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Multi-Wavelength Variable Drive-Voltage Modulator for use in High Dynamic Range Photonic Links

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Abstract—A novel technique for linearizing photonic links employing Mach-Zehnder modulators is presented. A truncated Fourier series representation of a linear transfer function is used to determine the modulator drive voltages V_π and the optical power levels to be applied to a dual parallel modulator configuration. Simulation results are used to compare the dynamic range performance of the dual modulator configuration with a standard single modulator photonic link. The dual modulator configuration shows that improvements in compressive and spurious-free dynamic range can be achieved over the single modulator configuration, and that it is possible to further optimize the parameters to yield a significant improvement in spurious-free dynamic range without degrading the 1dB compression point or the compressive dynamic range.

Keywords—linearization, photonic links, Mach-Zehnder modulators, high dynamic range links.

I. INTRODUCTION

The introduction of photonic systems in electronic warfare platforms has seen the improvement of dynamic range become a major research focus. High optical power and balanced detection has been used to maximize link gain while minimizing relative intensity noise (RIN) [1]. Linearity is also a significant factor limiting dynamic range and will be the focus of this paper.

The Mach-Zehnder modulator has an inherently non-linear transfer characteristic, which leads to the generation of unwanted harmonics and intermodulation products. These may then limit the dynamic range of the photonic link in which the modulator is embedded. An established technique for addressing this problem is to use multiple modulators to provide cancellation of unwanted distortion products [2, 3] or to use multiple polarizations within the one modulator to achieve cancellation [4]. In both cases the desired signals do not cancel.

The above-mentioned schemes have all been successful in significantly reducing harmonics or intermodulation products, but in all cases the cancellation is critically dependent upon the modulator characteristics. Bridges and Schaffner [5] have provided an excellent summary of the above linearization techniques and have presented link simulations using a simplified optical link model. They found that for systems

employing linearization, the distortion products no longer follow a simple exponential relationship to the RF drive level. Therefore, parameters such as the third-order intercept point cannot be simply calculated as the third-order products do not follow the typical 3:1 level increase versus RF input power level. Situations can also arise where a particular distortion product (IM_3 or 2nd harmonic) may cross the output noise level a number of times, with the slope of the curve being different at different locations. They therefore proposed that the dynamic range should be specified as a Spurious-free Dynamic Range (SFDR), being the difference in input RF power level between the point where the signal output level is equal to the output noise level and the point where the first distortion product is equal to the output noise level.

It should be noted that all of the schemes reported above employed modulators with the same V_π , and the biasing of the modulators and the selection of V_π were not used as design variables. Only the RF and optical power levels were used as design variables. Also, it has been assumed that the modulators are biased at quadrature, thus ensuring suppression of the second harmonic.

All of the cited analyses have also assumed operation at a single frequency. It is known that the modulator characteristics, and in particular the modulator drive voltage, may vary significantly with frequency. An investigation [6] has been published on the impact of bandwidth on optimal dynamic range configurations.

As concluded in [4], optimal dynamic range performance is very sensitive to the characteristics of the modulators used. In this paper we use a single modulator device type with multiple optical wavelengths. One issue that must be considered is bias point variation with wavelength. Even small deviations of the bias point from quadrature may result in the emergence of significant second harmonic distortion. A technique to optimize the biasing of a single Mach-Zehnder modulator has been reported by Dubovitsky et al. [7]. In this paper, the aim was to ensure that the bias point of the modulator was optimized across a range of wavelengths for WDM applications. The technique does not, however, improve the IM_3 performance of the modulator.

We propose a similar approach to [5], but instead of adjusting the RF attenuation, we propose varying the

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modulator drive voltage (V_π). Our novel implementation utilizing WDM techniques allows simultaneous operation with multiple V_π . A dual modulator scheme is compared with a conventional single modulator photonic link and then results are presented for an optimized dual modulator configuration.

II. PHOTONIC LINK ANALYSIS

A diagram of a standard photonic link is presented in Figure 1. The modulator is driven with two signal generators, which are combined using an RF combiner and the intermodulation products are measured on a spectrum analyzer. Typical parameters for the photonic link are given in Table I.

TABLE I. TYPICAL PARAMETERS FOR THE STANDARD PHOTONIC LINK

Parameter	Description	Value
P_{op}	Optical power	10dBm
RIN	Relative intensity noise	-160dB/Hz
α_m	Modulator optical loss	4.7dB
V_π	Modulator drive voltage	4.5, 13.5V
R_{mod}	Modulator electrode impedance	40Ω
α_{op}	Optical loss in transmission	10dB
G_{op}	Gain of the EDFA	10dB
$\mathfrak{R}$	Photodetector responsivity	0.8A/W
R_o	Photodetector load impedance	50Ω
BW	Noise electrical bandwidth	1MHz

Figure 1. Schematic of standard photonic link with system parameters labelled.

Agilent-EEsof's Advanced Design System (ADS) was used to perform nonlinear analyses on the various link configurations. In the analyses, the optical intensity was modeled as voltage. A harmonic balance analysis with the nonlinear noise analysis option activated was used to simulate the link and include the various noise sources within the photo detector and the optical amplification. The electrical bandwidth was used for the noise calculations.

An initial analysis using a V_π of 4.5V is shown in Figure 2. This link yielded an input 1 dB compression point of 13dBm, a compressive dynamic range (CDR) of 75dB and a SFDR of 56dB (SFDR is calculated throughout the paper for a noise electrical bandwidth of 1MHz). To investigate the impact of increasing the drive voltage, the system was remodeled with a V_π of 13.5V (3x4.5). As expected, the input 1dB compression point increased to 22dBm, but the CDR and SFDR have remained constant at 75dB and 56dB respectively. These results confirm that adjusting the modulator V_π voltage does not alter the inherent dynamic range of the photonic link. The

use of two identical modulators in parallel will now be discussed as a means of linearizing the photonic link.

Figure 2. The modulated power out as a function of input power for the first harmonic and M_3 products of the photonic link presented in Figure 1 and Table I with a V_π voltage of 4.5V. The noise floor is also presented (calculated for a 1MHz noise electrical bandwidth).

III. LINEARIZATION TECHNIQUE

The dynamic range of the Mach-Zehnder optical modulator is limited by the fact that when it is biased at quadrature, its transfer function is only approximately linear for small input signals. The transfer function is actually sinusoidal, so modulation with a large RF signal will lead to nonlinear effects.

In order to achieve a linear response, a combination of multiple modulators in parallel can be used to approximate a linear transfer function. Consider a triangular wave as an example of a linearized response. This function can be decomposed into a Fourier series given by:

$$F(x) = \sum_{N=0}^{\infty} \frac{1}{(2N+1)^2} \sin((2N+1)x) \quad (1)$$

Taking the first two terms of this series we have

$$F(x) = \sin(x) + (1/9) \sin(3x) \quad (2)$$

To implement such a linearized function with two dual parallel modulators, we can use the configuration shown in Figure 3. Here one modulator has a V_π voltage of 4.5V while the other has a V_π voltage of $3 \times 4.5 = 13.5V$. The optical power of the low V_π modulator is (1/9) that of the high V_π voltage device. Note that the ratio of the two optical powers and the two V_π voltages correspond to the ratios of the multipliers of the $\sin$ functions and the coefficients of x respectively in (2). Use of additional modulators with a subsequent increase in the number of wavelengths used allows additional terms of the Fourier series to be realized. A greater degree of linearization (at the expense of increased complexity) is then possible.

Figure 3. Schematic of dual parallel linearized photonic link.

IV. RESULTS

A. Linearized Link with Two Modulators

The system of Figure 3 was simulated using ADS and the response is given in Figure 4. The input 1dB compression point, the CDR and the SFDR are 22dBm, 75dB and 46dB respectively. Comparing these results with those for the standard photonic link discussed earlier, we can see that in addition to the decrease in dynamic range, a null occurs in the third order intermodulation (IM_3) response. The location of this null can be exploited to improve the IM_3 response as will be shown in the next section.

Figure 4. The detected RF power as a function of input RF power for the first harmonic and IM_3 products of the two modulator linearized photonic link.

B. Optimally Linearized Link with Two Modulators

The location of the null observed in the IM_3 response is related to the choice of triangular waveform for the linearized response. To optimally improve the dynamic range of the system, the parameters of the dual parallel modulator configuration can be adjusted such that the null and nearby lobe are just below the noise floor of the system and thus the dynamic range is determined by the second lobe of the IM_3 response.

This optimization was the topic of investigation reported by Bridges and Schaffner [5]. They found that the optimal configuration is a factor of 2.7 in V_π and a factor of $(2.7)^3$ in optical power. The optimized system results from the ADS simulations are shown in Figure 5. The input 1dB compression

point remains at 22dBm and the CDR at 75dB (the values obtained for the dual parallel non-optimized link) but the SFDR has increased significantly to 68dB.

Figure 5. The detected RF power as a function of input RF power for the first harmonic and the IM_3 responses of the optimised two-modulator linearized photonic link, with V_π voltages of 4.5V and 12.5 V and optical powers of 10dBm and -3 dBm respectively.

By comparing Figures 4 and 5 it is evident that a significant improvement in SFDR can be achieved, which agrees with the findings reported in [5]. In a practical system, the optical power can be controlled dynamically and remotely by adjusting the laser power delivered to each modulator. Trimming of the V_π voltages remotely is much more difficult and it is expected that the V_π voltages of the two modulators will vary with frequency. This will be further exacerbated by the RF power split between the two modulators not being balanced for all frequencies, leading to a further varying of the V_π voltages.

Figure 6 presents the response of the two-modulator system with $V_{\pi 2}$ adjusted from 12.5 to 17.5V. Here it can be seen that increasing the V_π of modulator 2 shifts the null in the third harmonic towards higher input powers and raises the nearby lobe above the noise floor. The dynamic range thus reduces (from 68dB to 55dB) approaching the un-optimized situation of Figure 4.

Figure 6. The detected RF power as a function of input RF power for the first harmonic and the IM_3 responses of the optimized two-modulator linearized photonic link. V_π voltages $V_{\pi 1} = 4.5V$, $V_{\pi 2}$ ranges from 12.5 to 17.5V, $P_{op2} = 10dBm$ and $P_{op1} = -3dBm$.

Figure 7 presents the response of the dual modulator linearized system with $V_{\pi 1}$ adjusted from 4.5 to 6.3V. For even a slight increase of the V_{π} of modulator 1 with respect to modulator 2, the null in the third harmonic disappears and the dynamic range degrades rapidly (from 68dB to 60dB).

Figure 7. The detected RF power as a function of input RF power for the first harmonic and the M_3 responses of the optimized two-modulator linearized photonic link. V_{π} voltages $V_{\pi 1}$ ranges from 4.5 to 6.3V, $V_{\pi 2} = 12.5V$, $P_{op2} = 10dBm$ and $P_{op1} = -3dBm$.

It can be concluded from this investigation that the V_{π} voltages of the two modulators must be precisely balanced. This suggests that the bandwidth of such a system will be limited by the RF components used to deliver the signal to the modulators and also by the differences in the modulators themselves.

V. CONCLUSIONS

A model in Agilent-EEsof ADS has been constructed that is capable of modeling the dynamic range of various photonic link configurations including single and dual-modulator linearized configurations. The dynamic range of a single photonic link has been accurately modeled and the dynamic range of a dual parallel modulator has been modeled and it has been shown that the third harmonic can be nulled at a particular input RF power level, thereby greatly enhancing the SFDR. The sensitivity of the optimized configuration has been investigated and it has been shown that even small changes in V_{π} voltage can significantly affect the resulting dynamic range. This will have a significant impact on the operating bandwidth of such linearized photonic links. It is recommended that further work be undertaken to investigate the possibility of recovering degraded dynamic range performance for wideband applications through fine-tuning of the optical power of each modulator. Experimental results for the dual modulator systems will be presented at the conference.

REFERENCES

- [1] Newberg, I.L., "High-performance lossless RF fiber optic link", IEEE International Conference on Phased Array Systems and Technology, pp. 375–378, 2000.
- [2] S.K. Korotky and R.M. de Ridder, "Dual parallel modulation schemes for low-distortion analog optical transmission", IEEE Journal on

Selected Areas in Communications, Vol. 8, No. 7, pp. 1377–1381, Sept. 1990.

- [3] J.L. Brooks, G.S. Maurer and R.A. Becker, "Implementation and evaluation of a dual parallel linearization system for AM-SCM video transmission", Journal of Lightwave Tech., Vol. 11, No. 1, pp. 34–41, Jan. 1993.
- [4] L.M. Johnson and H.V. Roussel, "Reduction of intermodulation distortion in interferometric optical modulators", Optical Letters, Vol. 13, No. 10, pp. 928–930, Oct. 1988.
- [5] W.B. Bridges and J.H. Schaffner, "Distortion in linearized electrooptic modulators", IEEE Trans. on Microwave Theory and Tech., Vol. 43, No. 9, pp. 2184–2197, Sept. 1995.
- [6] U.V. Cummings and W.B. Bridges, "Bandwidth of linearized electrooptic modulators", Journal of Lightwave Tech., Vol. 16, No. 8, pp. 1482–1490, Aug 1998.
- [7] S. Dubovitsky et al., "Analysis and improvement of Mach-Zehnder Modulator linearity performance for chirped and tunable optical carriers", Journal of Lightwave Tech., Vol. 20, No. 5, pp. 886–891, May 2002.