Experimental Investigation of Conversion Loss of Phase Conjugate FSS

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1. Introduction

Recently, the investigation of scattering properties of a two-dimensional double periodic array of wires that loaded with nonlinear lumped elements was reported [1]. The numerical investigation has demonstrated the evidence of parametric amplification of specular wave and the production of phase conjugated, retro directed wave. The ability to produce such signals as mentioned latter is useful in a variety of applications at microwave and millimeter wave frequencies, such as subwavelength imaging [2] and self-tracking wireless communications [3]-[4].

As is well-known the straightforward extension of optical phase conjugation techniques into the microwave frequency region is still a problem. This is due to the small nonlinear susceptibility of naturally occurring nonlinear materials at microwave frequencies. Hence, the sampling method of incoming wavefront using an antenna array has been proposed [5]. This array together with active microwave circuitry is applied to produce mixing of the wavefront samples with a local oscillator operated at the second harmonic of the signal to be phase-conjugated.

In this paper, a different approach wherein we assess the means for experimental characterization of a 2D nonlinear electromagnetic medium with phase conjugation properties is adopted. By using parallel plate waveguide (PPW) characterization techniques, a conversion loss of a doubly periodic diode loaded frequency selective surface phase conjugating structures is experimentally investigated.

2. PCFSS structure, PPW Simulator and De-embedding Technique

Figure 1 shows how the strips of the frequency selective surface (FSS) structure are loaded with HSMS-282X [6] Schottky diode pairs to build a phase conjugate frequency selective surface (PCFSS) structure. The diodes are biased to 150mV in order to maximise conjugated energy production. Under this bias condition the PCFSS and its S-parameters are measured and de-embedded. From the results and the SPICE parameters available in the device data sheet, then it is possible to obtain an approximate equivalent circuit for the diode. This model was then refined under numerical EM simulation, such that C_j, R_j, R_s, were adjusted from their initial values of 0.7pF, 270Ω, and 6Ω respectively to new values of 0.7pF, 170Ω, and 6Ω, at which point at the PCFSS fundamental resonant frequency is 3.28GHz.

Closed side waveguides have been used for some time to obtain the properties of phased array elements [7], however they suffer from the problem that the device under test (DUT), in this case a PCFSS, can only be examined for angles of incidence which lie away from the path of normal incidence. To overcome this parallel plate waveguide, PPW excited in a TM_0 mode is sometimes used [8]. For WG10 fed 2.6GHz to 3.95GHz operation, the PPW dimensions are: taper length 100mm, plate length 400mm, plate width 200mm, plate separation 75mm. The PPW simulator has been optimally designed to support a plane-wave normally incident beam [9]. Figure 2 shows the physical PPW simulator used for the experimental investigation. In order to achieve full 2D imaging of the 3 element test array metal plates of dimensions 75mm x 20mm are positioned on each side of the device under test. These plates do not significantly disturb the field distribution at the test sample position.

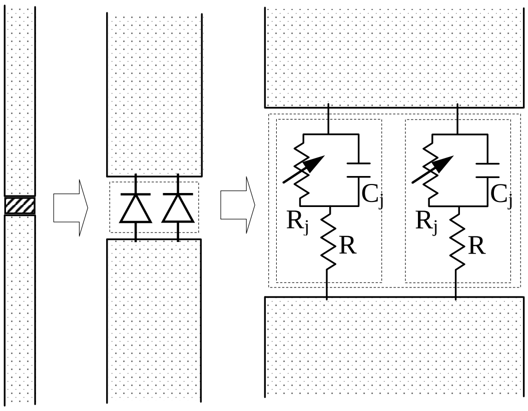

Figure 1: PCFSS structure and equivalent circuit

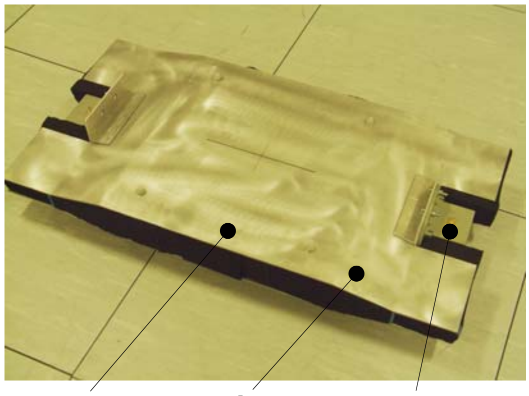

Figure 2: PPW simulator

In order to remove the effects of the PPW simulator so that the performance of the PCFSS can be isolated from the raw measurement data de-embedding is necessary. The de-embedding technique used here, namely hybrid de-embedding technique, takes measured data from the PPW simulator including the PCFSS as measured at the WG10 coaxial measurement planes. In principle, the technique employs the PPW test fixture cascaded with half structure 3D EM simulated models, and then processes the data in the term of *S* or *T* parameters [10]. Using the half structure models, then the de-embedding process is performed using *S* or *T* parameters matrix calculations.

3. PCFSS Conversion Loss Measurements and Discussion

The next issue which requires further consideration is how a controlled experiment inside a PPW simulator can be implemented. Ideally the PPW simulator should be able to deliver plane wave energy at normal incidence at both the signal and at twice the signal frequency. Unfortunately with a WG10 fed PPW simulator this is not possible since the wave guide bandwidth is between 2.6 and 3.95 GHz. To overcome this problem as shown in Fig. 3 the PPW unit cell consisting of three array elements is directly feed with an LO which is applied such that any associated feed/bias lines are orthogonal to the TM_0 mode within the PPW simulator.

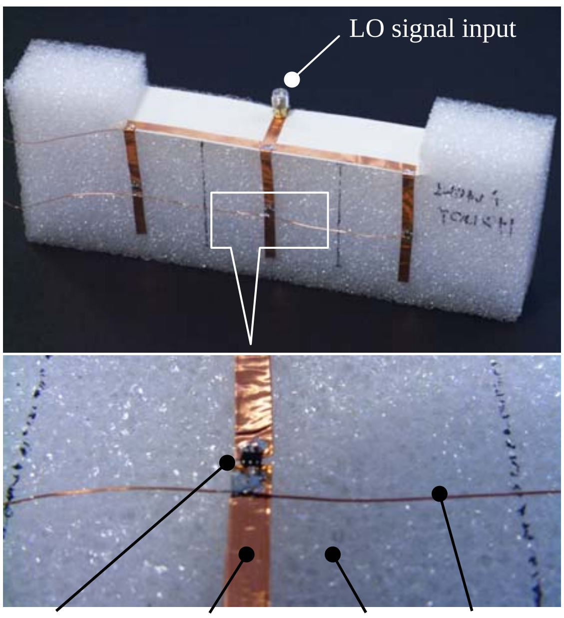

Figure 3: Photograph of diode loaded FSS including 6GHz feed network

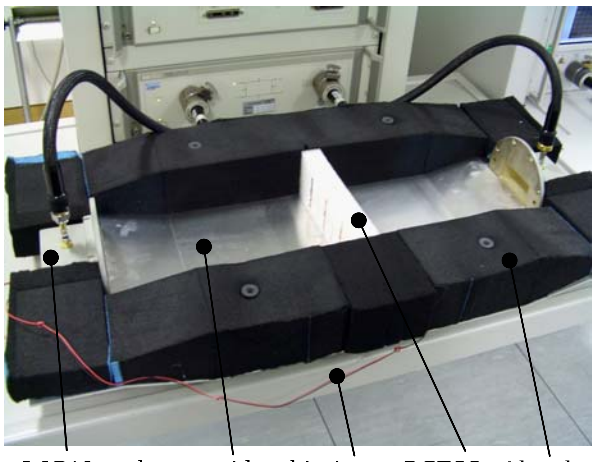

Figure 4: PPW simulator setup without top cap employed in the experimental investigation, black areas are absorbers

Figure 4 shows the dismantled PPW test fixture used to perform characterisation of the PCFSS conversion loss under normal incidence. In order to estimate the power levels of RF and IF signals available at the PCFSS structure we use the following procedure. At the RF input side incident RF level is fixed at the sweep oscillator, then cable loss and half of the total insertion loss of the empty PPW simulator are subtracted. At the second port of the waveguide simulator the IF power level as measured on a spectrum analyser is increased by the cable losses and half simulator insertion loss. In addition 3dB is added to account for the fact that the IF signal will radiate equally into both half spaces of the PPW simulator. Conversion loss is then calculated as the ratio of the power of the RF signal at the PCFSS to the phase conjugate IF power produced at the PCFSS. The measured results of PCFSS conversion loss for different input power level and bias voltage are plotted in Fig. 5 and 6, respectively.

Figure 5 shows that for a three strip PCFSS structure the mixer conversion loss scales with incident RF signal level. The RF frequency, 3GHz, is chosen to be at the PCFSS resonant point for maximum energy coupling. Figure 6 shows that the conversion loss of the PCFSS structure is depended of the diode dc bias with best performance being achieved in the region of 150mV to 170mV bias which corresponds to the diode square law region [11]. Here for the LO and RF frequencies used -3.3dBm incident power was selected as a representative level for conversion loss test. The RF and LO frequencies are chosen such that 2.9GHz represents the lower sideband, i.e. phase conjugated sideband.

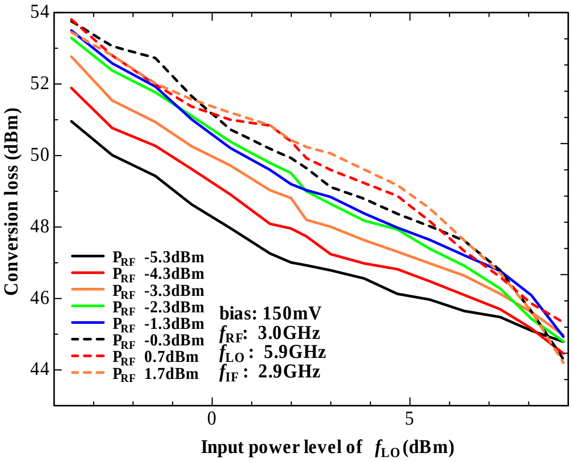

Figure 5: Conversion loss of PCFSS for different input power level (f_{RF}: 3.0GHz, f_{LO}: 5.9GHz)

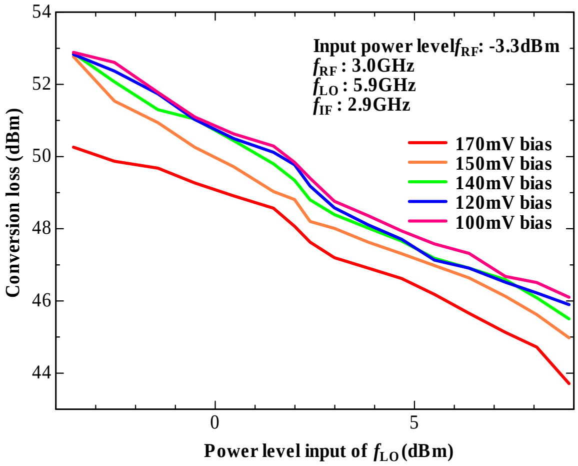

Figure 6: Conversion loss of PCFSS for different bias voltage (P_{RF} : -3.3 dBm, f_{RF}: 3.0GHz, f_{LO}: 5.9GHz)

4. Conclusions

Through experimental observations of the characteristics of a diode loaded doubly periodic array of wire elements we have established the probable fundamental limit on the maximum amount of phase conjugate energy that can be achieved through first harmonic pumping of a square law PCFSS, ~24dB conversion loss. The essential properties of such a structure with respect to conventional circuit based mixer performance as well as additional FSS performance metrics have been established and reveal that around 20dB RF to IF (worst case, sparse array), isolation should be achievable.

Acknowledgments

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