

Asymmetry in MSM Detector/Mixer and Its Implication in FM/cw Ladar Systems

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ABSTRACT

Metal-semiconductor-metal (MSM) structures have been widely used as high-speed photodetectors. In this application, the important parameters of the device are detectivity and speed. MSM detectors can also be used as optoelectronic (OE) mixers to generate radio-frequency (RF) subcarriers in fiber-optic microwave links. In this application, there is usually ample optical power on the detector so that detectivity is not a major issue. Recently, we have used MSM structures as detector/mixers in a FM/cw laser ranging system. In this application, an ac voltage at ultra-high frequency (UHF) from a local-oscillator (LO) is applied to detector/mixer. The device detects and down-converts the light signal that is amplitude modulated at UHF. Thus eliminates the need for UHF transimpedance amplifiers and reduces both the cost and complexity of the ladar system. The requirements for a detector/mixer used in a FM/cw ladar application differ from those described above. In addition to a high responsivity and mixing efficiency, the device should have no response to un-modulated background light. More importantly, in the FM/cw ladar application where the LO frequency is chirped, the detector should not develop an output current as a function of the LO frequency. This output current is sometimes referred to as a “self-clutter” signal, which induces identification of false targets. In this paper we demonstrate that the self-clutter signal is related to the voltage asymmetry of the device. We present a theory and define the origin of the asymmetry.

We derived an analytical model for asymmetric MSM structure and found that the asymmetry is related to the asymmetry of the potential barrier heights, variation of doping, and optical intensity distribution. We studied the mixing effect in symmetric as well as asymmetric detector/mixers and found that the resultant mixed signal is sublinear with LO voltage. We found that for a perfectly balanced device, the dc component is zero, and the device will not respond to un-modulated optical power. For an asymmetric device, however, a dc current that is proportional to the total optical power and quadratic to the driving LO voltage is present. We also performed computer simulation and found that this dc component depends on LO frequency. At low frequency, the current density is a constant throughout the device at any instant. The average of this current is non-zero in an asymmetric device. At high frequency, however, the electron current density is no longer a constant throughout the device. The fast oscillation of free carriers in the undepleted region results in a large displacement current. This current is more symmetric, resulting in a reduction of total asymmetry (and the dc current) at high frequency. Therefore, the origin of the LO frequency dependent dc current is the asymmetry of the detector/mixer.

We conducted experiments to compare the performance of a symmetric device to an asymmetric device with similar responsivity. The ideal symmetric self-mixing detector should recover an IF waveform which is a zero mean sine wave whose amplitude is proportional to signal power and whose frequency is proportional to target range. Figures 1(a) and 1(b) show the photocurrent IF waveforms as the LO frequency is chirped from 100 to 700 MHz in 127 ms for an experimental symmetric device and an asymmetric device, respectively. For the symmetric device, the IF waveform remained flat over LO frequency and was nearly symmetric around zero current thus closely approximating the behavior of the ideal symmetric detector/mixer. The IF waveform for the asymmetric device (Fig. 1(b)) has the ideal IF waveform riding on a positive slowly changing signal that varied by about 1 nA. This extraneous signal is the self-clutter signal. This self-clutter signal disappeared at an optical power of 0.9 nW (not shown) and decreased significantly when the LO voltage was dropped to 0.75 V. This behavior is in consistent with our theory.

To further investigate the origin of this self-clutter signal, we turned off the laser and recorded the dark current using the same chirp parameters as before. We found that the photocurrent followed the same self-clutter waveform as observed in Fig. 1 (b). This is also in consistent with our theory. Therefore, we concluded that the origin of the self-clutter signal in the FM/cw ladar is from the voltage asymmetry of the device.

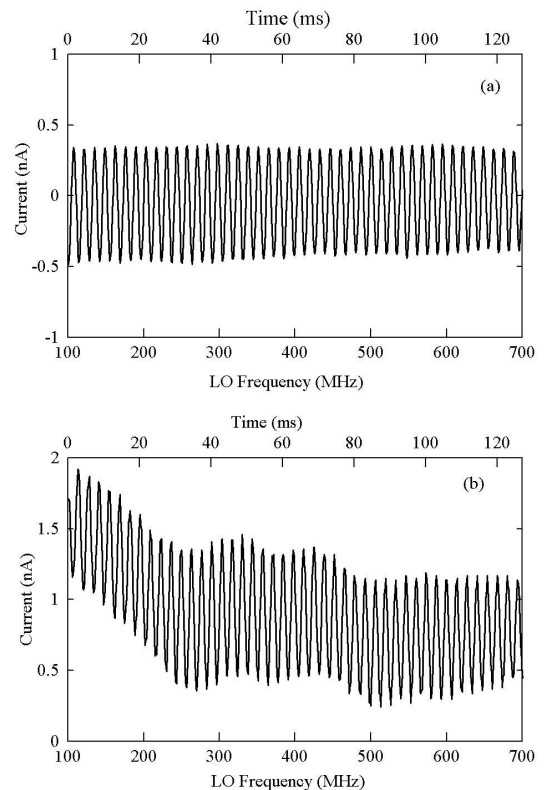


Figure 1: Comparison of mixer performance in a FM/cw ladar system: a) symmetric device, b) asymmetric device. The LO is chirped from 100 MHz to 700 Mhz in about 127 ms. The signal is from a target 11m away with optical power on detector of 9 nW.