MEASUREMENT OF INTERMODULATION DISTORTION IN OPTICAL DIODES

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ABSTRACT

A measurement technique has been developed to directly determine the output two-tone, third-order intercept of microwave frequency p-i-n optical detector diodes. This method has been used to determine the bias dependence and frequency dependence of output third-order intercept for a p-i-n diode. It has been found that the third-order intercept increases monotonically with increasing reverse bias and decreases with increasing frequency. The maximum measurable output third-order intercept for a p-i-n diode has been found to be in excess 10 dBm at 2 GHz.

INTRODUCTION

With the proliferation of analog applications of optical fiber links in areas such as antenna remoting, time delay networks and communication systems, dynamic range is of predominant importance. Heretofore, the dynamic range of microwave analog fiber optic links has been primarily dominated by the linearity of the laser diode for the high end. The noise floor for an optical link is determined by the shot noise or thermal noise of the optical detector or RIN noise of the laser depending upon the loss of the intervening optical network [1].

Continued development in semiconductor lasers, however, has resulted in higher power lasers operating at higher frequencies which are more linear than previous devices. With this inmind, it has become necessary to develop a method to evaluate the linearity performance of the optical detectors to determine the ultimate limits of performance for detectors utilized in fiber optic analog links.

MEASUREMENT TECHNIQUE

This paper presents the first two-tone third-order intermodulation distortion measurement optical detectors. Moreover, this test allows for the direct determination of the detector linearity at microwave frequencies. This method is then used to determine the bias and frequency dependence of output third-order intercept for optical detector diode.

Previous measurement techniques have not shown the bias dependent nature of output third-order intercept (OIP3) at microwave frequencies [2] or have measured harmonic powers with complex optical frequency heterodyne systems [3],[4].

The current test setup utilizes two 1.3 μm DFB laser diodes coupled to two separate optical fibers (Fig. 1). These separate optical fibers are then coupled to the single p-i-n detector diode under test. The use of two optical fibers insures excellent optical isolation to prevent coupling of one laser to the other laser resulting in electrical and optical spur generation.

The detector chosen for the test was a InP based front illuminated detector. The detector had a 3 μm thick active region composed of lattice matched GaInAs and a diameter of 75 μm. The p-type contact consisted of quarternary lattice matched GaInAsP and the p-i-n diode had a nominal responsivity of 0.95 A/W at 1.3 μm. The 3 dB bandwidth was measured at 5.5 GHz under 15 volts reverse bias.

The p-i-n diode was RF impedance matched to a 50 Ω transmission line by shunting the device with a 50 Ω resistor and a RF by-pass capacitor. The output of the transmission line was then connected to an electrical spectrum analyzer.

Electrical stimulus for the laser diodes came from two separate frequency synthesizers. In order to measure the intermodulation distortion of the detector, both lasers were biased above threshold through bias T's and connected to a frequency synthesizer. The DC optical power illuminating the detector from each laser source was independently adjusted by changing the optical coupling at the laser and detector end. Once completed, the frequency synthesizers RF powers were turned on and independently adjusted to obtain equal tone levels on the spectrum analyzer at the desired frequencies, F1 and F2. When both sources were on, the third order intermodulation products of the p-i-n detector results in intermodulation products at 2F1-F2 and 2F2-F1 (see Fig 2). The output third-order intercept (OIP_3) can be directly calculated by

$$OIP_3 = P_{F1} + \frac{1}{2}(P_{F1} - P_{IMD}) \ (dBm) \qquad (1)$$

where P_{F1} and P_{IMD} are the electrical output powers in dBm of the p-i-n diode at the modulation frequencies and intermodulation frequencies, respectively.

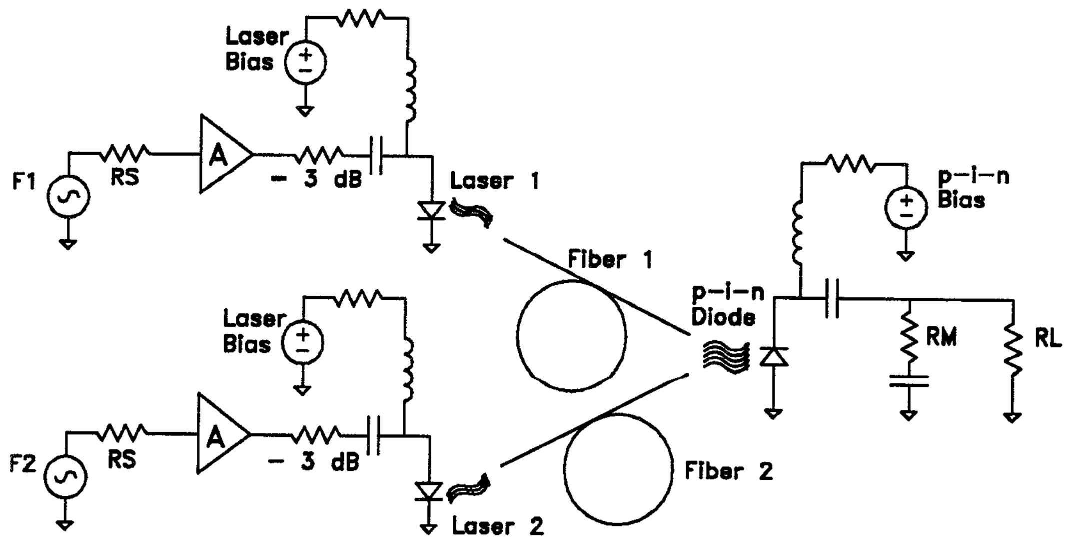

FIG. 1. Schematic representation of the intermodulation test set up for determining the third-order intercept point of optical p-i-n detector diodes.

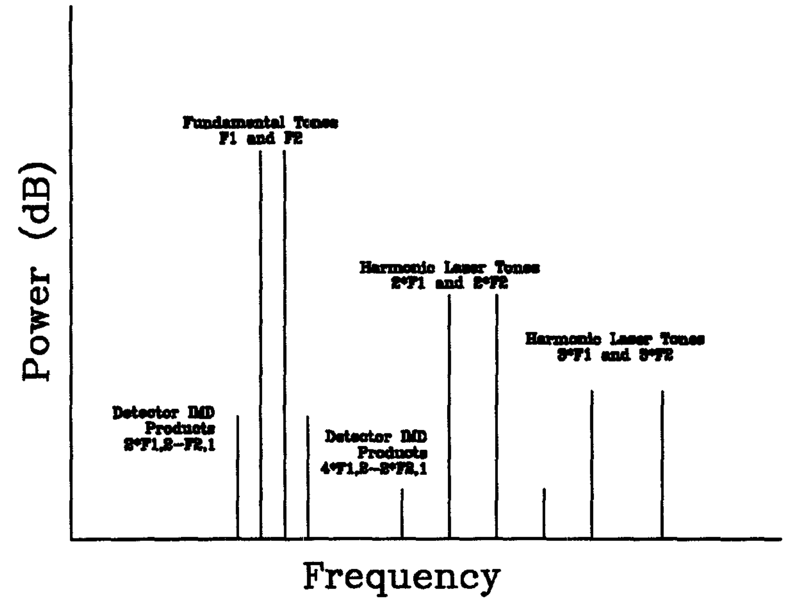

FIG. 2. Electrical output spectrum of p-i-n optical detector diode. Two-tone intermodulation distortion of the p-i-n diode is measured about the fundamental modulation tones F1 and F2.

The OIP_3 can be referenced back to the input of the optical detector by using the detector shunt impedance, the RF load impedance and the responsivity of the detector. The input third-order intercept is given by

$$IIP_3 = 10\log_{10}\left[\frac{1}{RR_M}\sqrt{\frac{OIP_3}{R_L} * (R_L+R_M)} \times 1 \right. \quad (2)$$

where OIP_3 is in mW, R is the responsivity of the p-i-n diode in mA/mW, R_M is the p-i-n diode shunt RF matching resistance and R_L is the load resistance in Ohms.

RESULTS

The results of the bias and frequency dependence of OIP_3 is given in Fig 3. It is noted that at low bias conditions, the p-i-n diode is strongly nonlinear and the OIP_3 increases monotonically with increasing reverse bias. The highest measurable OIP_3 was found to be in excess of 10 dBm for a 11 volt reverse bias. At this point, the intermodulation products were too close to the noise floor of the spectrum analyzer to yield a reliable measurement. In addition, it has been found that for a given bias condition, OIP_3 decreases with increasing frequency at a rate of approximately 2 dBm/GHz for this detector.

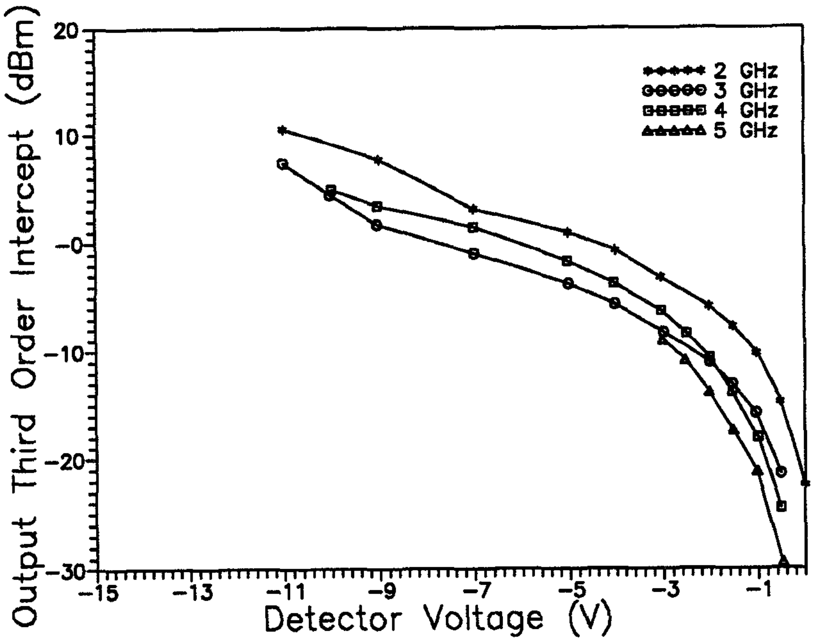

FIG. 3. Bias and frequency dependence of output two-tone third-order intercept for an optical detector diode at several microwave frequencies.

CONCLUSIONS

In conclusion, a novel measurement technique for the direct measurement of third-order intermodulation products resultant from optical detectors at microwave frequencies is presented. This technique can be expanded to smaller devices by the addition of an optical combiner and optical isolators. It has been found for the test optical detector diode that OIP_3 is strongly bias dependent improving to over 10 dBm at high bias conditions. Finally, it has been noted that for this device OIP_3 decreased at a rate of approximately 2 dBm/GHz.

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