51-82, 2003.
- [11] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE Journal on Selected Areas in Communications*, vol. 16, pp. 1451-1458, 1998.
- [12] G. R. Aiello and G. D. Rogerson, "Ultra-Wideband Wireless Systems," *Microwave Magazine, IEEE*, vol. 4, pp. 36-47, 2003.