Tackling Nonlinearity in Cost Effective Radio over Fibre

A Awoye, M S Leeson and R J Green

School of Engineering, University of Warwick, Coventry, CV4 7AL

Abstract: Analogue Modulation techniques, such as subcarrier multiplexing (SCM), are receiving much attention due to the advantage of centralised signal processing utilising a single wavelength combined with huge fibre bandwidth capability. Nonlinearity in the system, especially the E/O converter device, tends to be a limiting factor affecting the dynamic range capabilities of the system in terms of the intermodulation distortion (IMD) produced. A review of fibre optic system performance is presented with methods used to combat their IMD problems.

1. Introduction

The increase in demand for high bandwidth data in radio communications has led to the use of spectrally-efficient techniques such as Quadrature Amplitude Modulation (QAM), Quadrature Phase Shift Keying (QPSK) and Multi-carrier configurations for transmitting information. In Radio over Fibre (ROF) techniques such as subcarrier multiplexing (SCM), a single wavelength is used to transmit multiple signals that are multiplexed in the radio frequency (RF) domain. A significant advantage is obtained when SCM is combined with wavelength division multiplexing (WDM) technology to make use of the optical bandwidth capability of the fibre. In order to minimize the impact of fibre chromatic dispersion, optical single-sideband (OSSB) modulation is used [1], increasing the bandwidth efficiency.

The low dispersion, low loss and lightweight capability of optical fibre compared with electrical media have made it an excellent choice for the transmission of RF signals into the millimetre wave region. As the fibre is a dielectric, it is free from the effects of electromagnetic interference (EMI), unaffected by large electromagnetic pulses and can be closely confined with negligible crosstalk [2]. Fibre optic technology has recently seen a growth in applications utilising analogue point-to-point links that distribute RF signals in antennae (remoting applications) [3], cellular communications [4] and subcarrier cable television distribution networks [5]. The demand for broadband access has also led to interest in distributing signals capable of supporting systems operating in the microwave bands used for provision of UMTS and HiperLAN services. In fact, a major current objective of the telecommunications industry, is not only to provide voice and data services but also provide video services where applicable using economically viable techniques. A high degree of flexibility and upgradability must also be available so as to meet the high consumer demand for broadband access. This technological requirement has recently been met with the provision of high definition television (HDTV) by most of the cable television network operators.

Vertical cavity surface emitting lasers (VCSELs) as optical sources are receiving much attention, due to their economical and manufacturing advantages over edge emitting lasers, especially when combined with applications utilizing high bandwidth multimode fibre [6], [7]. The smaller cavity volume results in lower maximum optical power output, and these characteristics restrict the usefulness of VCSELs in high performance links to RF applications utilizing short optical links, making them suitable candidates for indoor distributed antennae systems.

The aim of this paper is to review the performance of RF fibre optic links in terms of the system characteristics. Section 2 will discuss the typical modulation methods employed with the associated components used in the transmission of RF signals. Section 3 will describe the issue of nonlinearity, the effect it has on system performance and also the techniques employed in compensating these problem. Section 4 will present the conclusions.

2. Fibre Optic Link

The basic fibre optic link consists of the required hardware (drive, matching and control circuitry) used to impose the RF signals onto the optical carrier for transmission over the fibre to the receiver, where the RF signals are recovered from the optical carrier. The optical carrier wavelength is usually made to coincide with the low dispersion or low loss windows of the optical fibre, depending on the required applications.

2.1 Transmission process

Two common methods exist for signal transmission from the optical carrier to the detector.

Direct modulation: In this technique the signal is imposed onto to the laser bias current, resulting in intensity modulated optical carrier. The simplicity of this method has been demonstrated in various RF analogue fibre links over some years [2].

External modulation: This technique makes use of separate devices that act as optical sources and RF or optical modulators. A laser operated in continuous wave mode modulates the RF signal to be transmitted. Two commonly used external modulators in RF optical links are the Mach-Zehnder interferometric (MZI) and electro-absorption (EA) modulator. The modulation capability of this technique is much greater than that of directly modulated links, with 3 dB bandwidths of 70 GHz [8] and 60 GHz [9] having been demonstrated for MZI and EA devices respectively.

2.2 Detection process

The intensity of the transmitted RF signal guided by the optical fibre is detected with the aid of a suitable photodetector and such a process is commonly referred to as intensity-modulation direct-detection (IM/DD). A simple block diagram illustrating the IM/DD process in analogue optical links is shown in Figure 1. Due to its relative simplicity, IM/DD [10] is widely used compared to techniques employing coherent detection, as these methods tend to be more complex [11].

2.3 Link characteristics

The direct modulation technique is the preferred modulation method due to its relative simplicity and low cost. The link gain in this technique is increased by utilising a laser with high slope efficiency. Alternatively, impedance-matching circuits may be inserted both between the RF source line and the modulation device and between the detector and the load output. It is also possible to employ a combination of both approaches. Noise within the link can limit the performance of the system, especially in distributed antennae applications. In IM/DD links, the main sources of noise include laser relative intensity noise (RIN), shot noise from the optical detection process, thermal noise of the RF source, modulation device, optical detector and any interconnecting circuit between the RF source and output load of the link. In general, laser RIN dominates over the shot noise and thermal noise processes [10], and can greatly degrade the link performance.

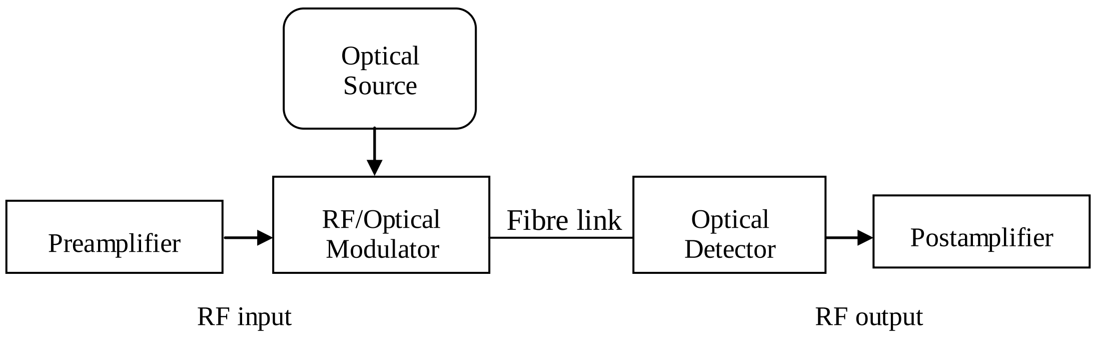

Figure1. Intensity-modulation direct-detection optical link.

3. System nonlinearity and compensation

In a directly modulated link, nonlinearity arises in the optical source from the static nonlinearity associated with the light-current characteristics, the dynamic nonlinearity associated with the electron-photon interaction and overmodulation due to clipping-induced distortion. Here it is assumed that the source is kept within the range where clipping is not significant, leaving the other two inherent causes as the main targets.

Non-constant envelope modulation schemes, such as those mentioned in section 1, are of great interest, as they are spectrally efficient but impose a strict linearity requirement on the optical source. When transmitting a multi carrier frequency signal through the optical source, transmitter nonlinearity produces harmonic and intermodulation distortion (IMD) products. In ROF systems, where the bandwidth of a single optical source can be used for the allocation of several services, some of these products fall within the transmission band, and can degrade the system performance.

Linearisation techniques are often employed to improve the system performance [12],[13]. The two main methods used to improve linearity are feedforward and predistortion. *Feedforward* techniques require the use of an extra optical transmitter to achieve linearisation thereby making the process more complex [14]. An economical viable solution called *predistortion* utilises the laser's nonlinear transfer function to distort the input signal by placing a nonlinear device of opposite nonlinearity before the laser input. This has the effect of creating an opposing IMD product of equal amplitude and opposite phase to that produced by the laser. Digital predistortion is often based on look-up table algorithms and tends to be more complex [15]. Analogue predistortion is a simpler alternative and is capable of handing larger signal bandwidths in adaptive architectures [16]. An open loop generic structure of a predistortion block is shown in figure 2.

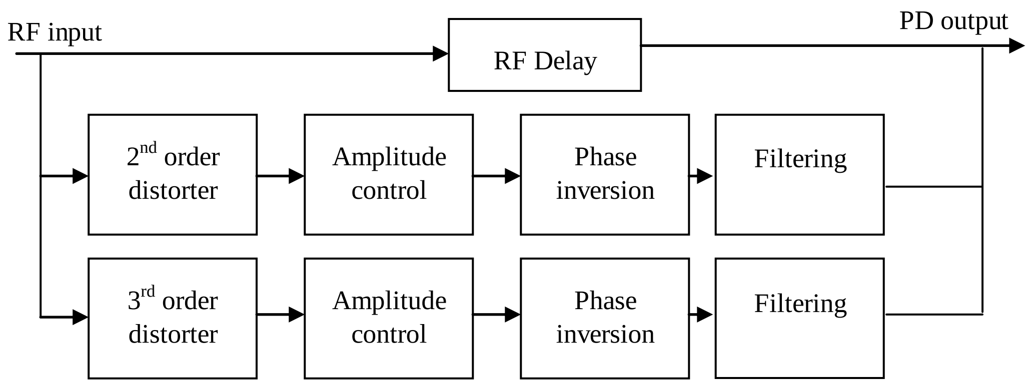

Figure2. Generic structure of a predistorter.

In this work, a memoryless polynomial work function capable of adjusting to changes in the laser device, based on the spectrum monitoring of a sacrificial channel is considered for the provision of a suitable solution. A threshold condition can be set up which feeds in the optimised coefficients into the predistorter block through the measurements in the adjacent channel emission band, in conjunction with a training sequence. To accommodate more general distortion, techniques from Intelligent Systems, such as neural networks in combination with fuzzy logic (neuro-fuzzy systems) [17], offer a good method of adaptation. The general dynamic structure is shown in figure 3.

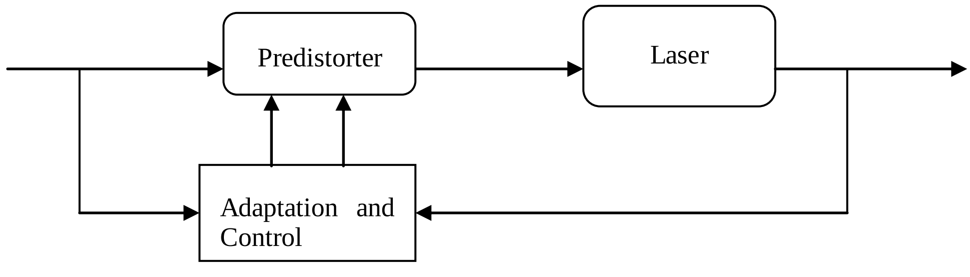

Figure3. Dynamic architecture.

4. Conclusions

This paper has presented the reasoning behind the utilisation of ROF and the employment of VCSELs in such systems. The fundamental properties of the ROF fibre link were briefly described leading to the introduction of the reasons for nonlinear behaviour. The linearisation options to ameliorate IMD products were reviewed with an outline of their pros and cons. Adaptive predistortion was introduced as a technique capable of improving the link dynamic range. In the next stage of this work, adaptive predistortion schemes based on neuro-fuzzy schemes will be developed for ROF VCSEL systems.

References

[1] R. Hui, B. Zhu, R. Huang, C. T. Allen, K. R. Demarest and D. Richards, “Subcarrier multiplexing for high-speed optical transmission,” Journal of Lightwave Technology, vol. 20, no. 3, pp. 417-427, 2002.

[2] W. E. Stephens and T. R. Joseph, “System characteristics of direct modulated and externally modulated RF fiber-optic links,” Journal of Lightwave Technology, vol. 5, no. 3, pp. 380-387, 1987.

[3] E. I. Ackerman and C. H. Cox III, “RF fiber-optic link performance,” IEEE Microwave Magazine, vol. 2, no. 4, pp. 50-58, 2001.

[4] M. Sauer, A Kobyakov and J. George, “Radio over fiber for picocellular network architectures,” Journal of Lightwave Technology, vol. 25, no. 11, pp. 3301-3320, 2007.

[5] T. E Darcie and G. E. Bodeep, “Lightwave subcarier CATV transmission systems,” IEEE Transactions on Microwave Theory and Techniques, vol. 38, no.5, pp. 524-533, 1990.

[6] R. Michalzik, G. Giaretta, A. J Ritiger and Q. L Williams, “10 Gbit/s VCSEL based data transmission over 1.6 km of new generation 850nm multimode fiber,” IEEE Lasers and electro-optical Society, San Francisco, CA, USA, 1999.

[7] C. Carlsson, A. Larsson and A. Alping, “ RF transmission over multimode fibers using VCSELs-comparing standard and high-bandwidth multimode fibers,” Journal of Lightwave Technology, vol. 22, no. 7, pp. 1694-1700, 2004.

[8] K. Noguchi, O. Mitomi, and H. Miyazawa, “Millimeter-wave $TiLiNbO_3$ optical modulators”, Journal of Lightwave Technology, vol. 16, no.4, pp. 615-617,1998.

[9] W. Bridges, F. Sheehy and J. Schaffner,“Velocity-matched electro-optic modulator”, Society of photo-optical instrumentation engineers, vol. 1371, pp. 68-77, 1991.

[10] C. H. Cox III, E. I. Ackerman, G. E. Betts and J. L. Prince, “Limits on the performance of RF-over fiber links and their impacts on device design”, IEEE Transactions on Microwave Theory and Techniques, vol. 54, no. 2, pp. 906-920, 2006.

[11] A. Seeds, “Optical transmission of microwaves”, in Review of Radio Science 1993-1996, W. R. Stone, Ed., London, U.K: Oxford University Press, pp. 325-360, 1996.

[12] R. Sadhwani and B. Jalali, “Adaptive CMOS predistortion linearizer for fiber-optic links”, Journal of Lightwave Technology, vol 21, no. 12, pp. 3180-3193, 2003.

[13] D. Hassin and R. Vahldieck, “Feedforward linearization of analog modulated laser diodes-theoretical analysis and experimental verification”, IEEE Transactions on Microwave Theory and Techniques, vol. 41, no.12, pp. 2376-2382, 1993.

[14] L. Fock, A. Kwan and R.S. Tucker, “Reduction of semiconductor laser intensity noise by feedforward compensation: experiment and theory,” Journal of Lightwave Technology, vol. 10, no. 12, pp. 1919-1925, 1992.

[15] H. Moon and R. Sedaghat, “FPGA-based adaptive digital predistortion for radio-over-fibre links,” Microprocessors and Microsystems 30, pp. 145-154, 2006.

[16] S. P. Stapleton, “Amplifier linearization using adaptive RF predistortion,” Applied microwave and wireless journal, pp. 40-46, 2001.

[17] H.-M. Deng, S.-B. He and J.-B. Yu, “An adaptive predistorter using modified neural networks combined with a fuzzy controller for nonlinear power amplifiers,” International Journal of RF and Microwave Computer-Aided Engineering, vol.14, no.1, pp. 15-20, 2004.