Improved laser dynamic range using feed-forward linearisation in a Radio over Fibre system for WLAN

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Abstract – This paper outlines an approach to optical feed-forward linearisation technique to reduce nonlinear distortion generated by a directly modulated semiconductor laser diode for application in Radio-over-Fibre Wireless Local Area Network (WLAN) operating in the 5.2 GHz band (IEEE802.11a). Suppression of greater then 26 dB for intermodulation distortion is achieved at 5.2 GHz and an improvement of 15 dB in dynamic range with feed-forward.

1. Introduction

The demand for higher data rate is continuously rising for broadband mobile services such as Wireless LAN. Higher bandwidth is required to support the increased demand for broadband services resulting in transmission of signals at microwave and mm wave due to congested spectrum at lower frequencies. The Industrial Scientific Medical (ISM) band at 2.4 GHz is used for the IEEE802.11b wireless LAN to support data rates of up to 11 Mbps. Higher frequency band at 5.2 GHz is to be used for the IEEE802.11a standard and Hiperlan supporting data rates of up to 54 Mbps. Radio over fibre (ROF) is the most suitable technology to realize these wireless network infrastructures and provides a low cost configuration, because the optical modulated signals are transmitted to the base station through fibre without significant loss and reach the mobile user via RF transmission allowing greater mobility. Figure 1 shows the configuration of a wireless network based on a ROF link.

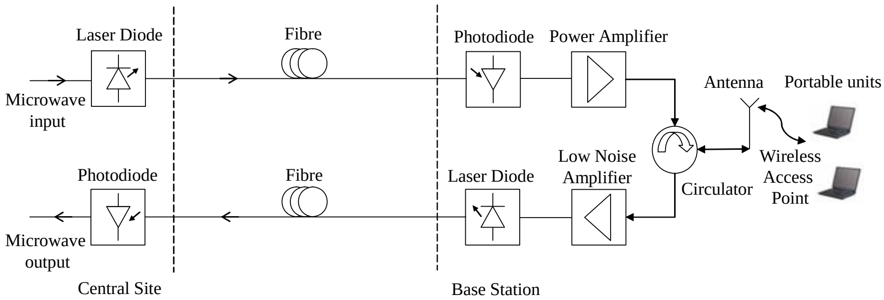

Fig. 1. Illustration of a radio-over-fibre system

Direct modulation of the laser diode is a simple, low cost approach for transmitting microwave signals. However, nonlinear distortion introduced by the directly modulated laser diode can limit the performance of the system considerably. In a low RF frequency range, static distortion which is caused by the nonlinear light-versus current characteristic of laser diode is dominant. At high frequency dynamic distortion due to nonlinear interaction of electrons and photons in the active layer of the laser diode is dominant and depends on the modulation frequency. Any non linear distortion generated by the semiconductor laser such as intermodulation distortion can give rise to interchannel interference which degrades the quality of the received signal.

In this work, feed-forward linearization is used to reduce these nonlinear distortion products with potential applications in radio-over-fibre wireless LAN. By suppressing the third order intermodulation distortion (IMD3), the dynamic range of the overall link is improved.

2. Background

If the input consists of two sinusoid signals with different frequency then third order intermodulation distortion signals are generated very close to the operating channels which are difficult to remove using filters. The magnitude of the 3^{rd} order signals can be large and can not be ignored. These undesired output frequency components produce distortion and degrade system performance.

Several techniques have been used to improve the linearity of semiconductor lasers using Opto-electronic Feedback technique, Predistortion and feed-forward linearization. Optoelectronic feedback

[1] can be used to reduce distortion in a same way as electronic feedback but the limitations are that the loop delay must be very small and this limits the maximum frequency of operation.
Predistortion is a simple linearization technique and utilizes a non linear device which generates distortion products that are equal in amplitude but opposite in phase compared to that of the transmitter. This results in the overall system that is much more linear. This technique has been widely used in linearising LEDs [2], laser transmitters for CATV [3] and radio over fibre systems for 0.4 – 2 GHz [4].
The Pre-distortion circuit requires the network to be matched and adjusted to the individual laser and does not reduce non linear distortion of all orders.
Therefore, feed-forward linearisation is preferred. Although the circuit for the feed-forward compensation is more complicated and can be difficult to implement, it seems to be the most promising technique for broadband linearization and offers number of advantages compared to other techniques such as broadband distortion reduction at microwave frequencies, reduction in all orders of distortion can be achieved, and the non linear characteristics of the lasers do not need to be known. Unlike predistortion, feed-forward is able to reduce the laser relative intensity noise (RIN) [5] as well. A reduction in the intensity noise of more than 10 dB has been observed over a frequency range of 1.7 – 3 GHz [6]. Since the noise limits the dynamic range in a system, reducing the nonlinear distortion together with the RIN noise can further enhance the dynamic range.
Other techniques have been reported for the reduction of nonlinear distortion such as External Light Injection [7], External Optical Injection Locking [8], and Sidemode Optical Injection [9].

3. Experimental arrangement of Feed-forward Linearization & Results

The circuit for the feed-forward linearization is shown in Figure 2 and the operation is based on two loops. The inner loop (also known as the error determination loop) and the outer loop (also known as the error injection loop). To test the system we performed direct modulation of the laser at 5.2 GHz. RF generators are used to provide two tone signals to the system. Microwave isolators are used at the output of each RF generator to provide high isolation between the generators. Two tone microwave signals at 5.2 GHz separated by 10 kHz were combined in the combiner. The signal is split at the input splitter. Considering the inner loop, the top path modulates the laser while the second path is the error free reference path. The output of the laser contains distortion due to nonlinearity of the laser. A sample of this signal is detected using a photodetector, amplified and combined with the reference path in the hybrid coupler which also provides 180 degree phase inversion. Since the two signals are out of phase the carriers cancel leaving only the distortion products. The output at the hybrid coupler is then amplified and modulates the second laser and combined with the first laser in the optical coupler and detected using a photodetector. This gives an output which has suppressed distortion products.

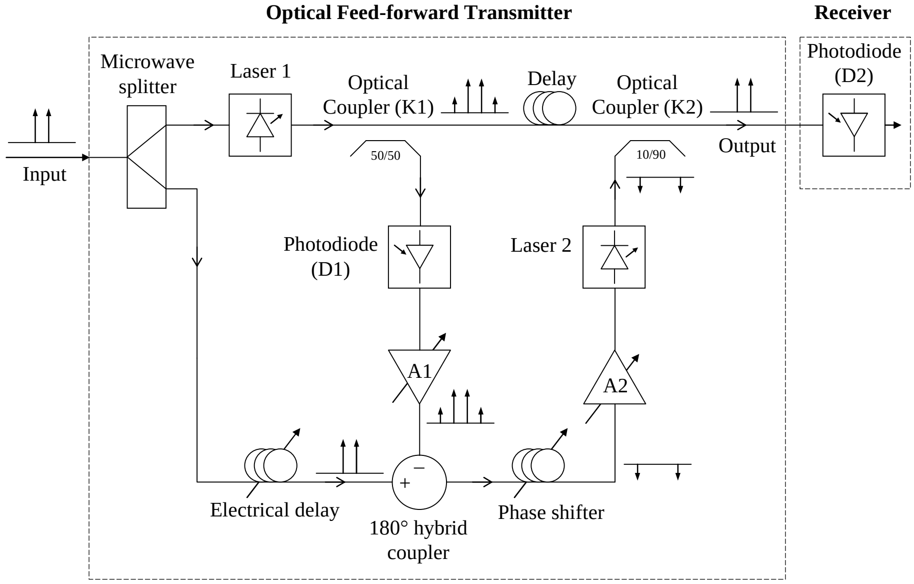

Fig. 2. Circuit for feed-forward linearization

Perfect cancellation of the distortion can be achieved when exact matching of the signals is obtained at optical coupler 2. In theory distortion can be completely eliminated. However, in practice this does not happen due to amplitude mismatch, nonideal frequency response of components such as amplifiers, photo-detectors and phase mismatch due to error in adjusting the time delay and the fibre delay in the feed-forward system. Also the distortion produced by laser 2 is not compensated but this can be minimised by ensuring that the second laser is driven by a small signal. The presence of intensity noise

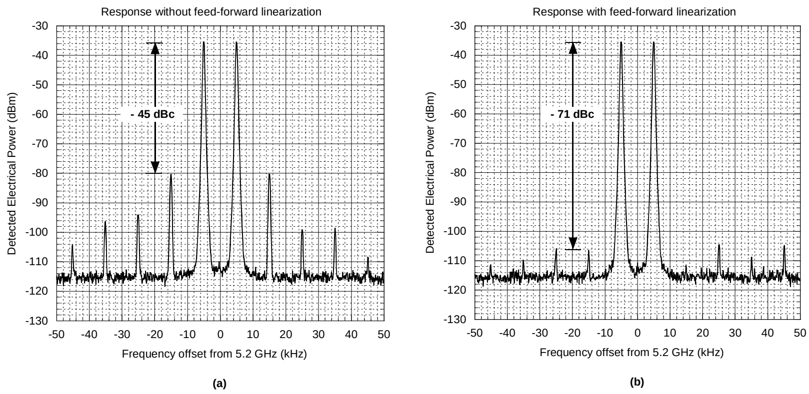

Fig. 3. Detected electrical spectra of overall system under direct two-tone modulation (a) without feed-forward linearization and (b) with feed-forward linearization. The mean optical output powers of the overall system were 0.9 dBm in (a) and 1.7 dBm in (b). The microwave input power per tone @ 5.2 GHz ± 5 kHz is 5 dBm at the power splitter input.

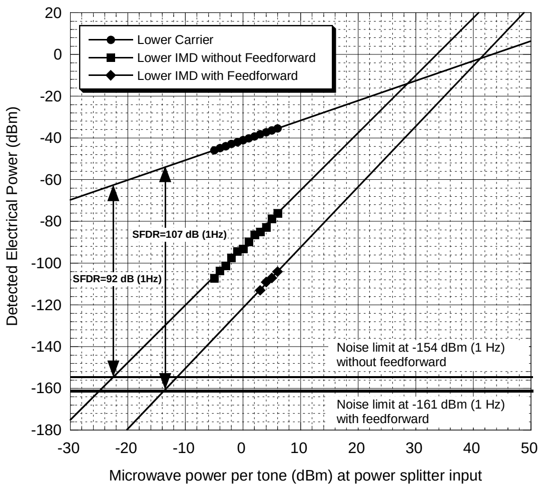

Fig. 4. Dynamic range measurement of overall system with and without feed-forward linearization @ 5.2 GHz ± 5 kHz

generated by laser 2, shot noise in the photodiode and amplifier noise limits the maximum achievable improvement in dynamic range. The proportion of noise coupled to the output depends on the coupling ratio of the optical coupler 2 and this can be minimised using a coupler which has a coupling ratio of 10 dB or more. The performance of the circuit with and without feed-forward was determined by enabling and then disabling the output of the secondary laser L2. The output response of the system is shown in Figure 3. The response without feed-forward shows that the IMD3 are approximately 45 dB below the carrier and with feed-forward 71 dB below the carrier, implying that a reduction of 26 dB in 3^{rd} order IMD is obtained. Also high order distortion products are reduced by at least 10 dB. In Figure 4 the dynamic range was measured. SFDR of 92 dB (1Hz) was obtained without feed-forward and 107 dB (1Hz) with feed-forward leading to an improvement of 15 dB in the dynamic range. As mentioned previously feed-forward also reduces laser relative intensity noise and this can be seen in Fig 4.

3. Conclusion and further work

In conclusion, the third order intermodulation distortion of a directly modulated semiconductor laser with and without feed-forward linearization has been investigated. The experimental results show approximately 26 dB reduction in IMD at 5.2 GHz and more than 10 dB for higher order distortion products is obtained. An improvement of 15 dB in dynamic range was also measured.
Further improvements will make the feed-forward a wideband system to cover the entire IEEE802.11a frequency band.

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