

A Retrodirective Diode Grid Array Using Four-Wave Mixing

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Abstract—We report retrodirection using quasi-optical diode grid arrays operating at 4 GHz. Phase conjugation is achieved through four-wave mixing. Antiparallel diode pairs provide the third-order non-linearity. We report retrodirection of beams with incidence angles of up to 60° in both the E-plane and the H-plane. Measured antenna patterns agree well with theoretical predictions.

Index Terms—Retrodirection, phase conjugation, quasi optics.

I. INTRODUCTION

When illuminated by a source, retrodirective antennas will re-direct a signal toward that source without any prior knowledge of its location. Applications of retrodirection include radar transponders and self-tracking wireless communication links.

Retrodirection in antenna arrays will occur when the transmitting phase of each element is the conjugate of the illuminating phase. In general, two types of such arrays have been reported. Van Atta arrays are constructed by connecting pairs of elements with transmission lines of equal length [1]–[3]. The heterodyne method, on the other hand, achieves phase conjugation at each element by mixing the illuminating signal with an external local oscillator [4]–[8]. In this paper, we describe a method of phase conjugation and retrodirection using four-wave mixing.

II. PRINCIPLE OF OPERATION

Phase conjugation through four-wave mixing has long been explored by the nonlinear optics community [9], [10]. A crystal with a high third-order Kerr nonlinearity (χ_3) is required. Attempts to create artificial third-order nonlinear materials suitable for phase conjugation at microwave frequencies have met with limited success [11], [12].

Our approach is illustrated in Fig. 1. Quasi-optical grids loaded with antiparallel diode pairs are used to provide the strong third-order nonlinearity. The grids are pumped by two normally-incident microwave beams at frequency f_0 .

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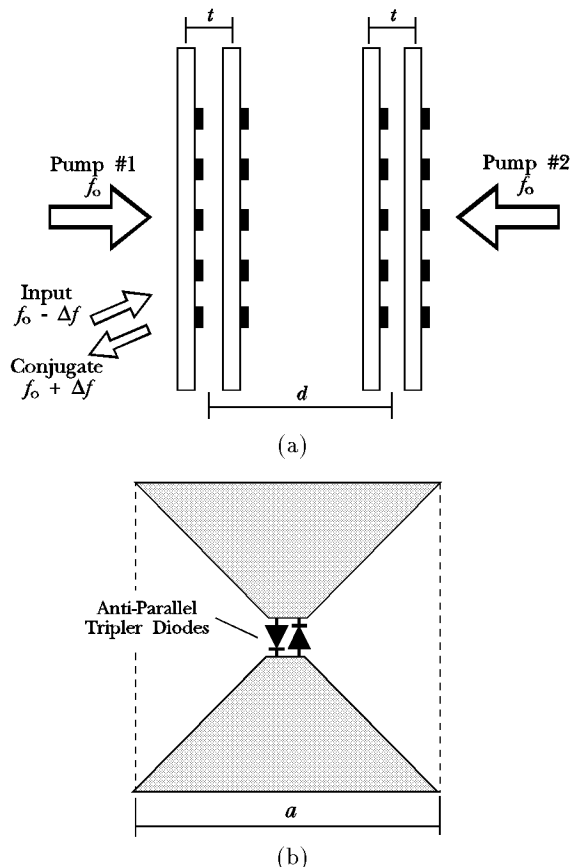


Fig. 1. (a) Four-wave mixing in nonlinear quasi-optical arrays. (b) Array unit cell with a strong third-order nonlinearity.

The retrodirected output beam is the phase conjugate of the input. In order to separate the output beam from the pumps and input, the frequency of the input can be offset below the pump frequency f_0 by Δf . The frequency of the retrodirected output will then be $f_0 + \Delta f$.

As a proof of the concept, four 25-element grids were constructed for operation near 4 GHz. A unit cell is shown in Fig. 1(b). A packaged Metelics MSS-30-346-E20 antiparallel diode pair is connected at the apex of a bow-tie antenna. The unit cell size a is 7.7 mm ($\lambda_0/9.8$). The grids were constructed on a 15-mil Rogers RT/Duroid substrate with $\epsilon_r = 2.33$. Best experimental results were obtained with the grid spacing shown in Fig. 1(a), with $t = 5.4$ mm ($\lambda_0/14$) and $d = 54$ mm ($\lambda_0/1.4$).

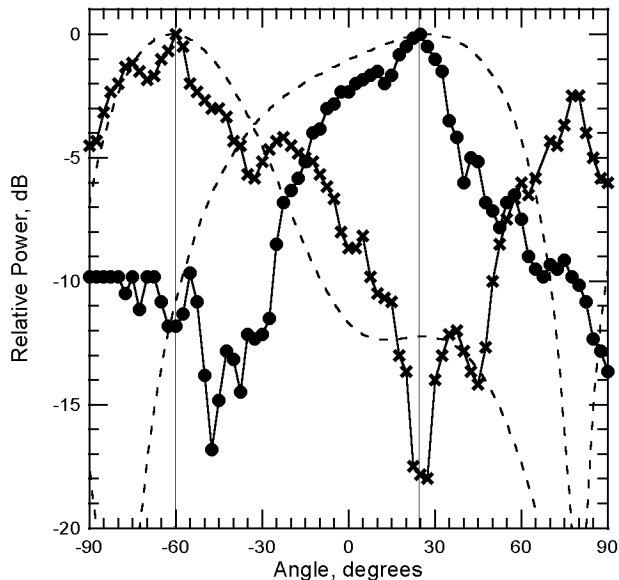


Fig. 2. Measured and theoretical retroredirected power with input beams incident from $+25^\circ$ (\bullet) and -60° (\times) in the H-plane. Dashed lines represent theoretical predictions.

III. MEASURED RESULTS

Fig. 2 plots the measured retroredirected radiation pattern with input beams incident from $+25^\circ$ and -60° . The frequency of the pump beams is 4.0 GHz, the input beam is 3.9 GHz, and the retroredirected beam is 4.1 GHz. These patterns show the array's H-plane pattern, with the illuminating beam incident in the H-plane. Retrodirection is clearly evident. The high sidelobes for the -60° incidence may be evidence of substrate-mode excitation. The array can also retroredirect beams incident in the E-plane. E-plane retrodirected patterns are shown in Fig. 3.

Theoretical patterns $U(\theta)$ are generated using the following expression

$$U(\theta) \propto EF(\theta) \frac{\sin^2(Nk'_x a/2)}{\sin^2(k'_x a/2)} \cos^2(k'_z t/2) \cos^2(k'_x d/2), \quad (1)$$

where N is the number of elements per side in each grid ($N = 5$). Furthermore,

$$k'_x = \frac{2\pi}{\lambda_i} \sin \theta_i - \frac{2\pi}{\lambda_c} \sin \theta \quad (2)$$

$$k'_z = \frac{2\pi}{\lambda_i} \cos \theta_i - \frac{2\pi}{\lambda_c} \cos \theta, \quad (3)$$

where λ_i is the wavelength of the input beam, λ_c is the wavelength of the conjugated beam, and θ_i is the incidence angle of the input beam. $EF(\theta)$ is an element factor. Because our antennas are short bowties, we assume $EF(\theta)$ is $\cos^2 \theta$

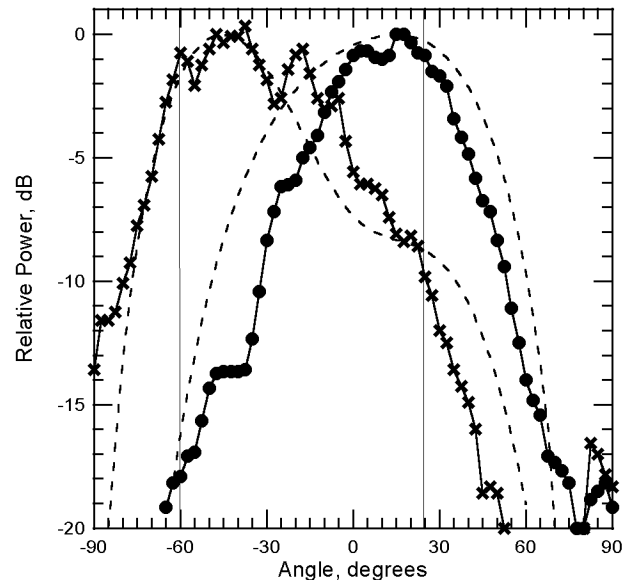


Fig. 3. Measured and theoretical retroredirected power with input beams incident from $+25^\circ$ (\bullet) and -60° (\times) in the E-plane. Dashed lines represent theoretical predictions.

for E-plane incidence and unity for the H-plane. The theoretical patterns agree well with the measured results. The element factor and the frequency offset of the input and output beams will cause the retroredirected beam to have a slight pointing error; this error can be minimized by minimizing the frequency offset.

Fig. 4 shows the measured retroredirected Effective Isotropic Radiated Power (EIRP) [13] as a function of incidence angle. Both E-plane and H-plane incidences are shown. The element factor causes the retroredirected power for E-plane incidence to fall off rapidly at higher incidence angles. Fig. 5 plots the retroredirected power as a function of offset frequency Δf . The frequency of the pump beams is fixed at 4 GHz. The 3-dB bandwidth is 350 MHz.

In order to estimate the conversion loss of the retrodirective antenna, we must know its directivity. By measuring the beamwidths in the principal planes, we estimate the directivity to be 10 dB [14]. With an incident input power of $2 \mu\text{W}$, we estimate a conversion loss of 10 dB. The power in each pump beam incident on the array is $75 \mu\text{W}$. With an incident input power of $100 \mu\text{W}$ saturating the array, we estimate a conversion loss of 14 dB. We suspect the conversion loss could be improved by increasing the pump power, possibly resulting in conversion gain through parametric amplification.

IV. CONCLUSION

We have demonstrated retrodirective antennas that achieve phase conjugation through four-wave mixing in quasi-optical

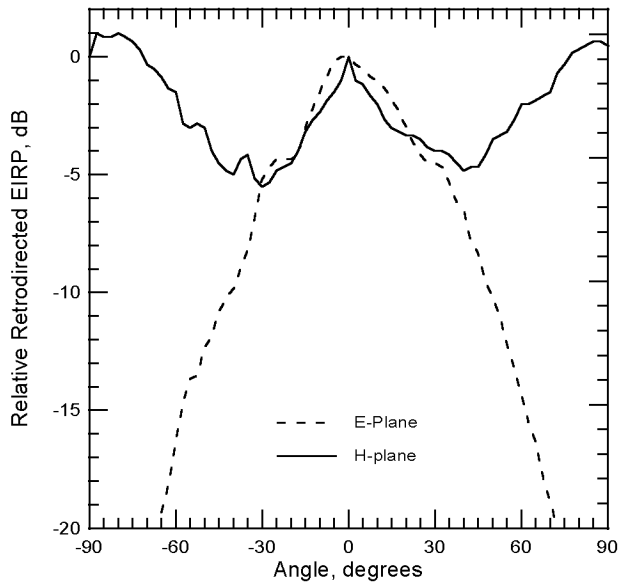


Fig. 4. Relative measured retrodirected EIRP as a function of incidence angle for H-plane and E-plane incidence.

diode grid arrays. The arrays will retrodirect power incident at angles up to 60° in both the E and H-planes. Although these arrays operated at 4 GHz, the approach should be scalable to higher frequencies.

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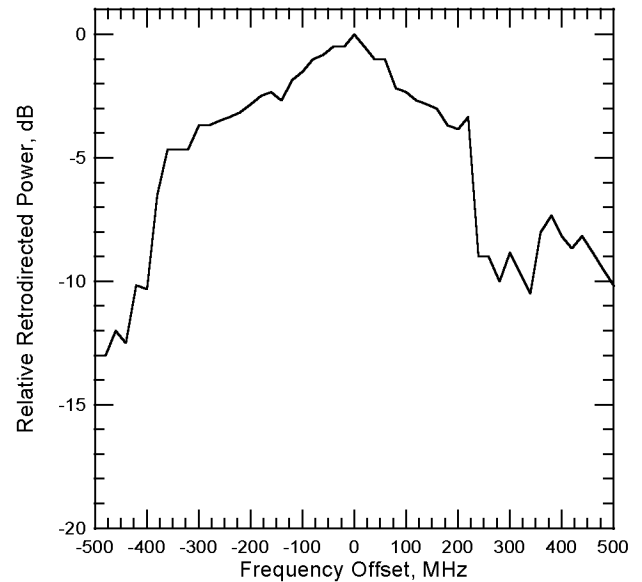


Fig. 5. Relative retrodirected power as a function of frequency offset Δf . The input beam is incident at an angle of 25° in the H-plane.

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