A comparison of the performance of different fibre radio mm-wave generation techniques in the presence of interferometric noise

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Abstract: The operation of a fibre supported mm-wave system (FSMS) overlaid over a WDM PON holds promise. A serious obstacle however is interferometric noise, which gives rise to BER floors and power penalties. In this paper we compare the performance of three mm-wave generation techniques, direct intensity modulation, double sideband suppressed carrier (one term) and double sideband suppressed carrier (two term) in the presence of interferometric noise using a first approximation based on the Gaussian approximation. It is shown that while their performance is close when used with ideal extinction ratios, the double sideband suppressed carrier (two-term) technique holds promise when used with non-ideal extinction ratios.

1. Introduction.

The application of optical networking techniques to fibre supported mm-wave radio systems (FSMS) overlaid over WDM PONs may potentially allow FSMS to coexist on the same fibre infrastructure with other services and enable the flexible reconfiguration of capacity in the radio network.[1,2] A serious obstacle to this implementation however, is interferometric noise, arising from data-crosstalk interference at the receiver. Interferometric noise may be a key performance-limiting factor, giving rise to BER floors and power penalties, severely limiting the scale of the network.

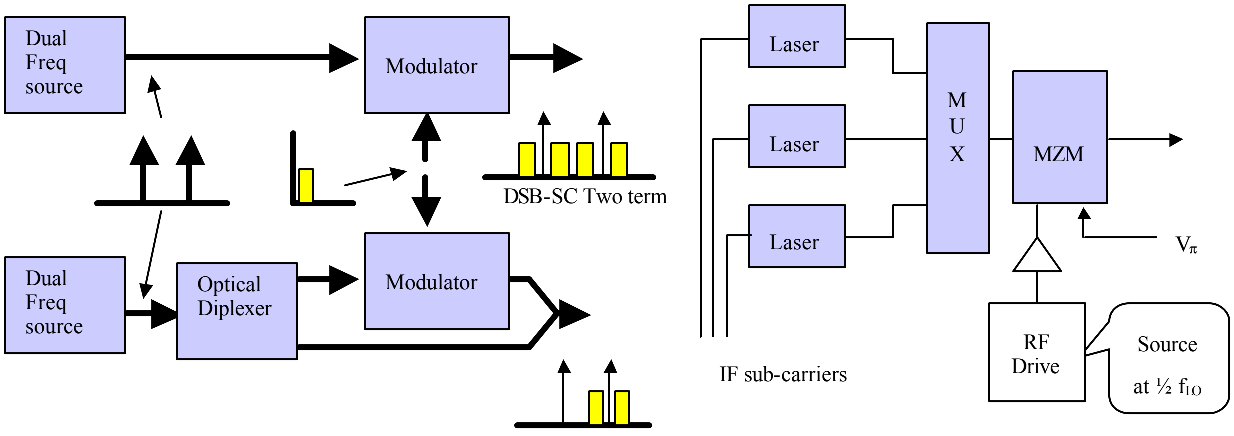
In WDM networks interferometric noise is more prevalent because of the more complex network architecture utilising multiple sources. Crosstalk will result from imperfect filtering, reflections in the system, non-ideal wavelength routers or the adopted optical mm-wave generation and modulation imposition technique itself.

In this paper we examine and compare the performance of three mm-wave generation and modulation imposition techniques, direct intensity modulation (three term), double sideband suppressed carrier with one term modulated (DSB-SC (one term)) and double sideband suppressed carrier with two terms modulated (DSB-SC (two term)), in the presence of interferometric noise. Section 2 provides a brief description of these techniques. Section 3 develops the models used for the comparison while the results are discussed in section 4. We conclude by outlining the main results together with some further improvements to the models.

2. Optical mm-wave generation and modulation imposition techniques

The simplest mm-wave generation technique uses the direct modulation of a Mach Zehnder modulator or an electroabsorption modulator at the mm-wave frequency. This generates a three term optical spectrum consisting of an optical carrier centred between two modulation sidebands. Although simple, propagation of a three-term signal through dispersive fibre results in repetitive, link length dependent nulls in the detected signal power, requiring the use of dispersion compensation techniques to increase the useful distance of operation.

Two term mm-wave generation techniques do not result in the periodic power variations. These hetrodyne two optical components separated by the mm-wave frequency on a photodetector to generate an electrical signal at a frequency equal to the frequency separation of the two optical components. For the generated RF signal to have a narrow linewidth the phase noise of the two optical terms must be correlated. Examples of two term techniques are the optical single sideband (OSSB) [3] and the double sideband suppressed carrier (DSB-SC) techniques [4]. An important issue associated with the use of DSB-SC techniques is how to impose the modulation signals. Modulation can be imposed on to both optical components or onto just one of the components as indicated in figure 1(a). Imposition of the modulation by intensity modulation of a composite two-tone signal without tone separation significantly reduces the complexity. Analysis shows that using this technique up to 30Km can be spanned at 1550nm using standard fibre, with a dispersion induced power penalty below 3dB for a 30GHz signal [5].



(a) (b)

Fig. 1: (a) Imposition of modulation onto a dual frequency optical source (b) SEOUC Technique

FSMS WDM operation may be achieved by using multiple optical mm-wave sources, but a particularly attractive approach is the suppressed electro-optical upconversion (SEOUC) technique shown in figure 1(b). In this approach baseband radio sub-carriers are applied directly to DWDM optical sources. The modulated optical signals are then multiplexed and the composite signal is upconverted to mm-wave frequency using a MZM to perform DSB-SC (two term) modulation.[6]

3. Theoretical analysis

For each of the following mm-wave generation and modulation imposition techniques, (i) Direct intensity modulation at the mm-wave frequency (three term), (ii) DSB-SC with one term modulated (iii) DSB-SC with two terms modulated, a model was developed. The model considered the case where an OOK signal is modulated by a random binary data sequence and where one incoherent interfering replica is present. Starting from the total electric field representation of the signal incident on the photodiode, (ie the desired signal plus one interferer), the detected photocurrent after bandpass filtering around the mm-wave and recovery of the data using coherent detection is shown in equations 1,2 and 3. It was assumed that the signal and interferer polarisations are aligned for worst-case performance and that no laser chirp is present.

$$i(t)_{DIMthreetone} \propto P_s\left[\left[d_s(t)+ed_i(t)\cos(\Delta q_{rf})\right]+\sqrt{e}\left[d_s(t)+d_i(t)\cos(\Delta q_{rf})\right]\cos(f_d(t))\right] \quad (1),[7]$$

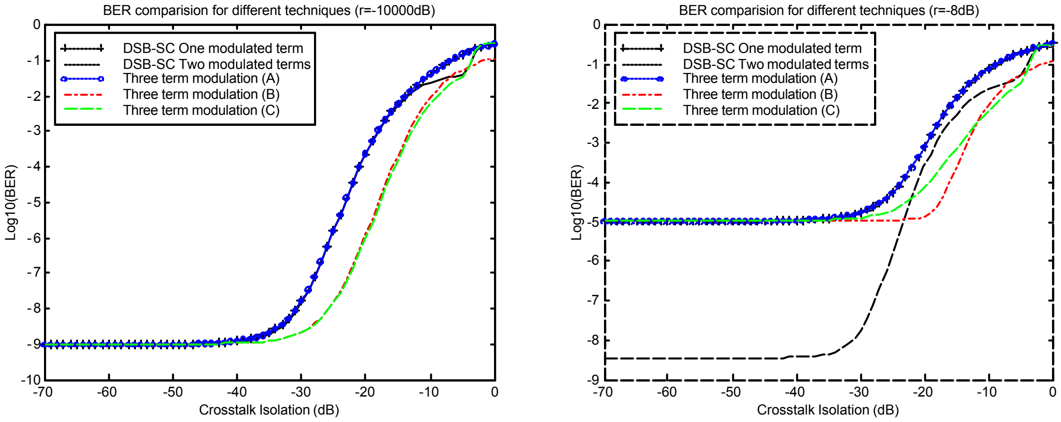
$$i(t)_{DSB-SConetone} \propto P_s\left[\left[d_s(t)+ed_i(t)\right]+\sqrt{e}\left[d_s(t)+d_i(t)\right]\cos(f_d(t))\right] \quad (2)$$

$$i(t)_{DSB-SCtwotone} \propto P_s\left[\left\{\left[d_s(t)\right]^2+e\left[d_i(t)\right]^2\right\}+2\sqrt{e}\,d_s(t)d_i(t)\cos\left[f_d(t)\right]\right] \quad (3)$$

where, P_s is the source power, $d_s(t)$ is the signal data, $d_i(t)$ is the interfering data signal, e is the crosstalk isolation ratio, $f_d(t)$ is the optical phase difference between the two optical carriers and, Δq_{rf} is the RF phase difference between the signal and the interferer in the Direct intensity modulation (three tone case). It may be seen that equations 1 and 2 are identical for the case when $\cos(\Delta q_{rf})=1$. In general it can be observed that the first term is the desired signal, the second term, the interfering crosstalk signal and the third term is an interferometric noise term resulting from the beating between the signal and interfering optical carriers.

As a first approximation the interferometric noise is assumed to be Gaussian. By adding the receiver thermal noise variance, d_{rec}^2, to the symbol conditioned interferometric noise variance, and applying the Gaussian approximation an estimate for the BER is obtained. It is also assumed that

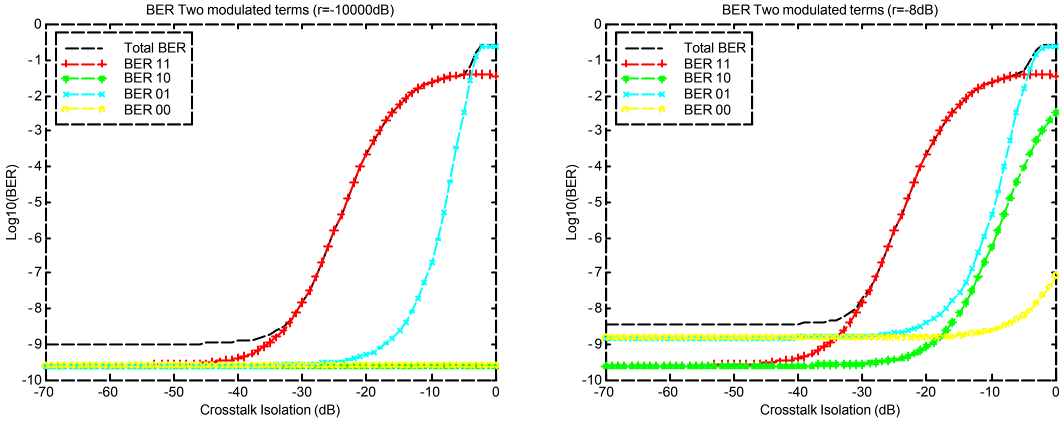
$f_d(t)$ is a stochastic process described by a uniform distribution between π and -π, since we assume delays which are greater then the laser coherence time. In [8] it has been shown that the use of the Gaussian approximation for the case of a single interferer is not accurate, tending to overestimate the BER and the crosstalk isolation tolerance by up to 5dB. This has been attributed to the fact that whereas the arc-sinusoidal PDF of the interferometric noise is strictly bounded, the Gaussian PDF is not. With this in perspective we proceed to discuss the comparison results obtained.



(a) (b)

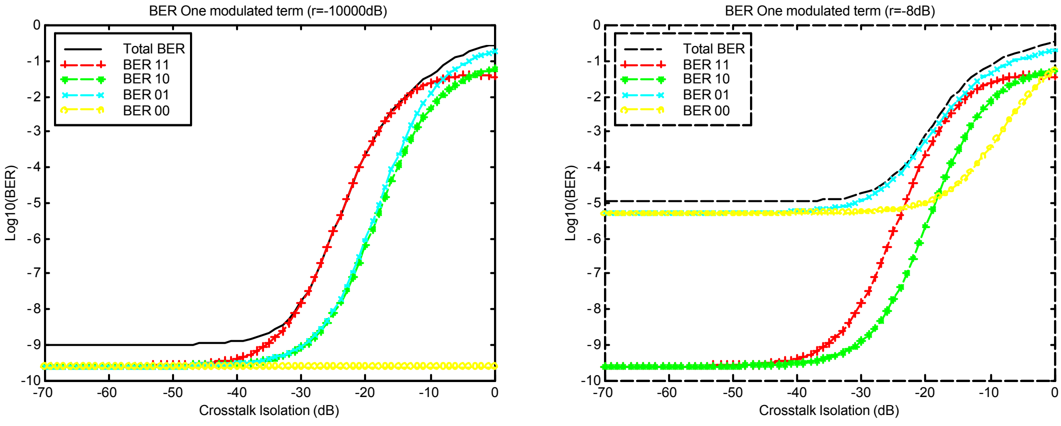
Figure 2: BER comparison for the different schemes (a) r=-10000dB, (b) r=-8dB
(Three term modulation A,B,C implies that cos($\Delta\theta_{rf}$)=1,0,-1 respectively

The results in figure 2 (a) show that for an ideal extinction ratio (*r* =-10,000dB), the performance of the DSB-SC (one term), DSB-SC (two term) and the worst case three term modulation (when cos($\Delta\theta_{rf}$)=1) is identical for crosstalk isolation levels less than –15dB. At crosstalk isolation levels less than –40dB, the performance is dominated by the receiver thermal noise, whose influence decreases in favour of interferometric noise as the crosstalk increases. It is observed that a better performance is obtained by the three term modulation technique for the cases when cos($\Delta\theta_{rf}$)=0 & –1. Figure 2 (b) illustrates the results obtained when considering a non-ideal extinction ratio (r=-8dB). It is seen that the performance of the DSB-SC two term scheme is significantly better at crosstalk isolations lower than –35dB than that of the other schemes. While its performance at high crosstalk levels although better than that of the DSB-SC (one term) scheme and the worst case three term scheme is outperformed by the three term modulation for the cases when cos($\Delta\theta_{rf}$)=0 and –1. A kink is also observed in the performance of DSB-SC (two term) scheme at around –6dB for both cases.



(a) (b)

Figure 3: Breakdown of the BER estimation for DSB-SC (Two term) (a) extinction ratio –10000dB (b) extinction ratio –8dB



(a) (b)

Figure 4: Breakdown of the BER estimation for DSB-SC (One term) (a) extinction ratio –10000dB (b) extinction ratio –8dB,

Since the worst case performance of the three term technique is identical to that of the DSB-SC (one term) technique, in figures 3 and 4 we breakdown the BER estimation of the DSB-SC (one term) and DSB-SC (two term) in more detail, showing the individual contributions from the different equiprobable logical combinations of signal and interferer.

Figures 3 (a) and (b), show that the performance of the DSB-SC (two term) scheme, when operating with different extinction ratios. It is observed that at a low level of crosstalk the performance is determined by the receiver thermal noise for an ideal extinction ratio. For crosstalk isolations between -35dB and –10dB the performance is dominated by the BER of the 11 combination, while for crosstalk isolations between 0 and –10dB it is dominated by the BER of the 01 combination (Note the steep rise). This change in relative dominance accounts for the observed kink in Figure 2.

Figures 4 (c) and (d) show the performance of the DSB-SC (one term) technique when using different extinction ratios. For an ideal extinction ratio the performance is very similar to that of the two term case, without the kink, indicating a smoother transition between dominant terms. When using a non-ideal extinction ratio the performance at low levels of crosstalk is however significantly worse than that of the two term case. At higher levels the performance of the two techniques converges.

5. Conclusion and Future work

From the above it may be concluded that the DSB-SC (Two term) technique performs better when compared to the DSB-SC (one term) technique, due to its superior performance under non ideal extinction ratios. Physically this may be attributed to the fact that the DSB-SC (two term) technique attenuates both tones on the zero level resulting in less interferometric noise. These first approximation results indicate that the performance of the SEOUC scheme in the presence of interferometric noise looks promising and further work must be carried out to estimate a more accurate upper bound on the BER by using the Modified Chernoff Bound Technique, while enhancing the model by taking into account a larger number of interferers, laser chirp and analogue RF modulation schemes.

6. References

[1] Attard J. C., Mitchel J. E., Lane P. M. and O'Reilly J.J. "System issues related to the overlay of FSMS over a WDM PON", NOC 2001

[2] Nirmalathas A., Lim C., Novak D., Castleford D., Waterhouse R., and Smith G., "Millimeter wave fiber wireless access systems incorporating Wavelength division multiplexing",

[3] Smith G.H., Novak D., and Ahmed Z., "Overcoming chromatic dispersion effects in fibre-wireless systems incorporating external modulators", IEEE Transactions on Microwave Theory and Techniques, Vol. 45, No. 8, August 1997, 1410-1415.

[4] O'Reilly, J.J., Lane P.M., Heidemann R., and Hofstetter R., "Optical generation of very narrow linewidth millimetre wave signals"" Electronics Letters, 1992, 28, pp.2309-2311

[5] Griffin R., Lane P.M., and O'Reilly J.J., "Dispersion tolerant sub-carrier data modulation of optical millimeter wave signals", Electronics letters, 1996, 32, No.24.

[6] Griffin R.A., Lane P.M., and O'Reilly J.J., "Radio over fibre distribution using an optical millimetre wave/DWDM overlay", OFC/IOOC'99 Technical Digest, San Diego, CA, USA, paper WD6

[7] Castleford D., Nirmalathas A., and Novak D., "Impact of Optical Crosstalk in fibre radio systems incorporating WDM", Microwave Photonics 2000, Oxford, U.K., paper TU 1.6.

[8] Moura L., Darby M., Lane P.M., and O'Reilly J. J., "Impact of interferometric noise on the remote delivery of optically generated millimetre wave signals", IEEE Transactions on Microwave Theory and Techniques, Vol. 45, No. 8, pp. 1398-1402, August 1997.