Modelling and Analysis of an Electro-optical System with an Off-quadrature Biased Modulator

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Abstract— This paper describes the behavior of a microwave external modulation link composed of: optical and radio frequency sources, Mach-Zehnder modulator (MZ), optical fiber and photodetector. The electro-optical circuit modulates the RF signals and transmits them to the detector through the optical fiber. The main contribution of this paper lies on the different approach to the system analysis; we consider an off-quadrature biased MZM.

By extending the mathematical model found in the literature for the case of different bias voltages, we compute a few performance parameters of the system like Gain and SFDR. For computing those parameters we use a custom made program written in the MATLAB environment.

In addition to the system's characterization and insights on its off-quadrature operation, another contribution of this article is the model validation. We assembled the electro-optical circuit and measured some performance parameters for different values of bias voltages. By comparing the experimental results with the theoretical ones, we validated the model. Finally, we also consider the applications for microwave signals distribution by optical fiber links.

1. INTRODUCTION

The low attenuation inherent to optical fibers, its immunity to electromagnetic interference and its physical dimensions [1] are factors that contributed to the widespread utilization of this propagation channel in a variety of communication systems in high frequencies.

Analog optical links are the basis of many applications in microwave photonics, such as: signal processing, telecommunications, networking, radars and other systems; being them military or commercial. This variety of applications stimulates research on the field of high capacity optical links. Some examples of related topics are the development of systems that operate at wavelengths in which the fiber attenuation is low [2], the chromatic dispersion of optical sources is reduced [3] and the performance of photodetectors is optimized [1].

In this paper, we present metrics such as Gain and Spurious Free Dynamic Range (SFDR) of an analog optical link based on a Mach-Zehnder (MZ) external modulation scheme. Starting with an on quadrature modulation the gain and SFDR are considered in the sense of link gain control without change the laser source power, the radio frequency modulation power or the MZ modulator. Instead those changes it is considered an off quadrature link operation and the corresponding effect on the SFDR.

2. ANALOG FIBER OPTIC LINK

The optical link is composed of three stages: modulation, transmission and photodetection [3, 4]. As illustrated in Figure 1, the analog signal is applied to a MZ optical modulator that controls the intensity of a carrier generated by a laser. The MZ output is transmitted through a low-loss optical fiber and detected by a high-speed photodetector.

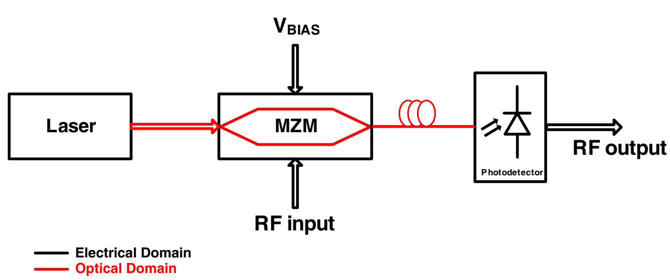

Figure 1: Optical link.

Based on models of this optical link [5, 6], we calculate the total gain of the optical power (g_{Tme}) as a function of the MZM slope efficiency (s_{mz}) with general bias (V_{DC}):

$$s_{mz} = \sqrt{\frac{R_S}{P_{RF}}} \left(\frac{T_{mz} P_{CW}}{2}\right) \left[\sin\left(\frac{\pi\left(V_{DC} + \sqrt{P_{RF} R_S}\right)}{V_\pi}\right)\right] \tag{1}$$

$$g_{Tme} = \frac{4 \cdot S_{mz}^2 \cdot r_d^2 \cdot R_{mz}^2 \cdot T_F^2}{\left[(R_s + R_{mz})^2 + (\omega \cdot C_{mz} \cdot R_s \cdot R_{mz})^2\right] \cdot \left[1 + 4 \cdot (\omega \cdot C_D \cdot R_L)^2\right]} \tag{2}$$

$$G_T = 10 \cdot \log\left(g_{Tme}\right) \tag{3}$$

where: R_s (modulation source resistance), ω (angular velocity of the RF signal), C_D (photodetector junction capacitance), R_L (laser resistance), r_d (optical receptor responsivity), C_{MZ} (MZM capacitance), P_{CW} (optical power of the laser), T_{MZ} (optical transmission coefficient of the MZM), T_F (optical transmission coefficient between the modulation and detection devices), R_{mz} (resistance of the MZM) $e\, V_\pi$ (half-wavelength voltage). On the Table 1 it is shown the values for the parameters used together the Equations (1), (2) and (3).

Using custom made MATLAB software we obtained the MZ transfer function for any V_{dc} bias voltage value.

In Table 1, we present the values of the parameters used to obtain the optical link gain according to the equations above.

Table 1: Values of the parameters.

$R_{mz} = 43\,\Omega$	$k = 1.38 \times 10^{-23}\,\mathrm{J/K}$	$R_s = R_L = 50\,\Omega$	$f = 1\,\mathrm{GHz}$	$V_\pi = 2.92\,\mathrm{V}$
$C_{mz} = 8.33\,\mathrm{pF}$	$P_{RF} = 0\,\mathrm{dBm}$	$T_{mz} = 0.3$	$r_D = 1$	$\Delta f = 5\,\mathrm{GHz}$
$C_D = 0.3\,\mathrm{pF}$	$V_{DC} = 0.73\,\mathrm{V}$	$T_F = 0.3$	$P_{CW} = 10\,\mathrm{mW}$–$15\,\mathrm{mW}$	$T = 293\,\mathrm{K}$

3. RESULTS AND DISCUSSIONS

The theoretical results are obtained as mentioned before from a custom-made program in MATLAB, which is based on the generalized equations mentioned in Section 2. For validating the routines we considered the optical link showed in Figure 1. After the measurements we obtained the following results for V_{DC} equal to 0 V: $P_{cw} = 10\,\mathrm{mW}$, $G_T = -34\,\mathrm{dBm}$ and SFDR $= 59\,\mathrm{dB} \cdot \mathrm{Hz}^{2/3}$.

Figure 2 shows the output optical link for the above parameters with V_{DC} equal to 0 V as mentioned.

Figure 3 shows the SFDR obtained with MATLAB routine to $V_{DC} = 0\,\mathrm{V}$.

Figure 4 shows the output optical link for the above parameters with V_{DC} equal to 0.73 V.

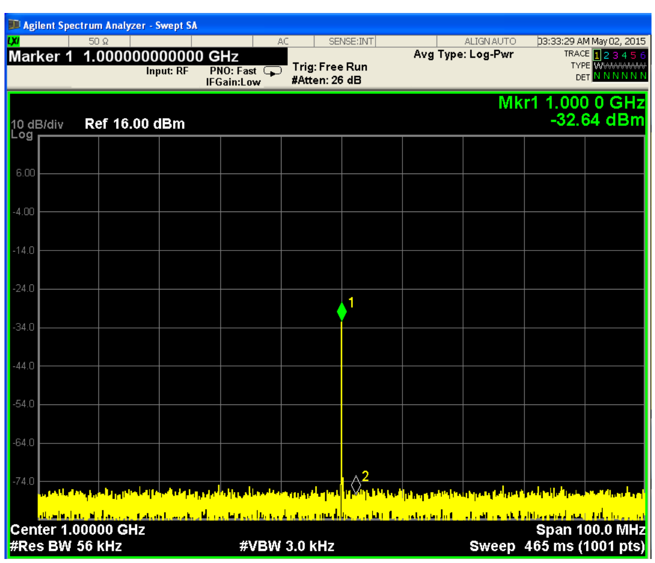

Figure 2: Optical link output for $P_{CW} = 10\,\mathrm{mW}$ and $V_{DC} = 0\,\mathrm{V}$.

Figure 5 shows the SFDR obtained with MATLAB routine to $V_{DC} = 0.73\,\text{V}$.

As we can see the G_T is a function of V_{DC}. The role characteristics of the optical link as gain and SFDR, for example, depend on V_{DC}.

The optical link characteristics controlled by the V_{DC}, enable the adjustment the link output

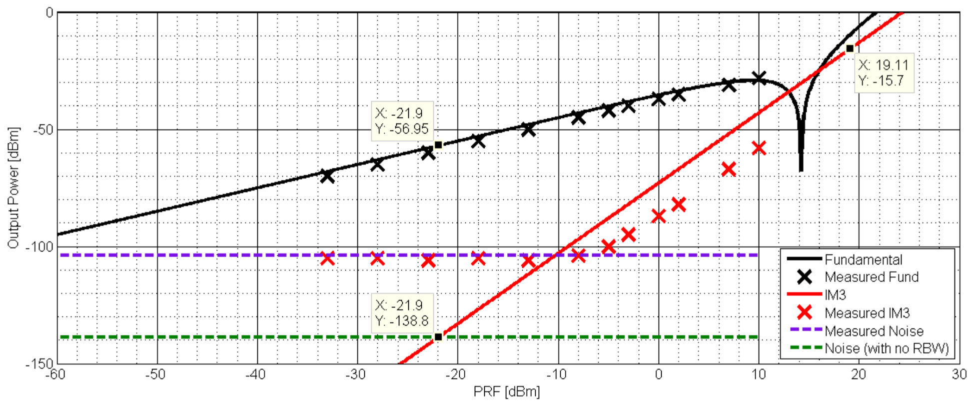

Figure 3: SFDR with $V_{DC} = 0\,\text{V}$.

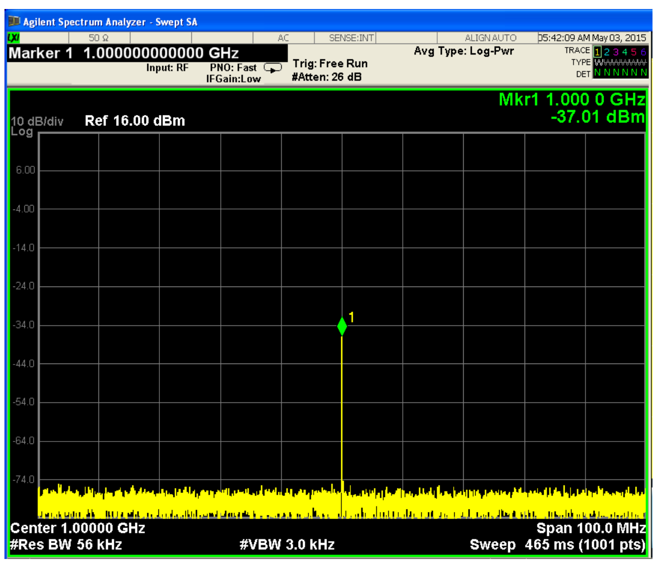

Figure 4: Optical link output for $P_{CW} = 10\,\text{mW}$ and $V_{DC} = 0.73\,\text{V}$

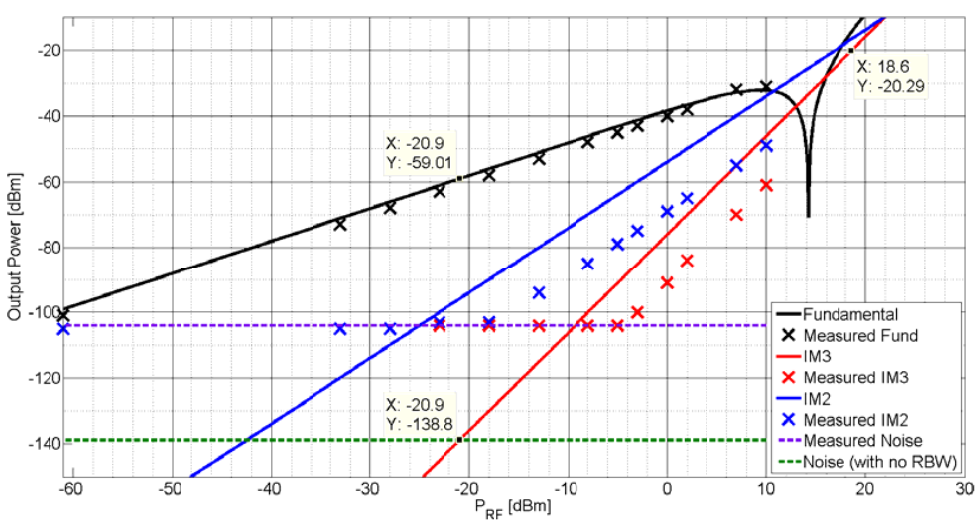

Figure 5: SFDR with $V_{DC} = 0.73\,\text{V}$.

characteristics without changing the parameters from Table 1. It is not necessary to change the laser source, the modulator or the photodetector.

For validating the model we investigate the optical link at different operation points.

As before, we obtained the following results for V_{DC} equal to 0.73 V: $P_{cw} = 10\,\mathrm{mW}$, $G_T = -37\,\mathrm{dBm}$ and $\mathrm{SFDR} = 56\,\mathrm{dB}\cdot\mathrm{Hz}^{2/3}$.

4. FINAL REMARKS

To summarize the article, we first introduced a generalized theoretical model for the analog link and then we validated the model by comparing experimental data with the equivalent values from the mathematical model (obtained from the MATLAB program or by simple algebra, depending on the case). The general results agree with the analysis based on the custom-made MATLAB routine. The authors are going to investigate more detailed optical link characteristics in the sense of RF input bandwidth and power. Such analysis will enable an electronic optical link control.

On a final remark, we emphasize the importance of the subject. Transmitting microwave signals through optical fibers can benefit many applications, ranging from transmission and distribution to high frequency reception systems. Its low attenuation and immunity to electromagnetic interference are the characteristics that stand out when dealing with long-range transmissions of signals, e.g., radars and mobile telephony. For this reason, modeling and assessing the characteristics of analog electro-optical links is increasingly important.

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