Using a Microcontroller to Optimize the Bias Voltage of Balanced Photodiodes to Minimize Even-Order Distortion in Analog Fiber-Optic Links

Mitchell D. Theys[1], Preetpaul S. Devgan[2], John F. Diehl[2], Christopher E. Sunderman[2], and Keith J. Williams[2]

1: University of Illinois Chicago, Chicago, IL
2: US Naval Research Laboratory, Washington, DC
mtheys@uic.edu

Abstract: Use of a microcontroller-based bias board for balanced photodiodes improves even-order distortion cancellation due to voltage dependent responsivity nonlinearities. The bias board improves the second order intermodulation distortion in balanced photodiodes by 8.3 dB.

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1. Introduction

Analog fiber optic links have been used for various applications from radio astronomy to antenna remoting [1,2]. The format of choice uses a quadrature-biased Mach-Zehnder modulator (MZM) for intensity modulation followed by direct detection at a receiver [3]. The quadrature-biased MZM is used because it adds no additional even-order distortion to the RF signal and the system performance metrics improve as the photocurrent increases. As the performance of these systems increases, the even-order distortion of the photodiodes becomes a limiting factor. The nonlinearity originates from the voltage dependent responsivity of the photodiode and has been studied [4]. In order to achieve the highest performance, links have been demonstrated using dual-output MZM with balanced photodiodes [5]. The balanced photodiodes can be arrayed so that each individual photodiode's input is within its linear region and the combined performance matches that of the combined photocurrent of the photodiodes. In addition, the use of balanced photodiodes has also been shown to cancel the even-order distortion due to the individual photodiodes [6]. Since the distortion originates from bias voltage dependency across the p-i-n photodiode, each photodiode will react differently and the cancellation will not be optimized when the bias voltages of the photodiodes are all set to the same value. In practice, each photodiode has to be set to the optimal bias voltage in order to cancel the even-order distortion when the diodes are placed in a balanced configuration. The optimal bias voltage will also change depending on the fiber link between the transmitter and the receiver. In most links, a bias board is used at the transmitter to insure that the MZM remains at quadrature bias. Most methods use an out-of-band RF dither tone in order to set the DC bias voltage for the MZM to remain at quadrature. Since the dither tone is out-of-band, the tone is transmitted to the receiver and filtered before the RF output. This same tone can be used at the balanced receiver to find the optimal bias voltage in order to minimize the even-order distortion due to the photodiodes.

In this paper we demonstrate a method to use the out-of-band dither tone used to maintain the MZM quadrature bias in order to optimize the photodiode bias voltage. The measured second harmonic decreases by 8.3 dB when compared to a nominally balanced bias voltage. Furthermore, the fundamental power and the third-harmonic distortion do not degrade when the photodiode bias voltages are optimized for canceling the second harmonic.

2. Experiment and Results

In order to measure the improvement in the even-order distortion, a dual output MZM modulator is set at quadrature bias using a bias board to ensure the bias does not drift over time. The dither tone used to maintain quadrature is set at 200 MHz. A 5 MHz tone is then added to the RF port of the MZM and sent to a receiver box. The two outputs of the MZM are then split using two 50/50 couplers to four individual

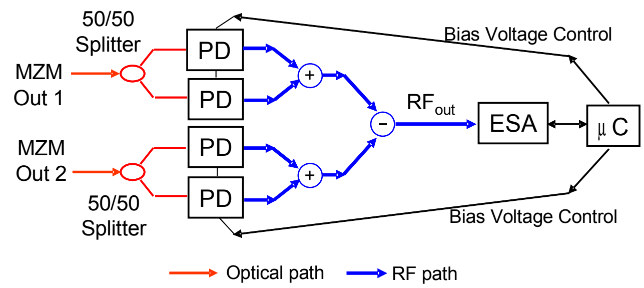

Fig. 1 Setup for optimizing bias voltage by using a microcontroller. MZM: Mach-Zehnder modulator, ESA: electrical spectrum analyzer, µC: microcontroller, PD: photodiode

photodiodes, as shown in Fig. 1. The photocurrent from each pair of photodiodes is summed and then the combined photocurrents of the two pairs are differenced. The bias voltage of the photodiodes can be set between 3.1V and 8.1V by a variable resistor controlled by a microprocessor. The output of the balanced photodiodes is sent to an electrical spectrum analyzer (ESA) in order to measure the second harmonic of the 5 MHz fundamental tone. The second harmonic of the 200 MHz dither tone is also measured by the ESA and is used in a feedback loop by the microcontroller in order to determine the optimal bias voltage of the balanced photodiodes. Since the second harmonic is the strongest even-order distortion, we will focus on minimizing this in the following measurements.

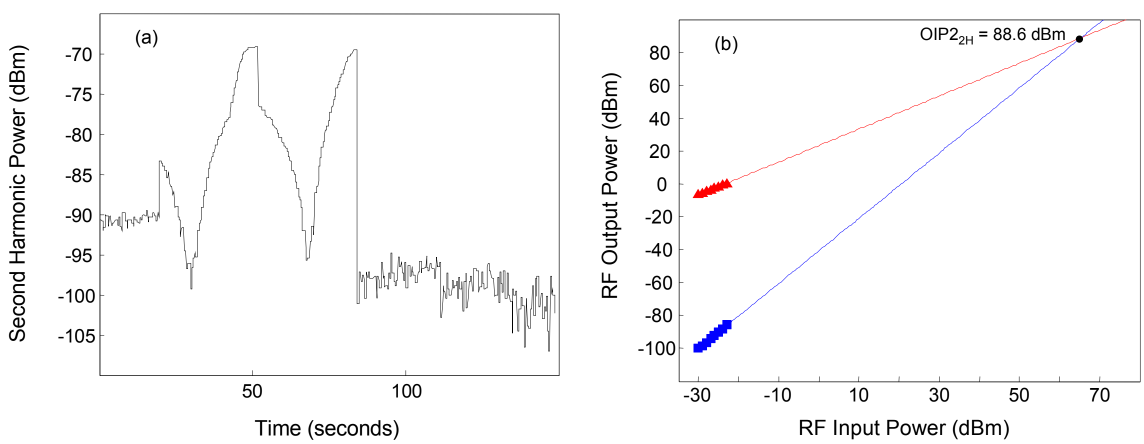

Fig. 2 (a) Optimization of second-harmonic of dither tone over time by the microcontroller bias board. (b) Measured OIP2$_{2H}$ for a fundamental tone at 5 MHz.

At first, the bias of both sides of the balanced photodiodes is set to 5.2V, which is in the middle of the bias range of the photodiodes. The second harmonic and fundamental of the dither tone are then measured to see how well the second harmonic is being canceled. The second harmonic of the dither tone is only -90.7 dBm while the fundamental is -12 dBm. In order to determine a single point OIP2$_{2H}$ from these values, we use the equation $OIP2_{2H}(dBm) = 2*P_f(dBm) - P_{2H}(dBm)$ [6]. This yields an OIP2$_{2H}$ of 66.7 dBm, which we then subtract 6 dB to get the intermodulation distortion output intercept (OIP2$_{IMD}$) of 60.7 dBm. The microcontroller is then used to map out the optimal bias voltage in order to minimize the second harmonic of the dither tone. Figure 2(a) shows the power of the second harmonic as the algorithm changes the bias voltage over time. After the minimum second harmonic power is found, the microcontroller sets the correct bias voltages for the photodiodes and the second harmonic is measured. Before the microcontroller begins its voltage sweep the power of the second harmonic is -90.7 dBm. After the bias voltage is swept and the optimized bias voltage is found, the second harmonic is down to -100.2 dBm. The optimized bias voltages are about 0.3 V apart. This is necessary to compensate the different voltage-dependent responisivities of the photodiodes in the balanced architecture. Checking that the fundamental power is still the same, the new OIP2$_{IMD}$ is 70.2 dBm. However the dither tone is not the real signal of interest in this measurement as the tone is out-of-band. Thus the second harmonic of the 5 MHz tone is

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measured to see that it also has improved. Before optimizing the bias voltages, the second harmonic is measured at -80.3 dBm when the fundamental is at 0 dBm. Note that the fundamental is higher at this frequency when compared to the dither tone as it is within the frequency range of operation for this receiver. After optimizing the bias voltage the second harmonic is measured as a function of input RF power along with the fundamental. From Fig. 2(b), the $OIP2_{2H}$ is now 88.6 dBm, which yields an $OIP2_{IMD}$ of 82.6 dBm. This is an 8.3 dB improvement over the original bias voltage settings. Using the equation for the required OIP2 in order to remain third-order limited $OIP2_{req}(dBm) = 47 + 70/3 * \log_{10}(I_{dc}(mA))$ [6], the achieved OIP2 can provide third-order limited performance for photocurrents up to I_{dc} = 33.5 mA.

In order to see that the optimized bias voltage does not negatively affect the third harmonic distortion, we also measured the noise of the system both before and after optimizing the bias voltage of the photodiodes. The results appear in Figs. 3(a) and (b). The $OIP3_{3H}$ is nearly the same for the cases when the photodiodes are set to the same bias voltage and when the bias voltages are optimized for even-order cancellation.

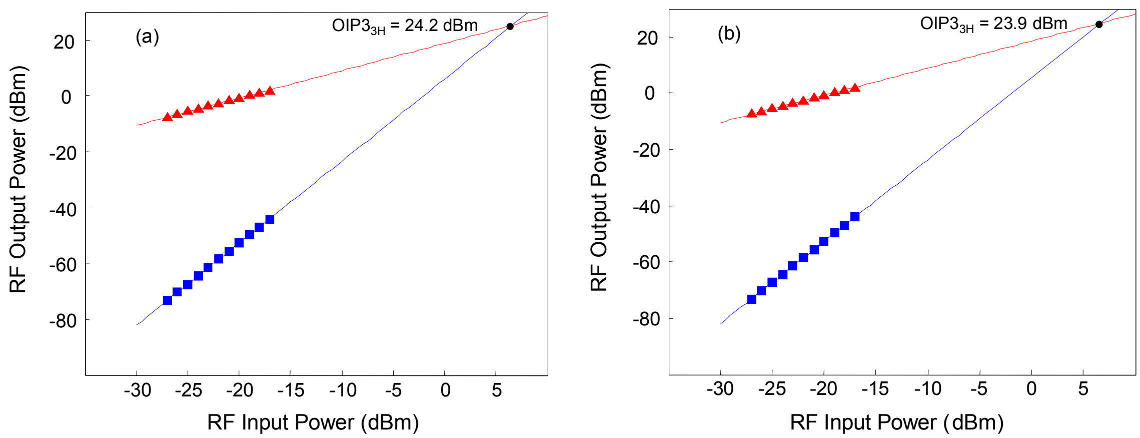

Fig. 3 Measured $OIP3_{3H}$ for a fundamental tone of 5 MHz (a) before and (b) after the receiver bias voltage is optimized for even-order cancellation.

3. Conclusions

We have demonstrated a method for optimizing the bias voltage for a balanced receiver in order to minimize the unwanted even-order distortion inherent in photodiodes. An improvement of 8.3 dB in the OIP2 is demonstrated. In addition, the third harmonic distortion is the same before and after the bias voltage is optimized. This method can be used for receivers to maintain the proper bias voltage just as the bias board on the MZM is used to maintain the quadrature bias for transmitters. Further work is ongoing to use the receiver bias method to compensate changes over time with the fiber link.

4. References

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