Performance Analysis of Multi-Wavelength Radio-over-Fibre system applying Double Sideband-Suppressed Carrier DSB-SC modulation

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Abstract: This paper reports modelling and performance analysis of a Multi-Wavelength Radio-over-Fibre optical system applying the second harmonic up-converted DSB-SC modulation technique. The analysis considers the noise and nonlinear characteristics of the electrical and optical devices and the overall system nonlinearity performance without using optical amplification. We investigate and analyse the effect of the inter-modulation distortion to specify the system performance limitations. System modelling has been used for this investigation supported by experimental validation to justify the models.

1 Introduction.

Wireless broadband and optical analogue links are becoming an attractive and integral part of today's communications for delivering broadband connectivity to the end users [1] [2]. Increased demands for broadband services are putting pressure on wireless systems to increase capacity. To achieve this, wireless systems must operate at higher carrier frequencies. Radio-over-Fibre (RoF) technology is emerging as an enabler of the enormous bandwidth necessary for future broadband wireless communications services and a cost effective approach for reducing radio system cost. It simplifies the remote antenna base stations (BSs) and enhances the sharing of expensive radio equipment located at central stations [3].

There is a number of possible modulation techniques used for delivering the modulated mm-wave signals over the optical link of single-mode fibre (SMF) at various lengths. Moreover, techniques must be employed that mitigate the power degradation of the fibre chromatic dispersion which limits the transmission distance using the conventional modulation techniques [4][5].

Techniques suggested include optical single-sideband OSSB [7], and double sideband suppressed carrier DSB-SC [8]. It has been shown that if the effect of dispersion can be overcome, the system performance limitations are still arise from the cumulative effects of noise and distortions from device's nonlinearities [9][10].

2. IM/DD analogue dispersive optical links.

In order to identify the characteristics of the optical transmission technique through fibre optic links, we need to explore the DSB-SC modulation technique characteristics to compare with the conventional scheme. In the conventional scheme, the RF signal to be radiated at the antenna, which is generated by electrically mixing the IF and local oscillator, is externally modulated onto the optical carrier. Alternatively, in our up-converting system, an intermediate frequency IF signal directly modulates the optical source, and optical up-conversion is achieved through the local oscillator LO signal driving the external modulator figure 1a and 1b.

When the second harmonic up-conversion is performed, as shown in Figure 1-b, the impact of the fibre chromatic dispersion depends on the biasing point of the Mach-Zehnder modulator (MZM). If the modulator is biased at the nonlinear minimum transmission bias MITB point (the null point), the optical carrier will be suppressed, and the optical spectrum will be comprise two optical modulated sidebands. Therefore, at the PIN receiver, two sidebands containing the modulation information along the RF carrier are generated which may be filter to produce a single modulated tone which can be radiated.

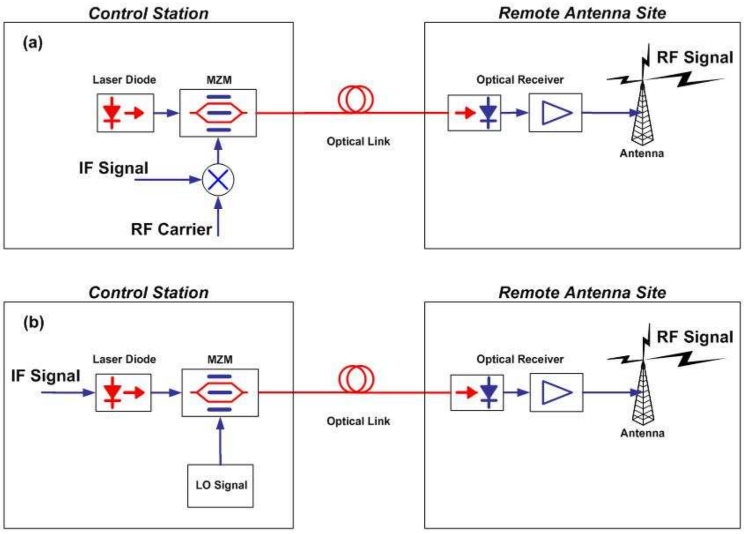

Fig. 1 Schematic diagram of the RoF (a) conventional, and (b) the up-conversion scheme.

Figure 2 shows the normalized power penalty curves, without including the fibre loss, to explore the dispersion effect of the received RF signal at 18 GHz when using the conventional DSB modulation compared to the second harmonic up-converted DSB-SC. It shows a power penalty of 6 dB after 100 km of fibre when DSB-SC is used, while there are four nulled power penalty points produced within the first 100 km of fibre using the conventional DSB modulation.

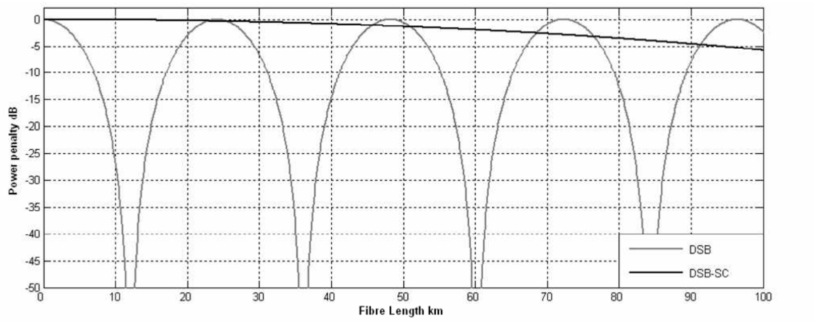

Fig. 2 Normalized dispersion-induced power penalty DIPP curves against fibre length for 18 GHz RF signal using conventional DSB and second harmonic up-converted DSB-SC.

This demonstrates that this method provides a sharp reduction of the dispersion induced, frequency-length dependant power penalty. In addition, this method is a simple and potentially low-cost method for the remote delivery and generation of millimetre-waves. In addition, it removes the need for complex circuitry to maintain the required frequency offset between two lasers as need with remote heterodyne detection (RHD) techniques.

3. Multi-wavelength DSB-SC.

In order to validate the simulation components and therefore the simulation models, practical components have been experimentally examined to determine their operating characteristics and performance parameters. Accordingly, the simulation device models have been specified to match the experimental component specifications.The up-converted DSB-SC system has a unique advantage over many other modulation techniques as it uses a directly modulated laser diode to generate the data signal rather than modulating the carrier at RF frequency. This offers the possibility of transmitting multi-wavelength optical signals simultaneously by using different wavelength directly modulated lasers in parallel prior the optical up-conversion stage. Therefore, this technique can be used as an optical multi-wavelength as well as electrical multi-channel system, without the need to replicate the high cost RF section of the generation circuitry.

The multi-wavelength system concept is to transform electrical signals with any format or data at the same RF frequency simultaneously through an optical RoF link using multiple optical wavelength carriers. The system can be constructed from two or more directly modulated lasers with different centre emission wavelengths. Each allocated to one certain IF signal and then the optical wavelengths should be combined prior the external modulator to be up-converted with one RF electrical carrier. At the receiver side, optical filters needed to separate the wavelengths prior the PIN receivers. Figure 3 illustrates the schematic diagram of multi-wavelength RoF system.

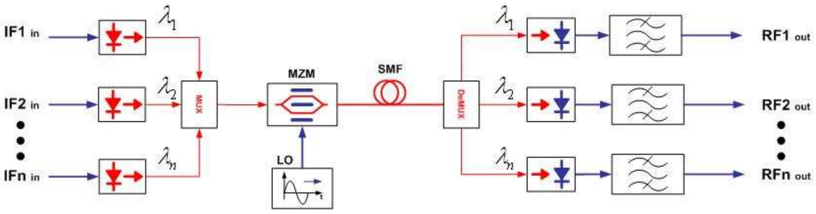

Fig. 3 Schematic diagram of the multi-wavelength DSB-SC using up-converted DM lasers.

In order to investigate the capability of implementing the multi-wavelength RoF system, a simulation model, figure 4, has been constructed using four laser diodes with centre emission wavelengths on the ITU grid specification channels 22 to 25. This corresponds to frequencies of 193.2 THz (1551.7208 nm), 193.3 THZ (1550.91804 nm), 193.4 THz (1550.11612 nm), and 193.5 THz (1549.31503 nm) respectively with 100 GHz (0.8 nm) channel spacing. A two tone test was performed for the system with four symmetric signals with tones of 1 GHz and 1.05 GHz (50 MHz spacing) applied to the lasers biased with 150 mA. The up-conversion carrier power was 21.6 dBm at f = 8.5 GHz = $f$mm/2.

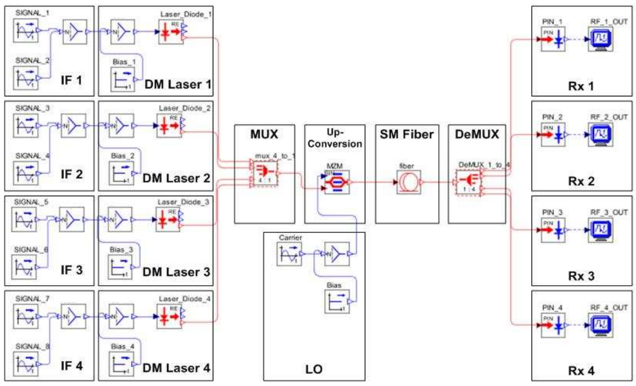

Fig. 4 OPTSIM simulation model of the ITU grid specification channels multi-wavelength

DSB-SC using up-converted laser.

An Arrayed Waveguide Grating (AWG) Multiplexer and De-multiplexer with insertion loss of 3 dB has been used to MUX/DeMUX the optical wavelengths of the lasers. Each electrical test signal applied to the lasers was 10 dBm and the electrical up-conversion carrier power was 21.6 dBm. The AWG comprises raised cosine filters with a bandwidth of 100 GHz which were set up to optimize the AWG's performance in terms of the filters roll-off factor. The only performance degradation was due to the addition of the AWGs as each of the MUX and DeMUX have an optical insertion loss of 3 dB which will correspond to 6 dB electrical loss. Results shows, figure 5, that the multi-wavelength system channels have an Inter-modulation free dynamic range of 53dB-Hz$^{2/3}$ and third-order Inter-modulation intercept point IM3 of -37dBm. Therefore, this system can be performing same as the single-wavelength system despite the optical power loss due to the AWG MUX/DeMUX.

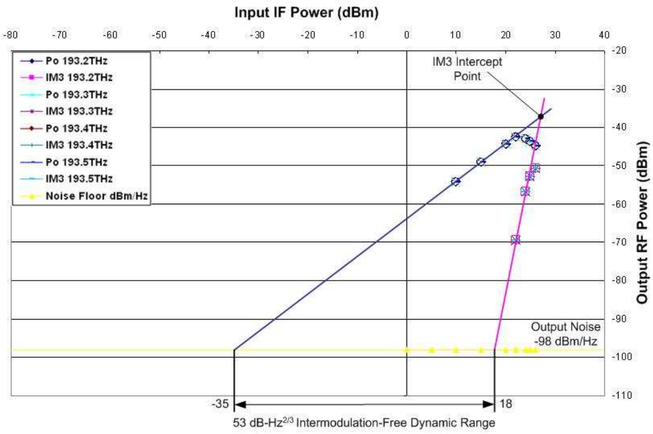

Fig. 5 Inter-modulation free dynamic range of the ITU grid specification channels multi-wavelength simulated DSB-SC RoF system.

4. Conclusions.

The inter-modulation free dynamic range of a Multi-wavelength DSB-SC RoF system was studied to identify the performance limiting components. The investigation used experimentally verified simulation blocks to determine the inter-modulation free dynamic range and the IM3 of the system. It was found that the directly modulated laser, the first nonlinear device in the signal chain, has the dominant nonlinear effect on the overall system performance. The single-wavelength DSB-SC system with DM laser can offer a dynamic range of 65dB-Hz$^{2/3}$ and an IM3 of -17dBm when the directly modulated laser diode and the RF drive power are optimized. This system offers the unique advantage of being able to transmit a multi-wavelength optical signals and multi-channels electrical signals without replication of the high frequency section of the system. It has been shown that even in the multi-wavelength configuration an Inter-modulation free dynamic range of 53dB-Hz$^{2/3}$ and third-order Inter-modulation intercept point IM3 of -37dBm can be achieved.

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