

THIRD-ORDER INTERMODULATION DISTORTION IN AN OPTICAL DOWNCONVERTER

P. D. Biernacki, L. T. Nichols, and R. D. Esman
Naval Research Laboratory, Code 5672
Washington, DC 20375-5338
TEL: 202-404-4205 FAX: 202-404-8645
e-mail: biernack@ccf.nrl.navy.mil

ABSTRACT

The first two-tone measurements of third-order intermodulation in a wide-band (1-18 GHz) optical downconverter utilizing cascaded Mach-Zehnder modulators are presented. Intermodulation originates in the RF modulator and is downconverted along with the fundamentals to intermediate frequencies (IF). The third-order intercept in the IF band is measured and agrees well with theory.

INTRODUCTION

Photonic links (PLs) are advantageous in microwave transmit/receive systems for both remote and multi-octave operation due to low frequency-dependent and incremental loss, low-weight flexible harnessing, immunity to electromagnetic interference, and large bandwidth. In the receive mode, heterodyning via cascaded Mach-Zehnder modulators (MZMs) can greatly increase sensitivity over the basic PL. Photonic downconverters have been demonstrated with noise figures as low as 12 dB and minimum detectable signals (MDS) as low as -162 dBm/Hz over many octaves (2-18 GHz) [1]. The use of Erbium-doped fiber amplifiers (EDFAs) and high-current photodetectors with balanced detection for shot noise-limited performance allows for even greater conversion efficiency [2-4]. In addition to remoting and bandwidth capability, the high RF/LO isolation of the MZM-based downconverter makes it an attractive alternative to conventional microwave diode-based mixers.

Even with single-octave receiver bandwidths, third-order intermodulation products are detrimental to spur-free dynamic range (SFDR) because they lie only $\Delta\omega = \omega_2 - \omega_1$ from the desired outputs $\omega_{1,2}$. The “distortion-free” power-handling capability of the link is characterized by the third-order intercept (TOI) power, the intersection of the small-signal fundamental and third-order spurious outputs. Although TOIs have been explored in a single modulator [5-7], such distortion has not been examined in the dual-MZM configuration; nor has optical amplification been taken into account. It can be shown, using the microwave-optical modulator transfer characteristics, that the output TOI of the photonic downconverter is simply that of the basic RF link times the *additional* small-signal (SS) conversion gain due to the LO modulator. Specifically:

$$P_{TOI}^{IF} = P_{TOI}^{RF} \left(G_{SS}^{IF} / G_{SS}^{RF} \right)$$
$$P_{TOI}^{IF} = 4i^2 R_L \left[J_1^2 \left(\pi \sqrt{2R_L P_{LO}} / V_\pi \right) \right]$$

where i is the quadrature photocurrent, R_L is the line impedance, P_{LO} is the input LO power, and V_π is the MZM switching voltage (at the LO frequency). Thus, the signal-to-interference ratio is preserved rather than degraded by the LO. The output TOI can be enhanced by increasing i , increasing P_{LO} , or decreasing V_π ; under shot noise-limited conditions, these will thereby increase SFDR.

SYSTEM CONFIGURATION

The fiber optic downconverting system is shown schematically in Fig. 1. A 25 mW distributed feedback laser (DFB) is fusion spliced to a MZM driven by a LO input of +15 dBm. The intensity-modulated optical output is then amplified by an EDFA containing a Faraday mirror and polarizing beam splitter to maintain polarization. This modulated power is then fed into a second MZM driven by a two-tone RF input. Both MZM's are maintained at quadrature. Microwave-optical mixing in the second MZM results in an intensity-modulated signal containing the RF and LO signals, upconverted and downconverted signals, third-order mixing terms, and odd harmonics of the inputs. The photodetector pair handles higher current for enhanced conversion gain. Since the detector 3 dB bandwidth is less than 2 GHz, the LO was tuned to provide IF's below 500 MHz. Finally, a spectrum analyzer scans the detected IF output along with the third-order distortion (TOD). The isolators provided greater than 20 dB of isolation and RF inputs were chosen such that TOD due to the microwave preamplifier would lie outside the input filter bandwidth so as to introduce distortionless tones to the MZM.

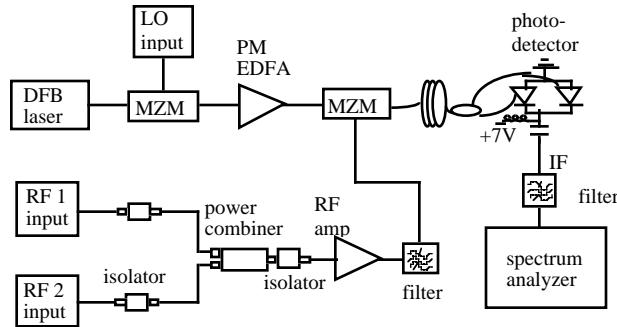


Figure 1: The third-order intermodulation test using an optical downconverter.

RESULTS AND DISCUSSION

The electrical output of the PD following the cascaded modulator pair consists of the two IF frequencies $|\omega_{LO} - \omega_{RF1,2}|$ along with TOD terms

$|\omega_{LO} \pm |2\omega_{RF1,2} - \omega_{RF2,1}|||$ [8]. All other components of the intensity modulation are effectively filtered by the PD response. Two different RF input frequencies (1 and 17.5 GHz) were tested for the down-converted signals as well as the corresponding TOD terms. Figure 2 shows down-converted frequencies along with the TOD products using a LO frequency of 17.5 GHz and a RF two tone frequency of 17.34 and 17.341 GHz respectively. The resulting downconverted signals of 160 MHz and 159 MHz respectively, and TOD terms at 158 MHz and 161 MHz are observed. For measurement accuracy, as well as providing input filtering, a tone offset greater than 1 MHz was used for all measurements presented. Figure 2 is provided to illustrate the system operation.

The measurement results for the third-order intercepts (TOI) at different frequencies are compared to theory [4-7] in Fig. 3. The modulator V_π is adjusted slightly in calculating the theoretical TOI (~16 V - 24 V for 1-17.5 GHz) since the measured V_π does increase slightly with frequency. The V_π used in the theoretical calculation was derived from the measured gain spectrum of a single modulator. All measurements used a LO drive level of +15 dBm and a detector current of 10 mA. Excellent agreement is observed in the results.

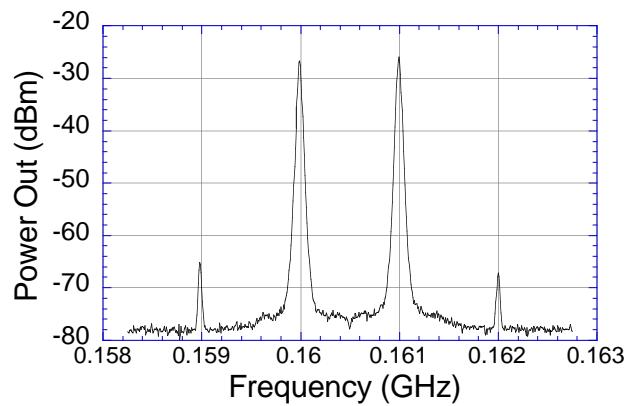


Figure 2: Spectrum analyzer trace of downconverted signal along with third-order distortion products.

Much lower conversion loss can be achieved by increasing the detector current as well as by increasing the LO to the maximum allowed (+27 dBm). Table 1 shows the measured TOI for different MZM LO and RF input frequencies as well as the V_π of the modulator at that frequency.

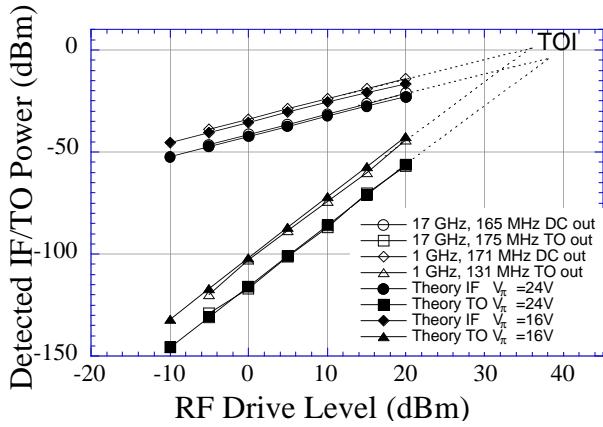


Figure 3: Measured and theoretical values of the down-converted signals and third order distortion products for a 17.5 GHz and 1 GHz LO and RF signals.

	Test 1	Test 2
LO (GHz)	1.161	17.335
RF1 (GHz)	1.01	17.17
RF2 (GHz)	.99	16.83
DC1 (MHz)	171	165
DC2 (MHz)	151	505
TO1 (MHz)	131	175
TO2 (MHz)	191	845
TOI (dBm) Measured	-1.3	-4.2
TOI (dBm) Theory	-2.3($V_\pi=16$)	-5.6($V_\pi=24$)

Table 1. RF and LO signal input frequencies and corresponding downconverted(DC1,2) and third-order distortion (TO1,1) terms.

It is interesting to note that the distortion terms are inherent only in the microwave-optical mixing occurring in the RF MZM. The cascaded LO MZM provides the downconversion of the RF signals but does not add to third-order intermodulation distortion within band.

CONCLUSION

In conclusion, the first measurements of two-tone third-order modulation distortion products in a wide-band (1-18 GHz) optical downconverter are presented and agree with the theoretical calculations. Microwave-optical mixing enhances sensitivity and bandwidth in receiver systems.

This work was sponsored by the Office of Naval Research.

[1] P. D. Biernacki, L. T. Nichols, D. G. Enders, K. J. Williams, and R.D. Esman, "A Two-Channel Optical Down-converter for Phase Detection," submitted to *IEEE Transactions on Microwave Theory and Techniques*, September, 1997.

[2] K. J. Williams, L. T. Nichols, and R. D. Williams, "Externally-modulated 3 GHz fiber optic link utilizing high current and balanced detection," *Electronics Letters*, vol. 33, no. 15, pp. 1327-1328, 1997.

[3] K. J. Williams, and R. D. Esman, "Optically amplified downconverting link with shot-noise-limited performance," *IEEE Photon. Technol. Lett.*, vol. 8, pp. 148- 150, 1996.

[4] G. L. Abbas, V. W. S. Chan, and T. K. Lee, "A dual-detector optical heterodyne receiver for local oscillator noise suppression," *J. Lightwave Technol.* vol. LT-3, pp. 1110-1122, 1985.

[5] B. H. Kolner and D. W. Dolfi, "Intermodulation distortion and compression in an integrated electrooptic modulator," *Applied Optics*, vol. 26, no. 17, pp. 2676-2680, 1987.

[6] G. K. Gopalakrishnan, W. K. Burns, and C. H. Bulmer, "Microwave-optical mixing in LiNbO_3 Modulators," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 2383-2391, 1993.

[7] C. K. sun, R. J. Orazi, and S. A. Pappert, "Efficient Microwave Frequency Conversion Using Photonic Link Signal Mixing," *IEEE Photon. Technol. Lett.*, vol. 8, no. 1, pp. 154-156, 1996

[8] G. K. Gopalakrishnan, R. P. Moeller, W. K. Burns, K. J. Williams, and R.D. Esman, "A low-loss downconverting analog fiber-optic link," *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 2318-2323, 1995.