Bit-Rate Doubling in Multi-Gbps Wideband ASK-Modulated 60 GHz RoF Links using Linear Feed-Forward Equalisation and Direct Conversion Transceivers

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Abstract

Linear feed-forward equalisation is used successfully to compensate for severe electrical and optical amplitude response impairments in a 60 GHz RoF link, enabling twice the bit-rate (4.25 Gbps), through SSB operation.

Introduction

Wireless communication at 60 GHz is experiencing renewed interest because it offers abundant spectrum resource ideal for ultra-high-speed wireless connectivity. In the US, the Federal Communications Commission (FCC) has set aside 7 GHz bandwidth (57 – 64 GHz) for license free use. However, 60 GHz communication presents many technical challenges owing to the high carrier frequencies used [1]. Radio-over-Fibre (RoF) technology may be used to overcome some of the challenges. For instance, the high optical bandwidth and low fibre loss make RoF technology ideal for the generation, processing, and transmission of 60 GHz signals.

One of the challenges faced by wide-bandwidth communication systems is the difficulty in maintaining reasonable uniformity (flatness) in the amplitude and group delay responses over the whole bandwidth. This is especially true for electronic communication systems, where 7 GHz of bandwidth is an extremely wide band. However, this is also true for optical fibre communications, where device (laser, modulator, photodiode, etc) characteristics do vary significantly over a bandwidth of few GHz or less. Techniques used to deal with this problem include the splitting of the band into many smaller bands and then using sub-carrier multiplexing in combination with extensive signal processing (e.g. OFDM) at both the transmitter and the receiver [2]. For high-bit-rate communication such as envisaged for 60 GHz wireless communication (5 Gbps and more), the required signal processing becomes very complex, leading to increased power consumption, and transmitter-receiver complexity and cost.

In this paper, we demonstrate the use of linear feed-forward equalization to overcome severe response fluctuations present in the electrical and optical components used in a 60 GHz RoF system employing Intensity Modulation and Direct Detection (IMDD). With this approach, single-side-band (SSB) modulation in the 60 GHz Direct Launch Transmitter (DLT) and Direct Conversion Receiver (DCR) was successfully used to achieve > 2 times the RoF link's spectral efficiency, enabling the transmission of 4.25 Gbps ASK-modulated data over the link. To the best knowledge of the authors, this is the first time feed-forward equalisation has been shown to overcome response impairments in a multi-Gbps RoF link for 60 GHz wireless communication.

Experimental Set-up

The set-up used in the experiments is shown in the schematic in Figure 1.

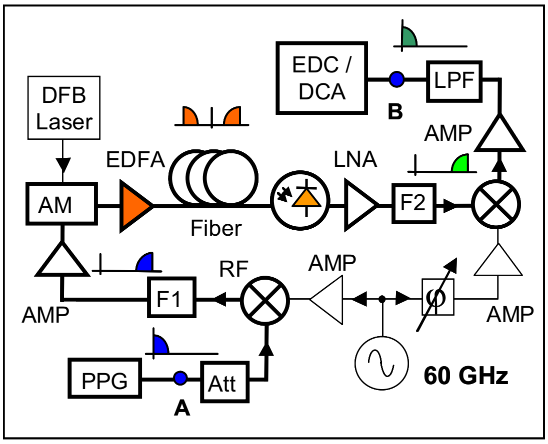

Figure 1: Intensity Modulated and Direct Detection RoF system incorporating a Direct Launch Transmitter and a Direct Conversion Receiver at 60 GHz followed by Linear Feed-Forward Equalization (F1/F2 = bandpass filters).

The RoF link consisted of a CW laser (NEL NLK3581SSI; λ = 1549 nm) connected to a high-speed Amplitude Modulator, AM (Versawave) with 50 GHz 3dBe bandwidth. Beyond 50 GHz, the modulator response rolls off fairly sharply falling an additional 7 dBe around 65 GHz. The modulator exhibits a large number of amplitude fluctuations (> 4 dBe) over the 59 – 62 GHz band of interest. The AM was driven by a 60 GHz electrical signal generated by the DLT. The DLT up-converted baseband signals directly to the 60 GHz band as shown. No IF stage was used. An

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Erbium Doped Fibre Amplifier (EDFA) was used to boost the optical signal, followed by an optical filter to remove ASE noise. A high-speed photodetector (u^2t) with 70 GHz 3dBe bandwidth was used to detect the optical signal. The recovered 60 GHz signal was fed into the DCR where the transmitted data was recovered and fed into a Digital Communications Analyzer with an inbuilt linear feed-forward equalization algorithm. The link bandwidth was limited by the bandwidth of the waveguide bandpass filters in the transmitter and receiver, which was 3 GHz in both cases.

Results

First, the flatness of the amplitude and the phase responses of the electrical transmitter and receiver seen by the baseband channel were measured. Both the transmitter and received showed significant amplitude fluctuations over the 3 GHz band. Afterwards, the flatness of the complete RoF system was determined by measuring the S21 parameters of the apparent low-pass channel between points A and B in Figure 1. The results are shown in Figure 2.

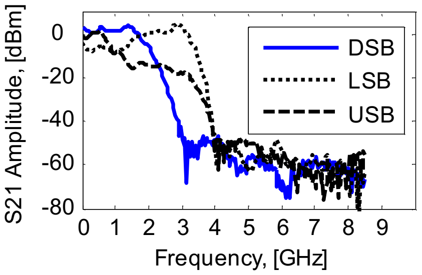
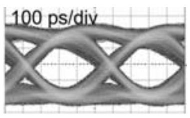
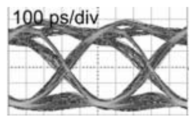


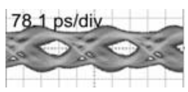
Figure 2: Amplitude flatness of the 60 GHz RoF link (DSB = double side band, LSB = lower side band, USB = upper side band).



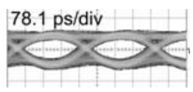
(a) 2.125 Gbps; DSB



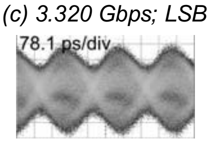
(b) with Equalisation



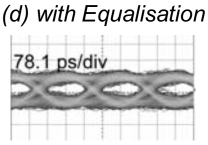
(c) 3.320 Gbps; LSB



(d) with Equalisation



(e) 4.25 Gbps; LSB



(f) with Equalisation

Figure 3: Eye opening improvement by Feed-forward Equalisation.

DSB was the case when the LO signal frequency corresponded to the centre frequency of the electrical bandpass filters (60.5 GHz). LSB and USB corresponded to the cases when the LO frequency was tuned to the edge of the bandpass filters so as to eliminate one of the sidebands (61.8 GHz and 59.2 GHz, respectively). As shown in Figure 2, significant amplitude response fluctuations over the three bands of interest were observed. The DSB case showed the most uniform response (2.5 dB), but also the least bandwidth (just 1.6 GHz), as expected. Both SSB cases showed severe roughness (14 dB and 19 dB for the LSB and the USB, respectively). Although not shown here, the measured group delay in all the cases was generally flat.

In order to examine the effectiveness of linear feed-forward equalization, various bit-rates of 2^{11}-1 PRBS data was transmitted over the RoF link. The quality of the data recovered with and without equalization was analyzed and compared. The results are summarised in Figure 3. The impact of severe ripples in the amplitude response as observed in Figure 2, on the quality of data transmission is evident from the distorted eye in the LSB cases (Figure 3 (c) & (e)). As Figure 3 shows, equalization (15 tap) substantially improved the eye opening in all cases. For the DSB case, a marginal increase of SNR from 7 dB to 9 dB was recorded. In the case of LSB transmission, equalisation increased the SNR from 3.3 dB to 6.2 dB for 3.320 Gbps data transmission.

The experiments were repeated with 500m of SMF28 fibres, which is roughly half of the measured dispersion-induced null fading length of the 60 GHz IMDD RoF system. Equalisation improved the measured SNR from 1.7 dB to 5.2 dB for the 3.320 Gbps LSB case, confirming successful system operation over fibre as well. In the worst case scenario, 4.25 Gbps transmission over 1 km SMF28 fibre (fading null) showed a completely closed eye before equalisation, which was clearly open after equalisation (SNR = 4.2 dB) as shown in Figure 3 (f).

Conclusions

Linear Feed-forward Equalisation was used successfully to compensate for severe electrical and optical amplitude response impairments in a 60 GHz RoF link over a wide band (3 GHz). With equalisation, SSB operation of the direct conversion electrical transceivers was successfully implemented resulting in the doubling of the maximum link bit-rate from 2.1 Gbps to 4.25 Gbps over the 3 GHz transceiver bandwidth. Simple ASK modulation format was used.

Feed-forward equalisation is much simpler to implement than the more complex signal processing employed in broadband (wireless) systems.

References

1. B. Razavi, IEEE Spectrum, (2008), pp 46-58
2. C. T. Lin, et al, OFC2008, (2008), Paper OMM5