Introduction

The accurate calibration of radio-frequency (RF) antenna arrays is critical to their performance. Real-time, in situ calibration is particularly desirable and recent photonic implementations [1],[2] have stirred interest for onboard naval applications. These photonic architectures are primarily suited for large shipboard arrays [3] but may also be pertinent to the calibration of the smaller arrays found in avionic platforms. The concept is to feed each receive-mode antenna element with an optically-encoded test signal that is demodulated with unbiased photodiodes placed near every element [1],[2]. This technique provides the distinct advantage of having no metallic components near the aperture but the unbiased photodiodes will exhibit reduced performance as compared to reversed-biased photodiodes of the same type. Most notably, an unbiased photodiode will demonstrate decreased optical-to-electrical conversion efficiency and increased RF distortion.

Here we consider unbiased balanced photodiode pairs for optical calibration of RF antenna arrays. We have previously demonstrated that reversed-biased balanced photodiodes will suppress photodiode-induced even-order distortion for RF-over-fiber applications [4]. In this work, we demonstrate a 26-dB increase in second-order output intercept point (OIP2) in unbiased balanced photodiodes for array calibration applications.

Experimental Results

The experimental apparatus employed to demonstrate the performance of unbiased balanced photodiodes is shown in Fig. 1. A distributed feedback semiconductor laser (EM4 EM253) is modulated with an RF test signal through a dual-output Mach-Zehnder modulator (EOSpace) with \( V_\pi = 2.0 \) V at 1 GHz. The two optical outputs of the Mach-Zehnder modulator (MZM) are passed through tunable optical delays and variable optical attenuators (VOAs) for phase and amplitude balance, respectively, before illuminating the balanced p-i-n photodiodes. The balanced photodiode package (Discovery Semiconductor DSC720) consists of decoupled bias ports and a 50-Ω matched RF output. As shown in Fig. 1, the unbiased (photovoltaic) measurements were conducted by placing current monitors (Keithley 2425) between the bias pins and ground.

With a quadrature bias of the MZM, the VOAs were varied to measure the RF response with a network analyzer as a function of DC photocurrent. It was determined that the maximum unbiased gain was achieved at 1.6 mA per photodiode (\( I_{DC,A} \approx I_{DC,B} \approx 1.6 \) mA) and, therefore, the remaining measurements were conducted...
under these conditions. The results of the experiments are shown in Figs. 2 and 3. Shown in Fig. 2 are the measured small-signal gains (881 points per curve) for six configurations: each photodiode alone and the balanced photodiodes, unbiased and reverse biased with 5 V. When reverse biased, the balanced pair exhibit a response that is consistent with theory and the roll off with frequency (-0.3 dB/GHz for a linear fit) is dominated by the $V_{π}$ of the MZM. The reverse-biased individual diodes exhibit well-matched responses and the expected 6-dB drop in RF gain compared to the balanced configuration. The unbiased balanced photodiodes demonstrated significantly less RF gain and degraded frequency response (-0.8 dB/GHz for a linear fit) compared to the reverse-biased case. In addition, the individual unbiased photodiodes are not as well matched across frequency as compared to the reverse-biased individual photodiodes and drop more than 6 dB in RF gain compared to the unbiased balanced configuration. As shown in Fig. 3, the unbiased balanced photodiodes provide a second-harmonic OIP2 = 17 dBm, a 26-dB increase over the OIP2 = -9 dBm for a single unbiased photodiode. Third-harmonic output intercept points were also measured as OIP3 = 0 dBm and -8 dBm for the unbiased balanced pair and for a single unbiased photodiode, respectively. The second-harmonic distortion for the unbiased case is definitely due to photodiode nonlinearities, as the biased balanced pair exhibited an OIP2 = 34 dBm limited by the MZM bias accuracy. The unbiased third-harmonic distortion is attributed to the MZM nonlinearity as the 8-dB difference between single- and balanced-photodiodes OIP3 agrees with the RF gain difference, also noting that OIP3 = 2 dBm was measured for the reverse-biased pair, which agrees with theory.

**Conclusion**

The performance of unbiased balanced photodiodes has been measured for RF antenna array calibration. As opposed to a single unbiased photodiode, the unbiased balanced photodiodes suppress the photodiode-induced distortion and demonstrates a 26-dB increase in second-order output intercept point. This increase in intercept point translates to a 13-dB increase in spurious-free dynamic range for the second-order-limited link.

**References**


