Photodiode nonlinear modeling and its impact on optical links phase noise

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The modeling of noise in microwave optical links is an essential step towards the phase noise optimization of optoelectronic oscillators. In these systems, the noise contributors and the non-linear devices are numerous. The phase noise is the result of the folding of some of these noise sources, through the system nonlinearities, onto the microwave carrier. Such a process can be predicted if the noise sources are clearly identified and measured and if the nonlinear elements can be modeled.

Our approach has been to develop an equivalent model of the microwave optical link[1] on an harmonic balance software (i.e. Agilent ADS). The laser is described as a noisy frequency source, including its AM and FM noise contributors. The modulator is a mathematical black box. The photodiode was up to now a simple quadratic detector, followed by a frequency filtering network. The purpose of this talk is to describe a more complex model of the photodiode, which includes the photo-generation time delay dependence on the optical power. This phenomenon is responsible for the conversion of the laser amplitude noise into microwave phase noise[2].

An optical link has been measured on a network analyser, and the amplitude and phase of the transmission coefficient S_{21} have been plotted at different RF frequencies while varying the photodiode illuminating power. The S_{21} phase features a parabolic like shape, with a maximum which increases with the RF frequency. To complete the model, the frequency response of the photodiode has also been measured and, for one of the devices under test which was available in chip, the output reflection coefficient of the photodiode has also been measured (S_{22}).

Because no evolution of the photodiode capacitance has been observed on the S_{22} parameter, the phase dependence of the transmission parameter has been attributed to a variation of the photogeneration delay versus the optical power. Therefore, a nonlinear delay cell, realized with a nonlinear capacitance and parallel resistance, has been implemented in the photodiode model, together with a phenomenological description of the amplitude saturation at high power.

With this model, it is now possible to evaluate the optical link phase noise dependence on the laser low frequency intensity noise. Of course, if the optical power is chosen at the maximum of the phase curve, this dependence drops to zero. In this case, different noise processes have to be taken into account. Up to now, the more efficient phase noise generating processes which are not related to the laser amplitude fluctuations in optical links are the conversion of the laser frequency noise through the fiber dispersion, or the Rayleigh scattering noise inside the fiber. We are thus now studying the possibility to include such processes in our model.

[1] H. Brahimi et al., Proc. of the 2009 European Microwave Conf., Rome, pp. 1642-1645.
[2] D. Eliyahu, D. Seidel, L. Maleki, IEEE Trans. on Microwave Theory and Tech., Vol. 56, N°. 2, Feb. 2008.