Characterization of Distortionless Analog Signal Multicasting by Parametric Mixer

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Abstract: We present characterization of a two-pump parametric device for analog linear multicasting. Linearity of parametric multicasting is assessed from highly linearized input seed by two-tone intermodulation measurements. Experimental results confirm distortionless behavior of four-photon mixers.

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1. Introduction

Photonic or photonic-assisted analog-to-digital conversion (ADC) is identified as a critical function required to analyze the waveform at the end of either analog or digital link. Analog applications have long recognized the importance of high-rate, high-precision ADC in completing the link [1] and photonic preprocessing was identified early for its potential for enhancing the performance of electronic ADCs beyond their classical limit [2].

A channelizer is a specialized class of preprocessor [3]. The ideal channelizer, should be capable of dividing the spectrum of the fast analog signal into a large number of arbitrarily narrow-band subchannels that can be easily processed by high-resolution ADCs. Conventional channelizers are often realized by an amplify-and-split topology. However, this simplistic approach imposes impractical requirements on the demultiplexing filter bank and suffers from inherent high losses. An alternative approach consists in replicating the original signal spectrum to a set of arbitrarily spaced frequencies, thus easing the filter bank construction and reducing losses. Unfortunately, the new channelizer architecture also requires the ability to spectrally multicast the original signal *in a distortionless manner* and the possible candidate devices are few due to either their low efficient, noisy or distorting behavior [4].

A viable candidate is the self-seeded parametric mixer which was recently used for digital multicasting [5]. Although such a mixer would intuitively be classified as a nonlinear device, it uses a set of continuous wave pumps and should support, at least in principle, the new concept of linear mixer. The linear assessment of the mixer can be performed with measurements of standard intermodulation distortions, i.e. multi-tone products between two or more RF tones. The device performance is quantified by the third order intermodulation intercept point (IIP3), i.e. the intersect of the extrapolated fundamental products and the intermodulation distortion (IM3) products. An ideal mixer should result in *identical* IIP3 points between the original input seed and any parametric copy. However, typical modulators have high nonlinear behavior which could mask the real performance of the optical mixer. In this letter we present distortion characterization by rigorous IIP3 two-tone measurements of an analog signal in a parametric multicaster using a linearized modulator. The measured results show that the high linearity of the original seed is ideally transferred to its copies, corresponding to perfect linear behavior of the mixer.

2. Experimental Architecture

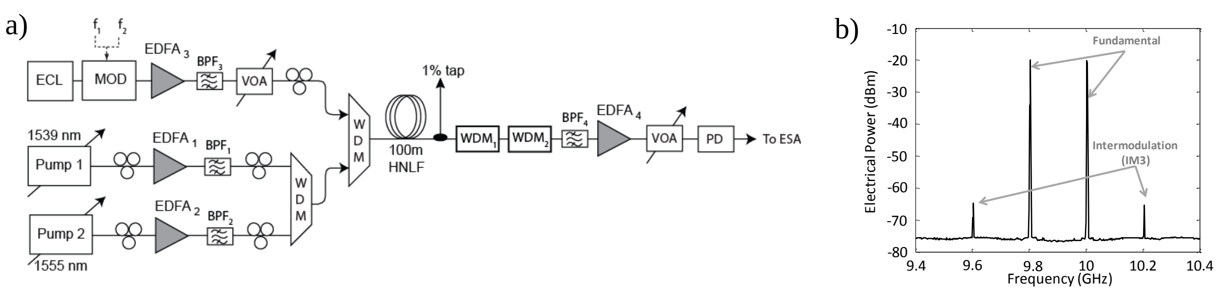

Fig. 1: a) Experimental setup. ECL: external cavity laser. MOD: modulator. BPF: band pass filter. WDM: wavelength division multiplexer. PD: photodiode. ESA: electrical spectrum analyzer. b) Typical RF spectrum at the modulator output showing fundamental and IM3 tones.

The experimental setup is shown in Fig. 1. To measure IIP3 points, two microwave sources at frequencies f_1 = 10 GHz and f_2 = 9.8 GHz were combined at the input of the specialized modulator (MOD). The modulator could be set to operate in two modes: normal modulation and linearized modulation, A 1550.9 nm source was modulated, amplified and filtered to remove any out-of-band amplified spontaneous emission (ASE). A 2-pump mixer was constructed from two tunable ECLs (Pump 1 and Pump 2) positioned at 1539 nm and 1555 nm, respectively. The pumps were amplified and combined by a wavelength division multiplexer (WDM) before being combined with the signal seed through an additional WDM. The pumps and signal were launched into a 100 m segment of highly nonlinear fiber (HNLF), characterized by a zero dispersion wavelength (ZDW) at 1550 nm, a slope of 0.03 ps/nm^2-km. Programmed longitudinal HNLF tension was applied to increase the Brillouin threshold of the fiber from 220mW to more than 1W. The optical power of the mixer input signal was controlled by a variable optical attenuator (VOA) in order to test the linear dynamic range. At the output of the mixer, the pumps where first stripped and individual copies were extracted by band pass filters. Finally, the selected copy was amplified and sent to a photodiode (PD) and an RF spectrum analyzer for measurements of the fundamental and IM3 products. The input power to the PD was kept constant for all measurements to avoid biasing the mixer characterization by nonlinear diode response. A typical RF spectrum collected at the output of the modulator is shown in Fig. 1 b) for RF fundamental tone powers of 8 dBm each, illustrating the fundamental tones (10 GHz and 9.8 GHz), and the generated IM3 products at 10.2 and 9.6 GHz, respectively.

Back to back measurements were done to establish the performance of the modulator, both in normal and linearized modes. The IIP3 point was estimated by varying the RF input power of the two fundamental tones: while the fundamentals grow linearly with the input power, the IM3 products have a cubic power growth until the mixer reaches saturation. Measurements on all generated copies were then performed for optical input signal powers spanning more than 20 dB. Finally, the measurements on the copies were compared to the back to back measurement for assessment of the mixer linear behavior.

3. Experimental Results

The output of the multicast mixer is shown in Fig. 2 for different input signal powers. The pump position and powers were carefully selected for flat gain generation of 5 copies of the 1550.9 nm signal seed, positioned at 1535 nm, 1543nm, 1550.9 nm, 1559 nm and 1567 nm. The results shown are for pump powers of 450 mW for P1 and 850 mW for P2. The power evolution of all 5 copies as a function of input signal power is plotted in Fig. 3 a). Linear power evolution of all copies was observed with excellent equalized performance over the 20 dB dynamic range, despite generation of higher order light. The individually selected copies for RF linearity assessment are plotted in Fig 3 b), depicting the high quality and good extinction ratio of the five copies at the input of the photodiode.

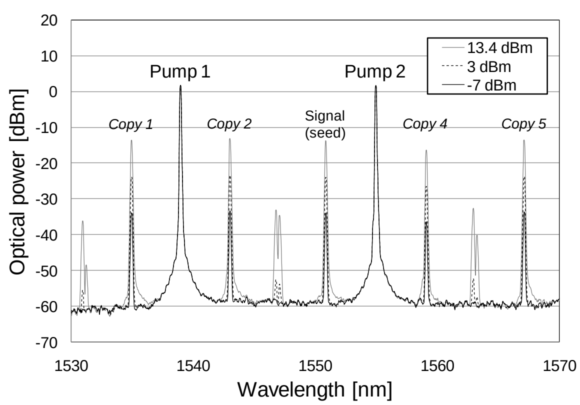

Fig. 2: Optical spectrum at the output of the multicast stage (1% tap) for 3 different signal input powers.

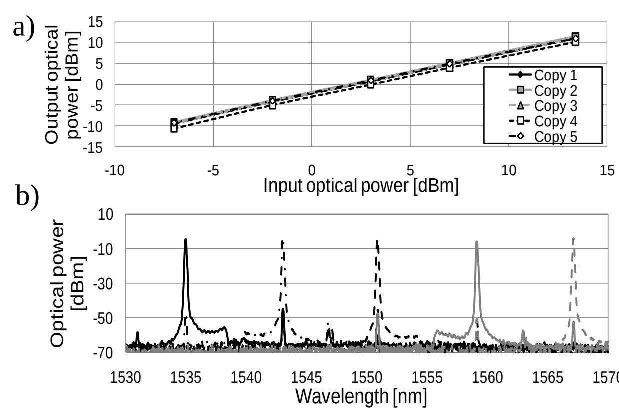

Fig. 3: a) Output power of multicast copies as function of input signal power. b) Superimposed spectra of selected copies before PD

The modulator was characterized through back to back intermodulation distortion measurements for both the normal and linearized mode of operation. The RF power of the fundamental tones was varied between – 8 and 8 dBm. Fig. 4 plots the back to back RF output power as a function of the RF input power. The IIP3 points for the normal and linearized mode, $IIP3_{non}$ = 24.3 dBm and $IIP3_{lin}$ = 30.4 dBm respectively, were retrieved, corresponding to a measured 6.1 dB improvement between the normal and linearized mode. RF powers below -95 dB could not be

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measured, due to limitation imposed by the ESA. The highly linearized input signal was then sent through the parametric mixer for multicasting. The distortions on Copy 2 for different input signal powers are shown in Fig. 5. The optical power was swept between -7 and 13.4 dBm, limited only by the EDFAs. The mixer resulted in *identical* IIP3 points between the back-to-back and Copy 2. The mixer did not add distortions resulting in perfect replication of the highly linearized input signal. It should be noted that slight nonlinear behavior of the mixer could have been buried within the distortions of a normal modulator. Furthermore, the input optical power to the multicast mixer did not have an impact on the IIP3: the measured linearity results indicated highly linear behavior over a range of input optical power of more than 20 dB.

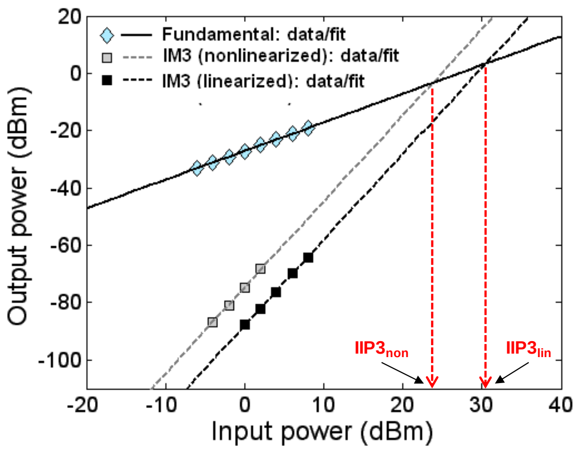

Fig. 4: Back to back variation of the fundamental for the normal and linearized mode of operation.

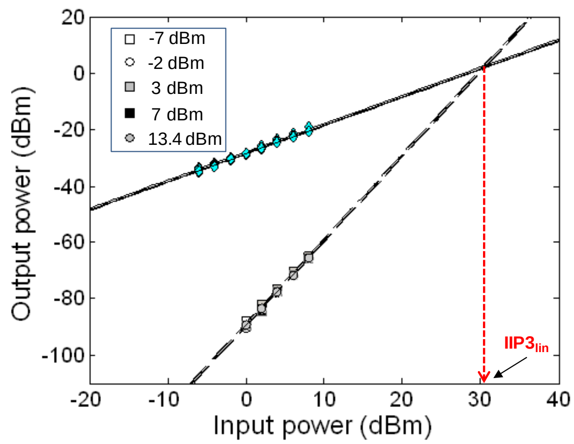

Fig. 5: Variation of the fundamental and IM3 powers for Copy 2 for optical input power to mixer between -7 and 13.4 dBm.

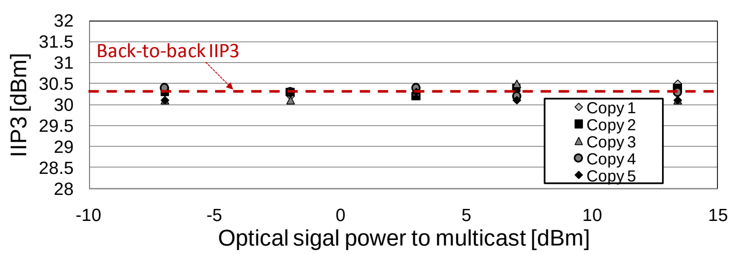

Fig. 6: Measured IIP3 values for all copies as a function of signal power. Back-to-back IIP3 shown in dash line.

Finally, the same measurements were repeated on the additional 4 copies and the results are plotted in Fig. 6. As expected all copies exhibited similar behavior. Less than 1% IIP3 variation was measured within the 5 copies and between the copies and back-to-back value of 30.4 dBm.

4. Conclusions

We presented the distortion characterization of an analog signal in a self-seeded parametric multicasting mixer. The linearity of the parametric device was assessed by two-tone measurements of the third order intermodulation products. A linearized modulator was used to facilitate and substantiate the evaluation of the mixer performance. The measured linearity results indicated highly linear behavior over a wide range of input signal power, confirming the viability of parametric mixers as *linear* mixers and possibly channelizer.

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