Three-Tone Characterization of High-Linearity Waveguide Uni-Traveling-Carrier Photodiodes

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The IMD3 of waveguide UTC photodiodes are characterized using a three-tone technique that is independent of harmonics from the optical sources. At 1 GHz, an OIP3 of 46.2dBm at 60mA of photocurrent is measured.

High-performance analog optical links require photodiodes (PDs) that have high power handling capability as well as high linearity. Waveguide PDs are of particular interest because they can be monolithically integrated with optical modulators and couplers to realize complex receiver functionality [1]. Uni-traveling carrier PDs (UTC-PDs) [2], which were designed for high speed and high current operation, have shown very high output saturation and linearity characteristics [3, 4]. Recently, we reported on waveguide UTC-PDs with OIP3s in excess of 40dBm for up to 80mA of photocurrent, measured at 1GHz [4]. Various techniques have been suggested to characterize the third-order intermodulation distortion (IMD3) generated by PDs [5]. Typically, a two-tone setup is used where the outputs of two commercial DFB lasers operating at ~1.5µm are externally modulated with optical intensity modulators biased at quadrature. The modulated signals are combined and amplified using a fiber amplifier before being coupled into the device. One of the drawbacks of this approach is that harmonics from the optical source (i.e. modulators) interact with the fundamental signals (at f_1 and f_2) to generate distortion terms at the IMD3 frequencies ($2f_2$-f_1 and $2f_1$-f_2). When the distortion of the device under test (DUT) is very low, such as in [4], the nonlinear contributions from the optical sources become significant. Consequently distortion characterization is limited by the distortion of the measurement system itself. An alternate approach to the two-tone technique is to use three tones to measure IMD3 [5, 7]. In this technique the third order non-linear distortion components are independent of the harmonics originating in the optical modulators and signal generators. Consequently, the IMD3 measured at these frequency components can be attributed to the DUT. Fig. 1 shows a schematic of the experimental setup.

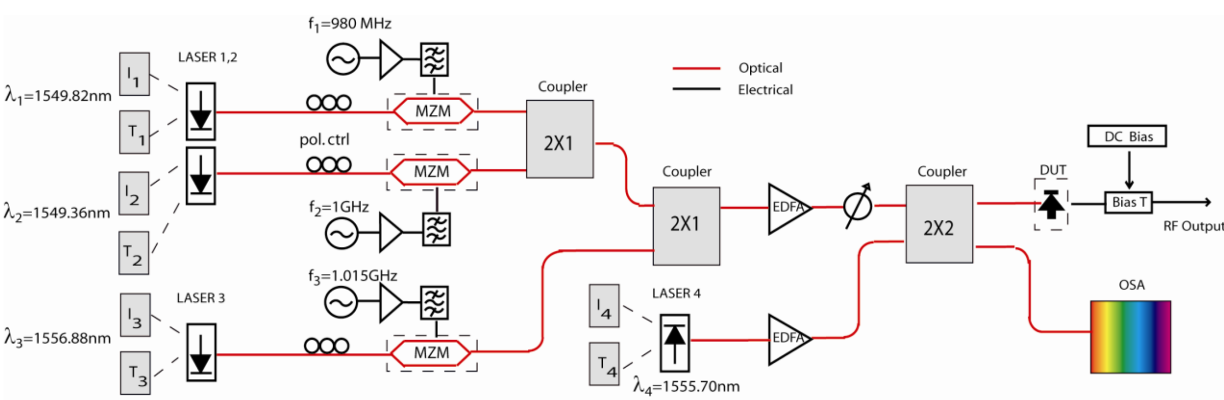

Fig. 1. Schematic of 3 tone experimental setup

The output of three CW lasers with differing wavelengths (Δλ ~0.5-7nm) are modulated separately at frequencies f_1=980MHz, f_2=1GHz and f_3=1.015GHz. The three optical signals carrying RF modulation are combined and amplified. An attenuator is used at the output of the EDFA to control the modulation index of the three tones. A fourth CW laser is used to ensure that the optical power and hence, photocurrent in the device remains unchanged as the optical modulation index is varied. For this experiment the optical modulation index is varied between approximately 20-30%. Additionally, an optical spectrum analyzer (OSA) is used to monitor the spectral content of the optical signal to ensure that four-wave mixing does not occur for the high optical powers used in this experiment.

The third order non-linear distortion components are measured at frequencies f_3–(f_1+f_2), f_2–(f_1+f_3) and f_1–(f_2+f_3). As outlined in [5] the three-tone IMD3 is 6dB larger than the ideally measured two-tone IMD3 and the three-tone IP3 is

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3dB smaller than the two-tone IP3. This distinction is more clearly illustrated in Fig. 2a). A factor of 3dB is added to the three-tone IP3 to relate this to the more commonly used two-tone IP3. Using this technique we measure the IMD3 of a UTC-PD that has a 1dB compression current of 80mA [4]. At a photocurrent level of 60mA the device has a two-tone OIP3 of 46.2dBm as shown in Fig. 2b).

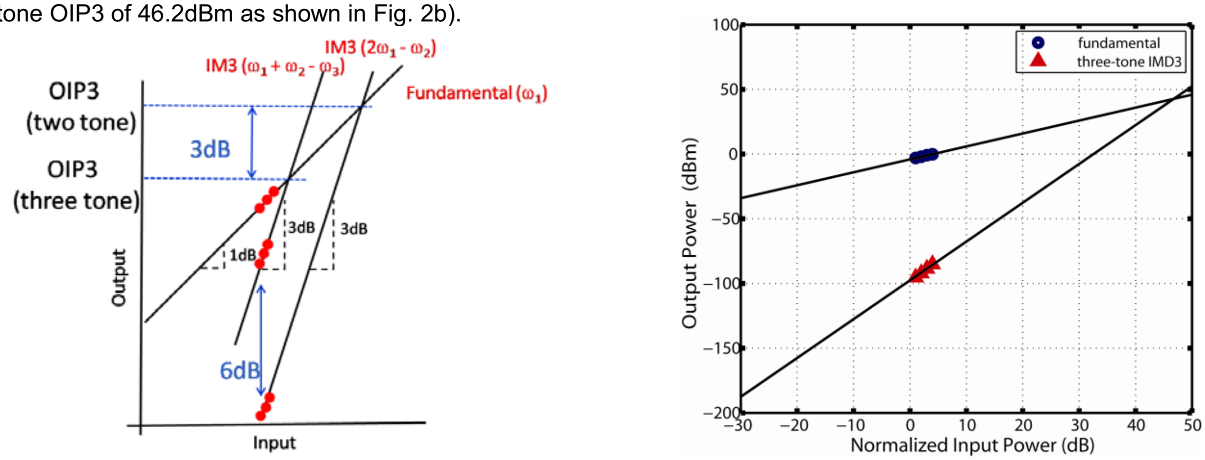

Fig. 2a). Relation between two-tone & three-tone IP3 *2b). Three-tone IMD3 measurement at 60mA*

In order to verify the measurements we compared results from different devices that were measured using both techniques. In Fig. 3 it can be seen that when the distortion of the DUT is comparatively higher (lower IP3), the two measurements yield nearly the same result, as for Device 1. However, when the distortion of the PD is very low (OIP3 > 40dBm) we observe a significant difference in the measured distortion. It can be concluded that the measurements using the two-tone technique are limited by the measurement system when the DUT exhibits very low distortion. Therefore alternate techniques such as the three-tone approach are necessary to characterize the distortion of highly linear PDs.

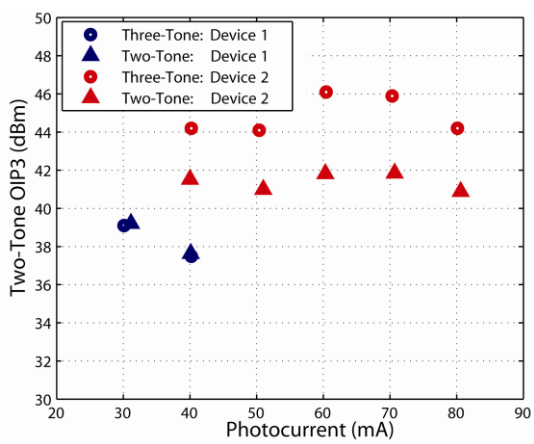

Fig. 3. Results from Two-tone & Three-tone Measurement

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[1] A. Ramaswamy, *et al.*, "Coherent Receiver Based on a Broadband Optical Phase-Lock Loop," Optical Fiber Communications Conference. (OFC). Postdeadline Technical Digest. Opt Soc. America. PDP3, 2007.

[2] T. Ishibashi, *et al.*, "InP/InGaAs uni-traveiling-carrier photodiodes," *IEICE Trans. Electron.*, vol. E83-C, pp. 938-949, Jun. 2000

[3] J. Klamkin *et al.*, "High Output Saturation and High-Linearity Uni-Traveling-Carrier Waveguide Photodiodes," *IEEE Photonics Technol. Lett.*, vol. 19, no. 3, pp. 149-151, Feb. 2007.

[4] J. Klamkin *et al.*, "Uni-Traveling-Carrier Waveguide Photodiodes with>40dBm OIP3 for up to 80mA of Photocurrent", Device Research Conference (DRC). Late News Jun. 2008.

[5] T. Ohno, *et al.*, "Measurement of intermodulation distortion in a unitraveling-carrier refracting-facet photodiode and a p-i-n refracting facet photodiode," *IEEE Photonics Technol. Lett.*, vol. 14, no. 3, pp. 375-377, Mar. 2002.

[6] K.J. Williams and R.S. Esman,"Design Consdierations for high-current photodetectors," *J. Lightw. Technol.*,vol. 17, no.8, pp. 1443-1454, Aug. 1999.

[7] T. Ohno and E.H. Hara., "Measurement of nonlinear distortion in photodiodes," *Electron. Lett,* vol. 12, pp. 80-90, 1976.