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Experimental Investigation of Power Distribution in Distributed Balanced Photodetectors

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ABSTRACT

A distributed *balanced* photodetector with high saturation photocurrent and excellent linearity has been experimentally demonstrated. Distributed detection is shown experimentally to be important for the high saturation photocurrents.

High-speed photodetectors with high saturation photocurrents are essential for high performance analog fiber optic links. In externally modulated links, the link gain, noise figure, and spurious free dynamic range (SFDR) improve with increasing optical power of the link [1]. This improvement will eventually be limited by the relative intensity noise (RIN) of the laser source and/or the amplified spontaneous emission noise (ASE) from erbium-doped fiber amplifiers (EDFA). It is known that the laser RIN and EDFA-added noise can be suppressed by balanced receivers [2]. Therefore, balanced receiver with linear photocurrent under high input power is a critical component of high-performance analog fiber optic links.

Previously, we reported a novel monolithic distributed balanced photodetector based on velocity-match distributed photodetector (VMDP) structure [3]. Broadband (1 to 12 GHz) noise suppression has been achieved. The maximum noise suppression of 24 dB was observed at the relaxation oscillation frequency of the laser [4]. However, the maximum DC photocurrent was limited to 12 mA. In this paper, we report on an improved distributed balanced photodetector with continuous optical waveguide and strong optical confinement. It exhibits superior DC and AC linearity as well as maximum linear photocurrent. The distribution of photocurrents in distributed photodetector was also measured for the first time. The distributed detection is shown to be very important for high saturation photocurrent.

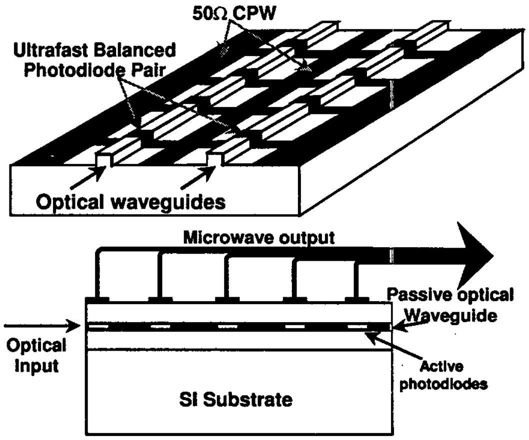

Fig. 1. (Top) Principle and schematic structure of the distributed balanced photodetector. Multiple balanced photodetector pairs are cascaded in series along a coplanar waveguide (CPW) to increase saturation photocurrent. (Bottom) Principal of power combining on each branch of the receiver.

Fig. 1 shows the schematic of the distributed balanced photodetector. It consists of two input optical waveguides, two arrays of high-speed metal-semiconductor-metal (MSM) photodiodes distributed along two passive optical waveguides, and a 50Ω coplanar waveguide (CPW) microwave transmission line. The detector operates in balanced mode when a voltage bias is applied between the two ground electrodes of the CPW. The photodiode arrays provide periodic capacitance loading to slow down the microwave velocity. The photodiodes are designed to operate below saturation under high optical input by coupling only a small fraction of light from the passive waveguide to each individual photodiode.

To fully exploit the advantages of the VMDP, it is important that the optical power is delivered to all the photodiodes. In our previous devices [3-4], the optical waveguides were discontinuous at the active photodiode regions where wider mesas were employed to facilitate the fabrication of MSM photodiodes. The discontinuity resulted in excessive optical loss at the waveguide transitions, and only the first few PD's had been effectively illuminated. In addition, shallow ridge waveguide was employed to ensure single lateral-mode operation. This also contributed to optical loss due to coupling to slab modes. In this design, we employ a strong index-guided, 5-μm-wide multimode optical

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waveguide with uniform width for both the active photodiode and the passive waveguide. The coupling losses at waveguide transitions are greatly reduced.

Fig. 2 shows measured photocurrent in one branch of the photodetector versus the input optical power at different bias voltages. The responsivity flattens above 4V bias with a value of 0.28A/W (without AR coating) for a structure with 11 pair of photodiodes. The photocurrent remains linear up to 33 mA. It should be noted that the 33 mA photocurrent in balanced photodetector is equivalent to 66 mA photocurrent in single-ended photodetectors because the RF signals from both branches of photodiodes add in phase. The device fails at higher photocurrent due to thermal runaway [5,6]. Measurements were made at lower voltages to investigate nonlinearities at high power. We did not observe any such nonlinearities in the measured photocurrent. For comparison, the photocurrent data from our previous device with wide mesa are also plotted in the same figure. The maximum linear photocurrent (12 mA) is much lower than that of the current devices. Also, in contrast to the current devices, the photocurrent becomes nonlinear before it reaches catastrophic damage. These indicate that most of the photocurrent in our previous device was contributed by the first photodiode. By employing a continuous waveguide in our present structure, the light is more effectively delivered to all the photodiodes. Nearly threefold improvement in the photocurrents was achieved.

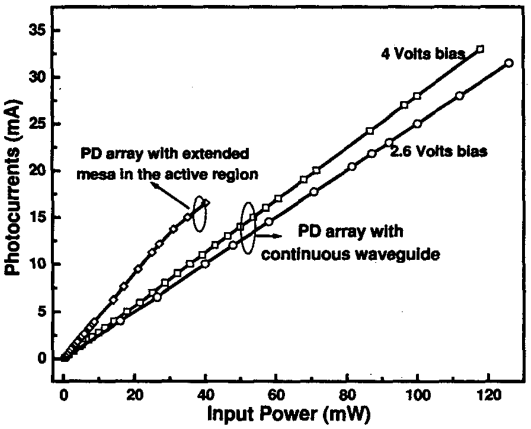

Fig. 2. DC photocurrent vs input power. The DC photocurrent remains linear up to 33mA in the structure with continuous waveguide. A similar receiver with wide active region results in a much lower linear photocurrents of 12mA.

The distribution of photocurrent in the distributed balanced receiver is also investigated experimentally. Fig. 3 shows DC responsivity of the receiver with different numbers of PD's. The highest linear photocurrents are also shown on the same graph. The distributed detection characteristics is evident from the figure. The responsivity of the receiver increases steadily with increasing number of photodiodes. A theoretical model was used to fit the experimental data.

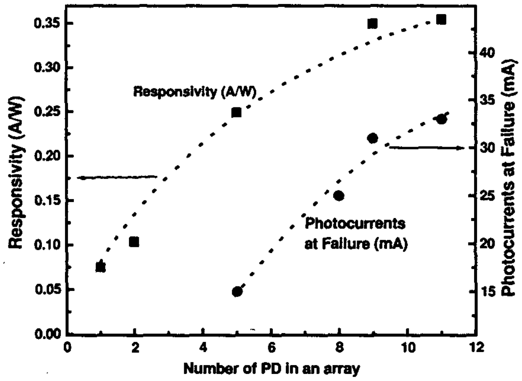

Fig. 3. Responsivity and DC photocurrent vs number of PD in each arrays of the balanced receiver. The dotted lines are generated using the experimentally obtained data.

The distributed balanced photodetector also exhibits excellent AC linearity at high photocurrent. In most previous works, nonlinear distortions are observed in photodetectors with photocurrents greater than a couple of mA's. Nonlinear distortions are attributed to high density of photo-generated carriers at high optical power, which results in nonlinear carrier velocity [7]. We did not observe any second or third order harmonics (H2 or H3) or third order intermodulation distortion with photocurrent as high as 20 mA in our receiver. The 3-dB frequency (14 GHz) remains constant from 0.5 to 10.5 mA. More detailed characterization of the AC linearity will be reported elsewhere.

In conclusion, we have successfully demonstrated a distributed balanced photodetector with high photocurrent and excellent linearity. It has a maximum linear DC photocurrent of 33 mA (equivalent to 66 mA in single-ended photodetectors). The distributed detection is measured experimentally for the first time and is shown to be important for high power linear photodetectors.

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