Wideband Dynamic Range Improvement of Microwave Photonic Links

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Abstract **Wideband (4-12 GHz) distortion improvement of a Mach-Zehnder fiber optic link using predistortion linearization is demonstrated. 30 dB IMD_3 improvement, corresponding to an overall 7.9 dB improvement in $SFDR_3$ at 8 GHz is shown.**

I. Introduction

Microwave fiber optic links offer advantages of decreased weight and increased EMI, in addition to the flexibility of an inherent broadband capability. Improvements in link dynamic range will enable greater use of fiber optics in avionics platforms. Methods of improving link dynamic range through linearization have been reported using optical, feedforward, predistortion, and hybrid techniques [1-4]. These have typically resulted in complicated circuitry or limited bandwidth. We report on improvements in microwave predistortion that have the capability of providing multi-octave correction of nonlinear distortion in fiber optic links.

II. Spur-free dynamic range

SFDR is a useful quality figure because it relates two of the limiting factors of fiber optic links: noise and linearity. In particular, third-order SFDR is given by the relationship:

$$SFDR_3 = \frac{2}{3}\left(IIP3 - F - B - kTo\right) \qquad dB \cdot Hz^{2/3} \tag{1}$$

where kTo is –174 dBm/Hz, B is the bandwidth in dB, F is the noise figure in dB, and IIP3 is the input third-order intercept in dBm. IIP3 is the (imaginary) point where the fundamental and third order intermodulation (IMD) responses intersect. $SFDR_3$ can be improved by improving the noise figure and the input intercept. Linearization results in improvement in IMD, and hence IIP3. $SFDR_3$ will ideally improve one-third as fast as the IMD products, i.e. a 3 dB improvement in IMD results in a 1 dB improvement in $SFDR_3$.

III. Linearized microwave link

Figure 1 shows the block diagram of our demonstration platform. A commercial $LiNbO_3$ MZM was driven by a 1550 source laser and locked to quadrature. The linearizer circuitry consisted of our single-device predistorter element, and amplifiers to set the levels at its input and output. We also embedded a slope equalizer at the predistorter output to offset the negative slope of the MZM.

The predistortion linearizer functions by providing an opposing gain and phase power transfer with respect to the nonlinear system. The linearizer expands the gain, offsetting the compression of the nonlinear system. In the case of MZM direct-detect links, there is little or no nonlinear phase change.

Figure 2 shows the gain responses as a function of input drive level for both the nonlinearized and linearized links at 8 GHz. The nonlinearized MZM exhibits its characteristic gradual gain compression; the input 1 dB compression point is 5.7 dB from saturation. With proper alignment of the linearizer, the linearized response shows a much sharper gain transfer, with the 1 dB compression point moved to about 1.2 dB from saturation. A properly aligned linearizer will result in a transfer response that approximates an ideal limiter. Similar linearized results were obtained from 4-12 GHz.

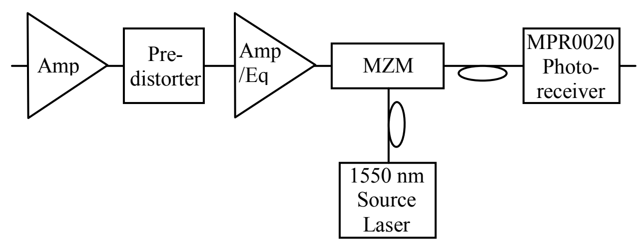

Fig. 1. Experimental wideband linearization demonstration system.

Figure 3 shows the small and large signal frequency response of the linearized link, from 5 to 13 GHz. The bandwidth of our predistorter element is inherently very broad. Frequency limitations arise primarily due to the amplifiers and impedance matching.

IV. Results

A. Linearity Improvement

The IMD products of the linearized and nonlinearized link were measured from 4-12 GHz. Figure 4 shows these results. The drive levels are normalized to input power backoff (IPBO) where 0 dB is the input-to-sat. The results show dramatic improvement in IMD over all drive levels except very close to saturation. The best result occurs at 8 GHz, with a peak improvement of 30.6 dB at 11 dB IPBO.

The nominal improvement at each frequency should be referenced to the region of the curve where the linearized IMD is parallel to the nonlinearized. This represents the baseline for IIP3 and SFDR improvement. Table 1 summarizes these results.

B. *$SFDR_3$ Capability*

$SFDR_3$ measurements were made directly and the results compare to those shown in Table I. At 8 GHz, the nonlinearized IIP3 was 19 dBm; it improves to nearly 31 dBm with a zero-loss linearizer. The noise figure of the link depends on the link loss, the optical level, and other factors as described in [5]. A typical direct-detect link with no noise reduction will exhibit noise figure on the order of 40 dB at 8 GHz. This results in $SFDR_3$ of 102 $dB{\cdot}Hz^{2/3}$ nonlinearized, and 110 $dB{\cdot}Hz^{2/3}$ for the linearized link. A zero-loss linearizer will not appreciably degrade the system noise figure. Link noise reduction techniques, such as described in [6], may provide 20 dB noise figure improvement, increasing the SFDR capability of the linearized MZM link to 123 $dB{\cdot}Hz^{2/3}$.

V. Discussion

A. *Bandwidth*

These results indicate that predistortion linearization has the capability of multi-octave correction of fiber optic links. The bandwidth is limited by the microwave amplifiers and matching of the system.

B. *Second-Order Response*

Predistortion circuitry as demonstrated here will primarily affect the odd-order components of the nonlinear system, while not improving the even order terms, such as two-tone second-order and harmonics. In some cases, the predistorter may degrade the second order response. This may limit the usable bandwidth to one octave. Techniques for improving the even-order linearity are being investigated, using the basic predistorter topology described here.

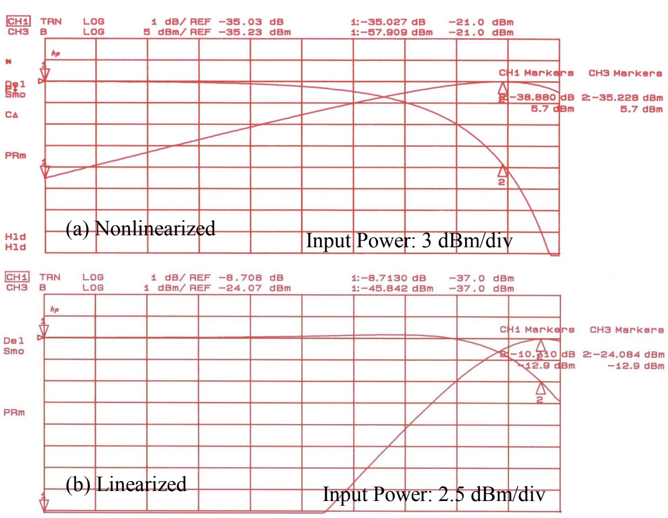

Fig. 2(a). Gain and power transfer response of (a) nonlinearized and (b) linearized MZM link at 8 GHz. The linearizer moves the 1dB compression point to within 1.5 dB of saturation.

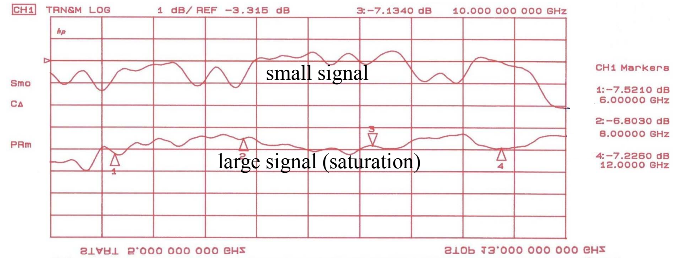

Fig. 3. Small and large signal gain of the linearized link. The predistorter is generally flat beyond the range from 5 to 13 GHz.

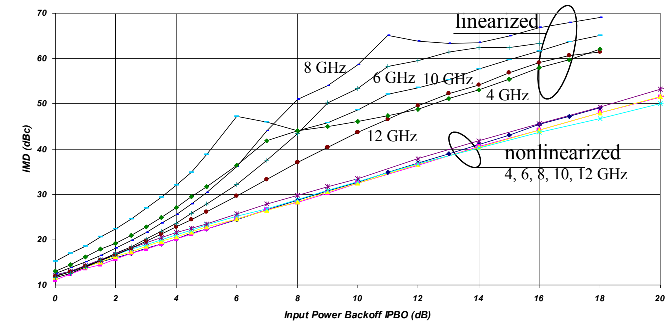

Fig. 4. Measured third-order IMD products of nonlinearized and linearized link. The linearizer provides C/I improvement over 1.5 octave.

TABLE I

IMD, IIP3, and SFDR Improvement of Linearized Link

Frequency (GHz)	IMD Improvement (dB)	IIP3 Improvement (dBm)	SFDR3 Improvement ($dB{\cdot}Hz^{2/3}$)
4	13.3	6.65	4.43
6	20.0	10.0	6.67
8	23.6	11.8	7.87
10	17.9	8.95	5.97
12	12.3	6.15	4.10

Acknowledgment

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