Research Data for the article “Mitigation of Nonlinear Effects in Optical Communications using Digital and Optical Techniques”

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1. Supplementary details for Figure 1:

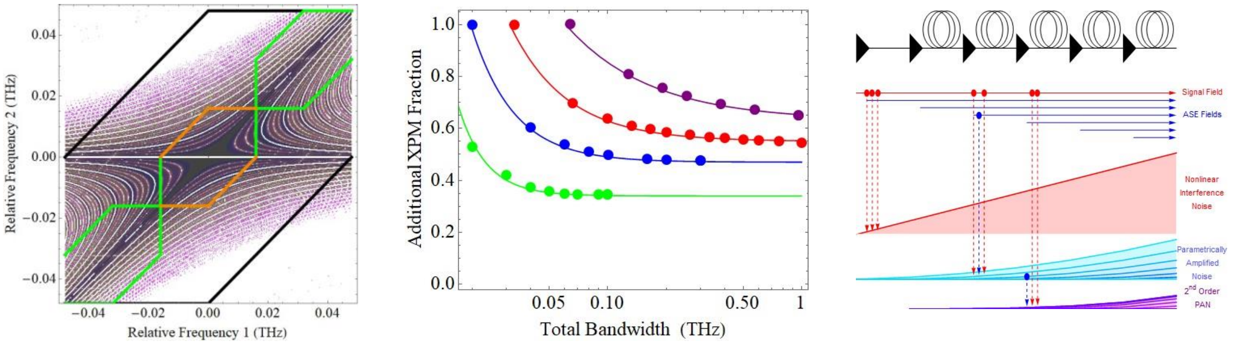

Fig. 1. (left) Four wave mixing efficiency (density plot) against frequency, showing integration bounds for self-phase modulation like terms (orange) cross-phase modulation like terms (green) and four wave mixing (black), (center) relative fraction of nonlinear noise from phase modulation-like terms as a function of WDM signal bandwidth for 10 (green) to 64 (purple) GHz channel bandwidths (right) illustration of the generation of nonlinear mixing products.

Figure 1 (left and center) present integration of the conventional FWM efficiency according to the approach in [5]. For figure 1 left, the integration limits for compensation of cross phase modulation are given by:

$$f_2^{\pm}(R) = \begin{matrix} Min \\ Max \end{matrix}\left(\left|\frac{f_1}{R}+\frac{1}{2}\right|, f_1\right) R \pm \frac{R}{2}$$

Where f_1 is relative frequency 1, f_2 relative frequency 2 and R the symbol rate or WDM signal bandwidth. Figure 1 (centre) is calculated by diving integration of the FWM efficiency between $f_2^-(R)$ and $f_2^+(R)$ by the integration of the FWM efficiency between $f_2^-(N.R)$ and $f_2^+(N.R)$ where N is the number of channels considered. In this example the integration was carried out assuming an 80km span of standard single-mode fiber.

Coordinates of the points shown in Fig 1 (centre) are (to two significant figures):

10 GHz: {{0.02, 0.53}, {0.03, 0.42}, {0.04, 0.37}, {0.05, 0.36}, {0.06, 0.35}, {0.07, 0.35}, {0.09, 0.35}, {0.1, 0.35}, {0.1, 0.35}}
20 GHz: {{0.02, 1.0}, {0.04, 0.60}, {0.06, 0.54}, {0.08, 0.51}, {0.1, 0.50}, {0.2, 0.48}, {0.3, 0.48}, {0.3, 0.48}, {0.16, 0.48}}
33 GHz: {{0.033, 1.}, {0.066, 0.70}, {0.1, 0.64}, {0.13, 0.61}, {0.17, 0.60}, {0.2, 0.59}, {0.27, 0.57}, {0.33, 0.57}, {0.4, 0.56}, {0.5, 0.56}, {0.6, 0.55}, {0.77, 0.55}, {1., 0.55}}
64 GHz: {{0.064, 1.0}, {0.13, 0.81}, {0.26, 0.73}, {0.96, 0.65}, {0.96, 0.65}, {0.19, 0.76}, {0.38, 0.69}, {0.58, 0.67}}

Figure 1 right illustrates the length scaling rules reported in [1].

2. Supplementary details for Figure 2:

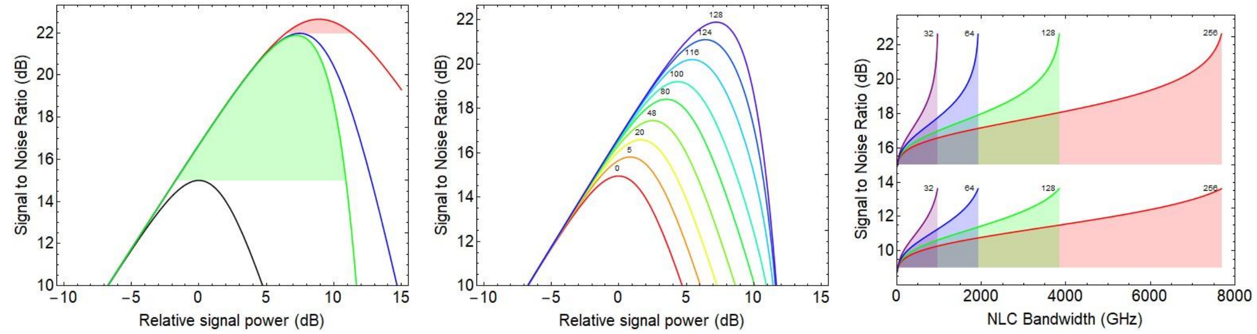

Fig. 2. Theoretical predictions of nonlinear compensation benefits showing (left) signal transmission limited by: black – inter signal nonlinearity, red – PNA, blue – second order PNA, green – all orders of PNA. (center) potential benefit of ideal nonlinearity compensation in a 128-channel system with a SNR before NLC of 15dB, and (right) potential SNR of 32 (purple), 64 (blue), 128 (green) and 256 (red) channel systems as a function of compensator bandwidth for a starting SNR of 9 (bottom) and 15 (top) dB.

Figure 2 is plotted for a generic system with 20 spans, and arbitrary nonlinear coefficient and an ASE noise spectral density selected to give a 15dB SNR without any compensation of nonlinear effects. Equations governing the curves are taken from [1], except for the “all-order” PNA, where the length scaling is adapted from [7]. For Figure 2 (centre) and Figure 2 (right) the proportion of residual inter-signal nonlinearity is simplifies to

$$1-\frac{Log\left({}^{R_C}/_{B_0}\right)}{Log\left({}^{N.R}/_{B_0}\right)}$$

Where R_C is the effective bandwidth of the nonlinearity compensation, and B_0 a parameter reflecting the bandwidth of the first lobe of the FWM efficiency [5].

3. General References

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4. References for Figure 3.

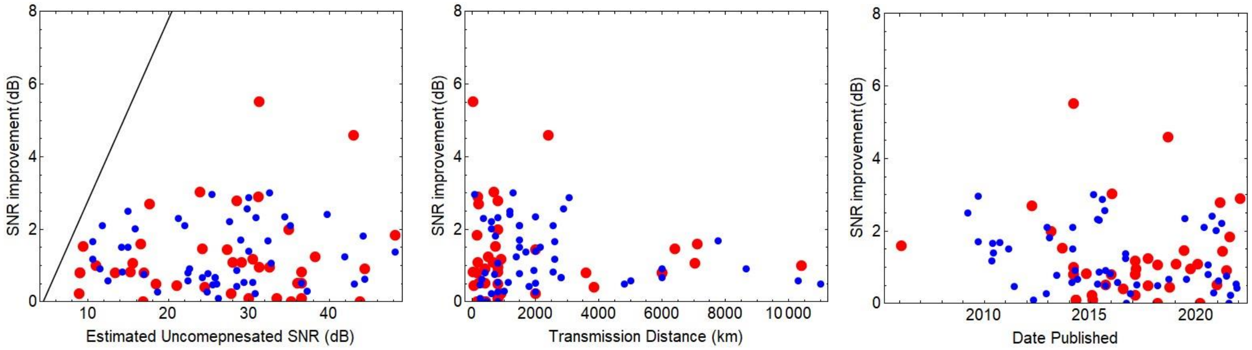

Fig. 3: Progress in digital (blue) and OPC-based (red) nonlinearity compensation.

For figure 3, results reported in each paper were converted to an equivalent SNR using the approach proposed in [1], except results reporting mutual information, where the SNR was taken assuming that the mutual information and SNR were related by Shannon's capacity formula.

4.1. References for Compensation of Nonlinearity by Optical Phase Conjugation

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