Improve Gain, Noise figure and Spurious Free Dynamic Range in Intensity Modulation Analog Photonic link using Digital Signal postprocessing compensation by Linearized Downconverting Algorithm.

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Abstract - In this paper, we describe technique for performance improvement in analog photonics link incorporating digital signal post processing compensation technique by linearized down converting algorithm. We are investigating the performance components in this link and discuss the extent to which their performance varies with frequency, and show which of these components frequency-dependent parameters which affect; figure of merit in terms of gain, noise figure, and spurious free dynamic range. The proposed linearization does not require knowing the precise transfer function of the whole nonlinear system, which is achieved by directly acquiring the output third-order intercept point (IMD3) from Down converting algorithm. Using a high-performance improved link noise figure and gain are obtained while the nonlinearity can be also be compensated by the proposed algorithm. In our previous work measured noise figure and gainof the photonic link are 8.9 and 27.5 dB, respectively and spurious-free dynamic range of 128.3 dB in 1-Hz bandwidth which when compared by using linearized down converting algorithm improves to give noise figure and gain of the photonics link as 2.7 and 31.08 dB and spurious-free dynamic range of 130.49dB in 1-Hz bandwidth for a digitizer noise limited analog photonics link without using any cascade structure of pre and post amplifier

Keywords- Fiber optics, Radio frequency photonics, Digital signal post processing compensation technique, Low biasing.

I. INTRODUCTION

Analog photonics is the study of photonic devices, such as lasers and photo detectors, performing operations at microwave frequencies, and the application of these devices to microwave systems. The impact of photonics on digital communication systems is extensive and well known. Fiber optics carry massive amounts of data between users and services around the globe. These systems are finding applications in shorter and shorter distances, from long-distance telecommunications, to communication between servers in data centres, to interconnects within computers themselves.

Analog photonic link has become very attractive during the past years for both commercial and military applications, such as antenna remoting, radio astronomy, etc. In some challenging applications such as military use, analog photonic link must meet the stringent performance requirements in terms of dynamic range, gain, and other figures of merit.[1] Spurious free dynamic range (SFDR) is an important figure of merit that is usually used to evaluate the degree of linearity in analog photonics link . The inherent nonlinear characteristics of Mach-Zehnder modulator (MZM) introduces both harmonic product and inter-modulation distortions of the analog RF signal, of which the third-order intermodulation distortions (IMD3) are most pronounced and limit the SFDR of the system .[2] the third-order

intermodulation distortion (IMD3) components should be particularly considered as they lie very close to the radio frequency (RF) carriers and are impossible to be eliminated by simple RF filtering. The IMD3 will then significantly reduce the SFDR performance of the link [3].

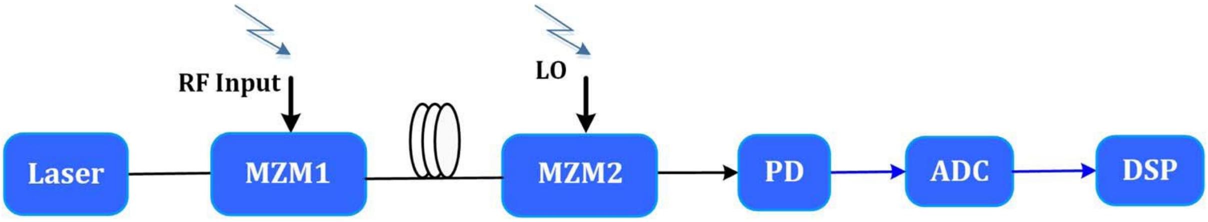

Fig. 1.General IMDD analog photonic link with optical down-conversion and DSP-based linearization.
LO: local oscillator; ADC: analog-to-digital converter[1]

Multiple link parameters related to the laser, the modulator, and thephotodiode should be precisely known, which may otherwise result in significant imperfections. Furthermore, the SFDR capability does not tell the complete story for an analog photonics link, the gain and noise figure (NF) are also very important metrics that generally used to quantify the performance.[4] The design of the analog photonics systems requires careful consideration of all the performance parameters in terms of SFDR, gain and NF [6].

Downconversion Theory

Figure2. is a simplified block diagram of the down conversion scheme .A continuous-wave (CW) laser is modulated by MZM and transmitted over fiber to the receiver. In the receiver, the signal enters a second MZM that is driven by a strong microwave LO.Local Oscillator (LO) and the amplified two-tone input RF signal is converting to IF. This process is known as down conversion.

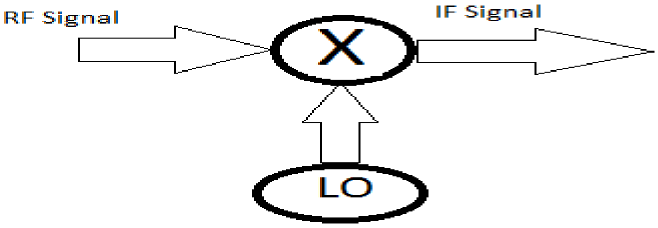

Fig. 2 Down-converted electrical signal

The optical down-conversion combined with DSP has been considered as a promising strategy forremote RF receiving[7]. Digital linearization for phase and polarization modulation has been widely discussed, for its linear modulation and demodulation at both ends[8].

Mach-Zehnder Modulator

Optical modulators are used for electrically controlling the output amplitude or the phase of the light wave passing through the device. To reduce the device size and the driving voltage, waveguide-based modulators are used for communication applications. Mach-Zehnder Modulator is use for the power of the input is split equally into the two output waveguides of the first directional coupler.

Our proposed method of the analog photonics systems requires careful consideration of all the improve parameters in terms of SFDR, gain and NF .

II. Principle of the Scheme

Analog photonic link using digital signal post processing compensation by linearized down converting algorithm without any cascade structure of pre and post amplifier .The schematic architecture of the proposed method shown in Fig. 3(a).and The block diagram of the proposed method shown in Fig.3(b).

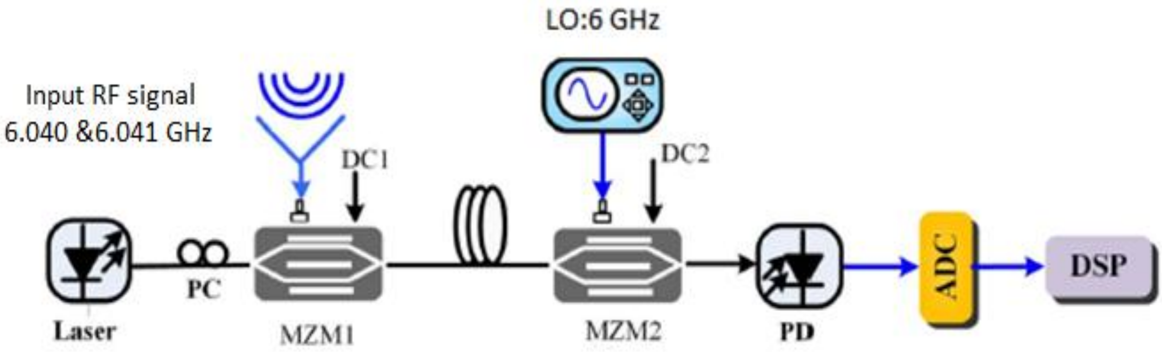

Fig3(a) The schematic diagram[1]

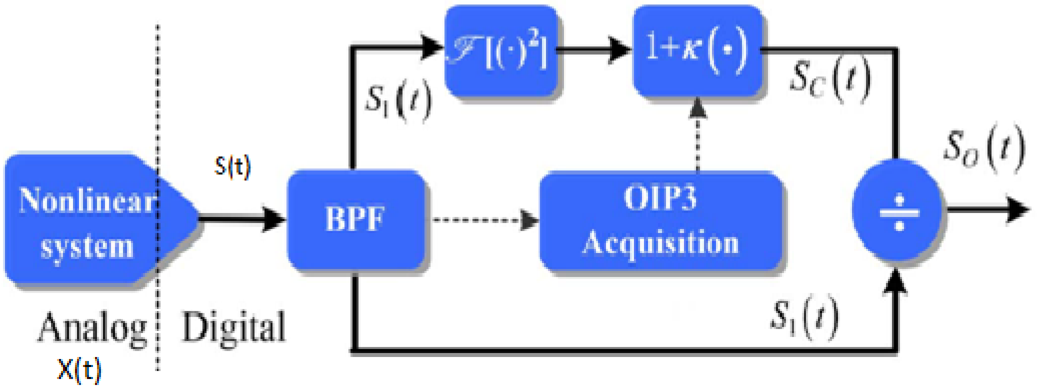

Fig.3(b) The block digram of the proposed Method .

The output of the optical source is modulated by an electrical band-pass signal [1].

$$X(t) = A(t)Cos(\omega_{RF}t) \qquad (1)$$

Where $A(t) = 2V(t)\cos(\Omega t)$ is the equivalent amplitude of the input two – tone signal. Here

V (t) is amplitude of input signal.

The RF angle frequency isω_{RF}.

We apply proposed method .From equation(1) is output of the laser .The output of laser is detected by link. We assume link voltage to voltage transfer function which is amplified by MZM2. We can be expressed in terms of input two tone signal X(t). andgiven by the power series expansion.

$$S(t) = C_0 + C_1 X + C_2 X^2 + C_3 X^3 + \ \dots\dots\dots\dots\dots \qquad (2)$$

where$C_j\,(j = 1, 2, 3 \dots.)$ are the coefficients of the power series. Which are determined by the specific parameters of the MZM2 and the PD .

Substitute equation (1) into (2), and signal S(t) pass through band pass filter(BPS) , after band pass filter the output voltage around the fundamental signal can be given as

$$S_1(t) = C_1\left[1 + \frac{3C_3}{4C_1}A^2(t)\right].A(t)Cos(\omega_{RF}t) \qquad (3)$$

Band pass filter is pass middle power and stop low power and high power solow order harmonic and higher order harmonic are ignored .

Output of band pass filter $S_1(t)$ is through $\mathcal{F}[(*)^2]$the narrow-band and low-pass filtering. Than algorithm 1+k(*) .such that as expression is

$$S_c(t) = \left[1 + \frac{3C_3}{4C_1}A^2(t)\right] = 1 + kF[S_1^2(t)] \qquad (4)$$

Where k is nonlinear compensation constant.

Here $k = \frac{3C_3}{2C_1^3}$

Result of after algorithm shown in equation (4); its bandwidth should be large enough so that there is no obvious distortion on $A^2(t)$ .which will be increased when the signal bandwidth is enlarged. However, the bandwidth should be less than $\omega_{RF}/2\Pi$. which also shows a limitation on the bandwidth of the input signal. Since the filter is a digital one, its phase response can be ideally linear by a finite impulse response (FIR) filter.

Our proposed method also we note that the third-order output intercept point (OIP3) of the system can be expressed
As

$$OIP3 = -\frac{2C_1^3}{3C_3Z_{out}} \tag{5}$$

whereZ_{out} is the output impedance,
Note that the negative sign results fromthe negative C_3.
We can calculate relation between OIP3 and nonlinear compensation constant. This relation is given as

$$k = -\frac{1}{OIP3\ .Z} \tag{6}$$

The OIP3 should be known by the algorithm, which can be easily and precisely acquired by using a dual-tone signal. The RF spectrum is captured and the corresponding powers of fundamental and IMD3 tones, $P_1$and P_3, can be calculated.it is given as

$$OIP3 \approx \sqrt{\frac{P_1^3}{P_3}} \tag{7}$$

By using the compensation signal in equation (4), the distortion can be eliminated and the linearized output signal can be finally calculated as

$$S_0(t) \approx \frac{S_1(t)}{S_c(t)} = C_1A(t)\cos(\omega_{RF}t) \tag{8}$$

A system containing a pair of modulators, cascaded in series, can be employed to down-convert the RF signals to intermediate frequency .The MZM2 is driven by a strong local oscillator (LO) . The nonlinearity introduced by the MZM2, both difference-frequency and sum-frequency of RF signal and LO are generated. The sum-frequency is beyond the operational bandwidth of the system. Consequently, it doesn't need to be taken into consideration. The presented difference-frequency component is the desired intermediate frequency (IF) signal. After the optical down-conversion, $S_1(t)$is shifted to the IF and additional insertion loss is imposed to it[2].

Our proposed method is made possible by acquiring the OIP3 of the cascaded system therefore The IMD3 induced by the nonlinear voltage to voltage transfer function. We can be eliminated through using digital signal post processing compensation technique, resulting in an improved upper limit for the SFDR..The fundamental to IMD3 ratio is deteriorated once the estimated OIP3 in the digital algorithm deviates from the actual one. The OIP3 will change due to the laser output power fluctuation or link loss variation, which can be updated based on equation (7).

We haveachievedthe best overall NF, a low noise and high gain in this system. The detected IF output is amplified by MZM the photonics link, through which the output level is matched with that of the ADC. So the system is ADC noise dominated while the upper limit of the SFDR can be extended by the proposed method .

This system requires a photodiode capable of handling high optical power. Research devices have been demonstrated that can handle much higher powers than this, but this is still an expensive device. In order to evaluate the performance improvements of the proposed technique. The third-order distortion and noise limited SFDR for this link is derived in dB units per 1 Hz bandwidth by as

$$SFDR = \frac{2}{3}.10\log(\frac{2I_{DC}}{e}) \qquad 9$$

Where: e is the elementary charge
$I_{DC}$the effective DC photocurrent.

The Noise figure is calculated by using

$$\mathrm{NF} = 10\log(\frac{2\mathrm{e}\mathrm{V}_{\Pi}^{2}}{\mathrm{I}_{\mathrm{DC}}\,\Pi^{2}\mathrm{KT}\,\mathrm{Z}_{\mathrm{in}}}) \qquad 10$$

Where: V_{Π} is the modulator half-wave voltage,
K is Boltzmann's constant,
T is the system temperature ,
$Z_{in}$is the input impedance of the system

The Gain is calculated by using

$$G_{dB} = OIP3_{dBm} - \frac{3}{2}SFDR + 174\frac{dBm}{Hz} - 10\log(B) - NF_{dB} \qquad 11$$

Where: B is bandwidth in Hz.
$OIP3_{dB} = 10\log(OIP3\ W/0.001\,W)$.

III. Simulation and Results

Result Analysis

We have evaluated Figures of merit and Spurious Free Dynamic Range in Intensity modulation Analog Photonic Link without using any cascade structure of pre and post amplifier. Here we have applied the continuous-wave (CW) laser source which operates at wavelength of 1550 nm is used as the optical carrier. and have generated by two vector signal generators two RF frequencies of 6.040 GHz and 6.041 GHz, and after follow both signal MZM1 . Another polarization controller (PC), which is placed before MZM2, is used to adjust the principal axis of the modulated output of the MZM1 with that of the following MZM2.Now we have applied 6GHz Local Oscillator (LO) and the amplified two-tone RF signal input which isemployed to down-convert the RF frequency to IF.

Table 1

Parameter	**Value**
Input RF signal	6.040 & 6.041 GHz
LO	6 GHz
The effective DC photodiode current (I_{DC})	3 A
The modulator half-wave voltage(V_{Π})	6 V
The coefficientsC_1 *and*C_3 *respectively*	8 & - 60
The input impedance (Z_{in})	50 Ω
The output impedance(Z_{out})	50 Ω
Thesystem temperature (T)	300 K
Boltzmann's constant (K)	1.381 X 10^{-23} J/K
Bandwidth in Hz (B)	1 Hz
OIP3	37.5dB
SFDR	130.49 dB in 1-Hz
NF	2.7 dB
Gain	31.08 dB

Simulation

Uur proposed method concept is carried out and shown in Fig. 3. The laser operates at a wavelength of 1550 nm .Two RF tones, with frequencies of 6.040 GHz and 6.041 GHz, respectively, are generated by two vector signalgenerators and used to drive the modulator. The polarization controller (PC), which is placed before MZM1, is used to adjust the principal axis of the modulated output of the laser with that of the following MZM1. the output modulated light beam is aligned with the following standard MZM2 by another polarized controller. The amplified two-tone input is then introduced to the quadrature biased MZM. Another MZM in series, which is driven by a 6 GHz LO, is employed to down-convert the RF frequency to IF. The modulated optical signal is received by a photo diode (PD) and which makes the output level comparable with that of the following digitizer. The output voltage is then recorded by the ADC (ADC linkwith 14-bit level and 200 MS/s) The digitized signalprovided by the ADC then undergoes the digital signal postprocessing(DSP) linearized down converting algorithm as shown in Fig. 3(b) . Firstly, the OIP3 is initialized by using Eq. (6) with a training dual-tone. Consequently, the down-converted signal is obtained and linearized according to Eq. (3) and (7).

In order to evaluate the performance improvements of the proposed technique. Thespectram of the proposed technique is compared with that of a conventional link without the proposed technique, which is demonstrated in Fig. 4. The down-converted fundamental at 40.2 MHz and 41.1 MHz as well as the corresponding intermodulation distortions at 39.1 MHz and 42.0
MHz are presented for both cases.

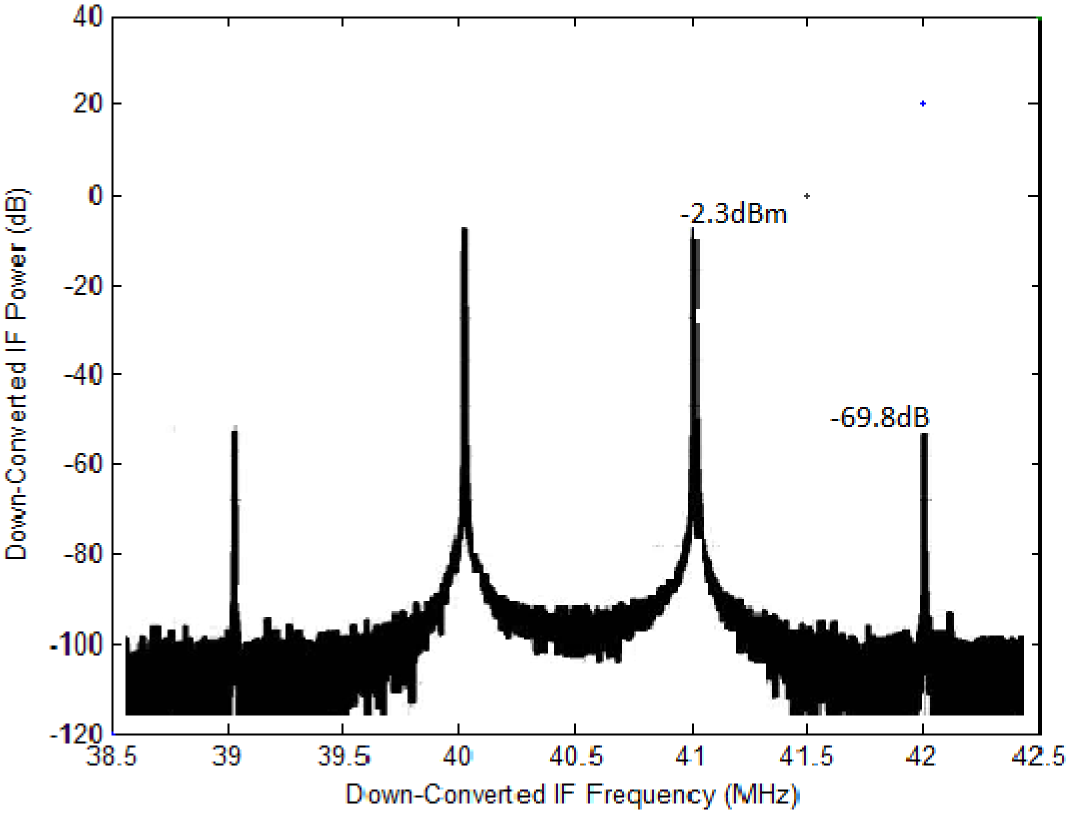

Fig.(a)

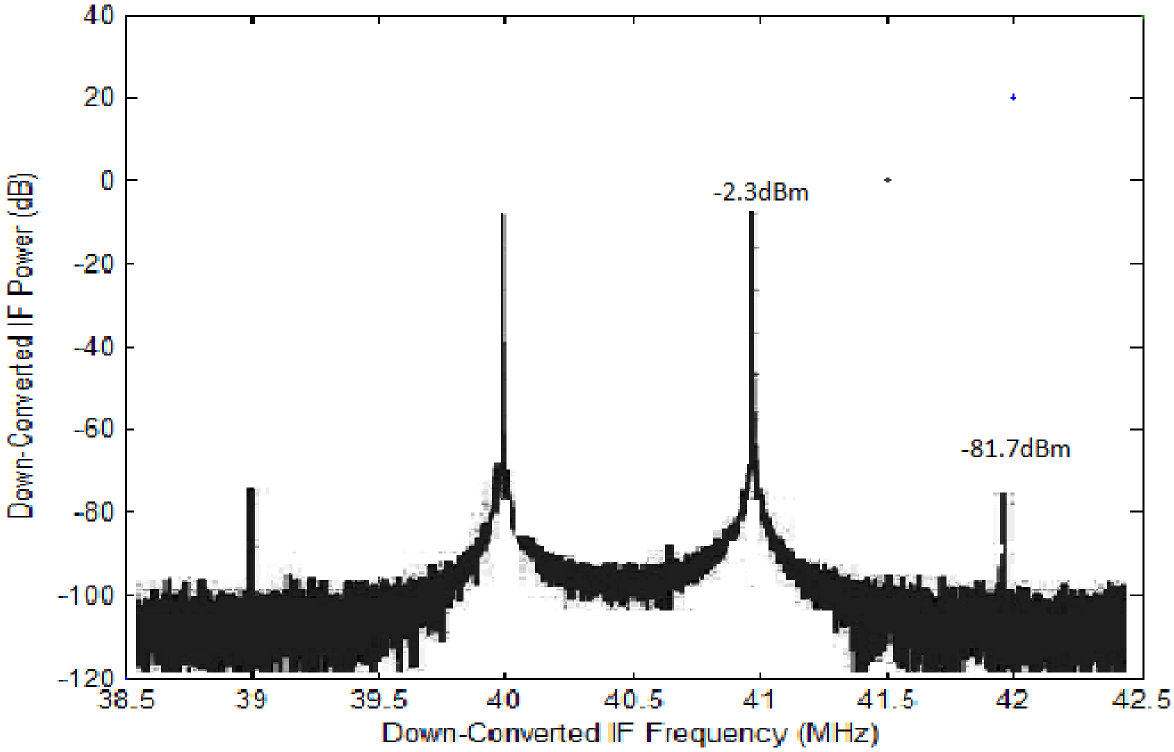

Fig.(b)

Fig. 4. Down-converted electrical spectra (a) before and (b) after the proposed digital signal linearization down conversion algorithm .

The OIP3 used in the algorithm is 37.5dB, which is also the measured value as shown in Fig. 5(a). Fig. 5(a) and 5(b) illustrate the output IF power versus the input RF power at the fundamental frequencies of 6.040 and 6.041 GHz for systems with and without the linearization, respectively.Note that since the proposed approach is performed in digital domain, The IF output is amplified by a specially selected. The down-converted SFDR with nonlinear compensation is 130.49 dB in 1 Hz bandwidth, which is 25.09 dB more than that without compensation, as shown in Fig.5(b).

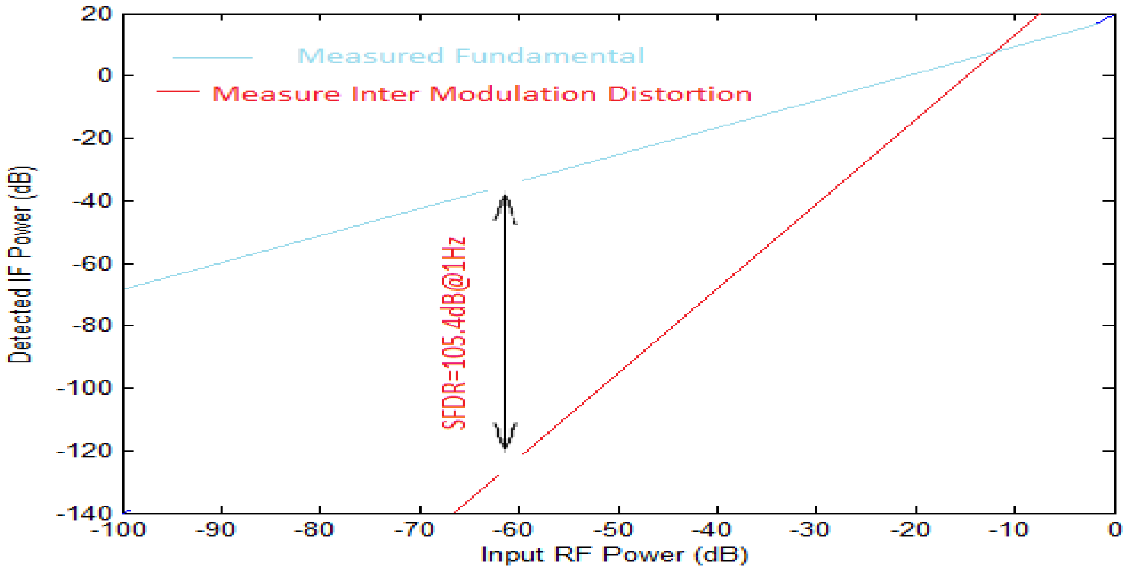

fig.5(a)

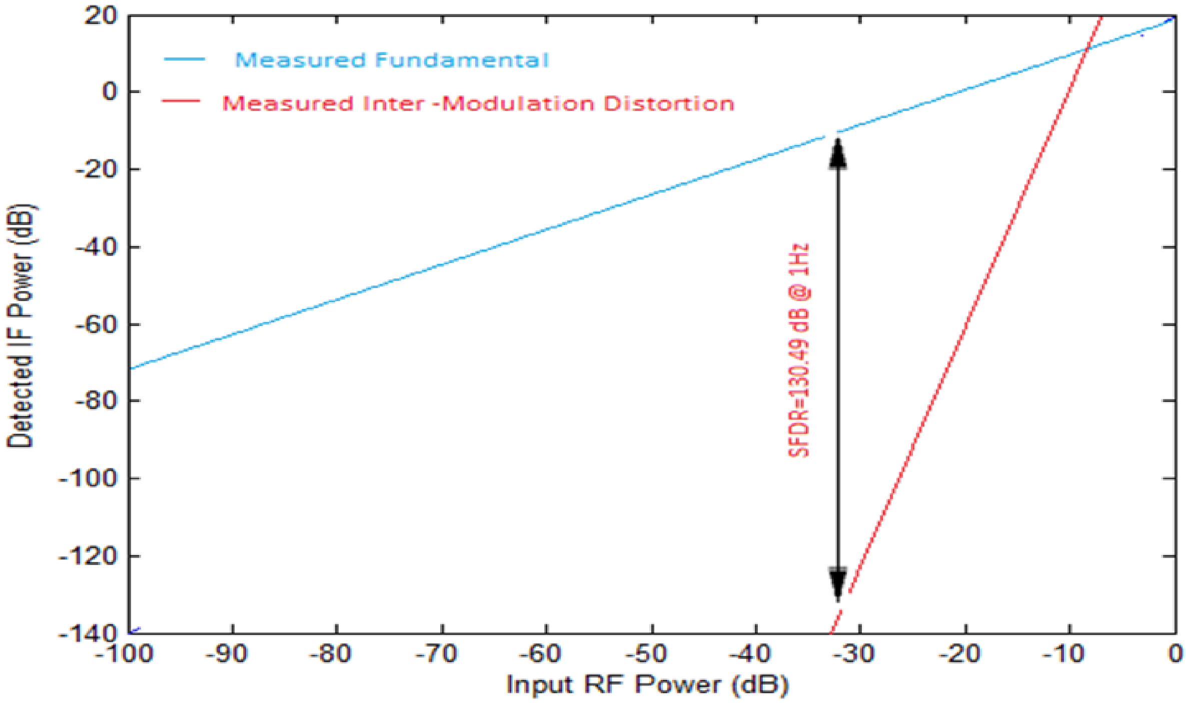

fig.5(b)

Fig. 5 Output fundamental and intermodulation distortion powers versus the input RF power at 6.040 and 6.041 GHz. (a) Before and (b) after the proposed linearized down converting algorithm

IV. CONCLUSION

We proposed and demonstrated a digital signal for the conventional MZM-based intensity-modulation direct-detection analog photonic link maintaining the noise figure, gain and SFDR same without using any cascade structure of pre and post amplifier. Comparatively measured noise figure and gain of the photonic link are 8.9 and 27.5 dB, respectively and spurious-free dynamic range of 128.3 dB in 1-Hz bandwidth as well as experimental results shows improved noise figure and gain of the photonics link as 2.7 and 31.08 dB, respectively as well as spurious-free dynamic range of 130.49 dB in 1-Hz bandwidth is achieved for a digitizer noise limited analog photonics link without using any cascade structure of pre and post amplifier

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