Application of Active Frequency Selective Surfaces to the Modulated Scatterer Technique

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***Abstract*—The modulated scatterer technique (MST) has long been used for rapid antenna measurements, but has also found application in many systems that first require measuring the spatial distribution of electromagnetic fields. Traditionally, small probes are modulated to spatially tag the fields scattered by the probe. Many practical limitations arise from this, limiting the overall robustness of the measurement. To improve on several aspects of MST for certain applications a frequency selective surface (FSS) loaded with PIN diodes has been designed. This design is particularly useful for rapid qualitative microwave imaging systems utilizing synthetic aperture focusing techniques, which are well suited for various nondestructive testing applications.**

***Index Terms*—Frequency selective surfaces, microwave imaging, modulated scatterer technique**

I. Introduction

ONE common technique for measuring the spatial distribution of electromagnetic fields is known as the modulated scatterer technique (MST). Originally developed to be a fast method for mapping the electric field distribution for measuring antenna radiation properties, MST and its similar variants have since evolved into a number of different applications [1]. One notable application has been to use MST to rapidly map the electric field over an aperture and then use synthetic aperture focusing techniques (SAFT) to produce microwave images at or near video frame rates (real-time) [1]-[2]. Systems employing this imaging methodology have found particular use in nondestructive testing (NDT) applicable to many industries such as civil infrastructure, space, aerospace, and biomedical [3].

In a traditional measurement, MST involves placing a small (non-perturbing) antenna, such as a dipole, at a point in space where the electromagnetic fields are desired to be measured. At this location, the small antenna scatters the electromagnetic fields incident upon it. By loading the scatterer with an active element, the scattered fields may be modulated. This spatially tags the fields radiated from the scatterer when the total radiated fields (modulated and unmodulated) are received at another location. The modulated portion of the total received signal can then be extracted and referenced back to the location of the scatterer. This can be performed over an aperture by mechanically scanning a single scatterer or using an array of scatterers. The received fields, referenced to the measurement aperture, can then be used with SAFT to produce microwave images.

Although MST is used to improve the robustness of the measurement, limitations often arise in practice. These are generally related to the low modulation depth of traditional scatterers and the large total signal received. The modulation depth of a scatterer is defined as the ratio of the scattered fields in the two different modulation states. When this is small, a complex receiver must be used to extract the small variation from the large overall signal. To simplify the receiver design, different scatterers may be used, such as those of the microwave camera in [2]. These scatterers are resonant and form a reflecting array, providing a higher modulation depth and improved isolation between the receiver and total radiated fields.

Although very successful, the microwave camera of [2] still has some shortcomings. For nondestructive testing, many applications can be improved by creating images for two orthogonal polarizations to detect more defects [3]. This is not possible with the system from [2] without mechanically reconfiguring the measurement setup. Further, the scatterer design of this system is very specific for its receiver. More applications can benefit from a scatterer with similar properties, but that can be used in a more general collector design. To reduce some of these limitations, an active frequency selective surface (FSS) may be potentially designed to act as an array of modulated scatterers for similar microwave imaging applications.

II. Frequency Selective Surfaces for the MST

An FSS is a periodic array of conductors that can be described by a single unit cell. When excited by incident radiation, these structures exhibit a resonant response which is caused by the geometry of the FSS element and the mutual coupling between nearby elements. Depending on the FSS element used, the structure generally becomes either completely reflecting or transmitting to the incident radiation. By loading the FSS with active components, each FSS element can be independently controlled.

For microwave imaging applications it is desired to design an FSS that when resonating presents a reflective surface to incident radiation. This provides a high level of isolation between the collector and total radiated fields, as desired. Further, by modulating a single element between the reflecting and transmitting states, a small “window” can be made in the

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reflecting surface to allow locally incident radiation to leak through to the collector and be easily measured.

Another benefit of using FSS as modulated scatterers is that many are already designed to have identical responses for two orthogonal polarizations. By choosing an element of this type, the imaging system can be developed to make images for two polarizations, improving the robustness of the system.

III. Meandered Line Loop Active FSS

To test the concept of using active FSS for measurements employing MST, a meandered line loop FSS was designed to operate at ~11 GHz. This type of FSS is reflective when resonating, and can control two polarizations independently through proper placement of active components. A rectangular loop is used to correct for the uneven reactive loading of the bias network on the FSS to make the resonant frequencies of both polarizations identical. The meandered line loop is used to lower the resonant frequency so that the unit cell size is less than half a wavelength at the operating frequency, maintaining Nyquist sampling criteria for the mathematical transformations of common imaging algorithms. Four PIN diodes are strategically placed within the loop so that a pair of diodes may control one polarization without affecting the response of the other polarization. Other components to provide RF and DC decoupling of the bias network and FSS are also integrated into the unit cell. A picture of one of the assembled unit cells is shown in Fig. 1.

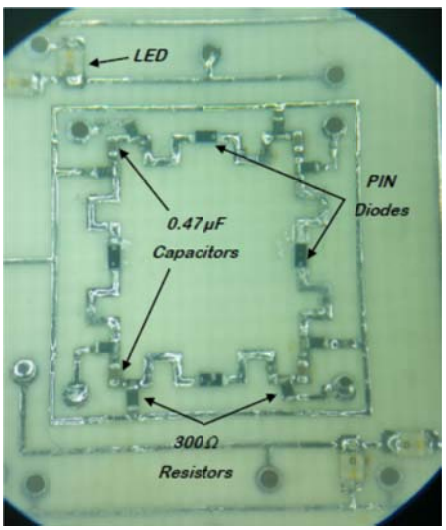

Fig. 1. Magnified picture of an assembled unit cell of the meandered line loop FSS and supporting bias network.

Measurements were performed to provide preliminary results for the efficacy of using active FSS in systems using MST. A small 3x3 subsection of the full 11x11 FSS was assembled. Open-ended rectangular waveguides were positioned at the 3x3 section and were used to measure the transmission through the FSS. Only the two PIN diodes to control the vertical polarization were biased in different states, with measurements performed for both polarizations to characterize the FSS. The total system loss without the FSS present was measured to be ~20 dB. The results of the various measurements are shown in Fig. 2. The results show that at the single frequency of operation, 11.19 GHz, a modulation depth of ~13 dB is achieved for the vertical polarization, which is comparable to [2]. At the same time the horizontal polarization is unaffected. When not modulated, the FSS provides ~35 dB of isolation. By biasing both polarizations to resonate and modulating a single polarization for one unit cell at a time, the desired behavior is achieved to allow rapid image formation for two linear polarizations.

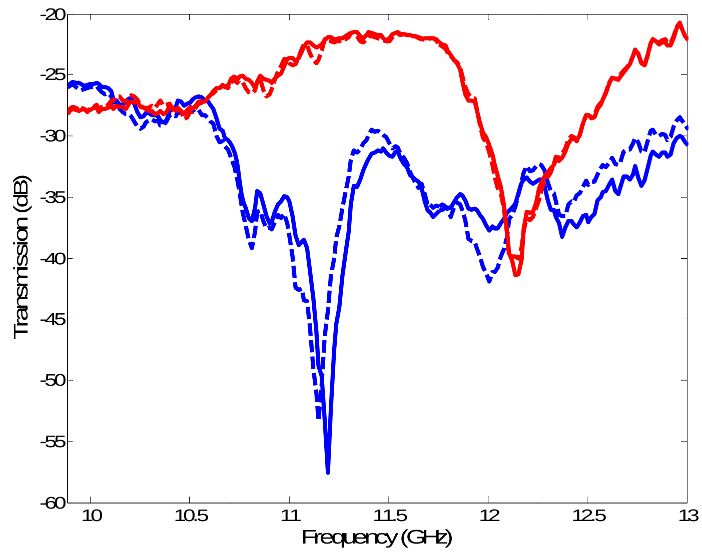

Fig. 2. Measured results for different bias states and polarizations. Blue traces are vertically polarized, red traces are horizontally polarized. Solid traces are for closed PIN diodes, dashed traces are for open PIN diodes. Only PIN diodes to control vertical polarization are switched.

IV. Conclusion

An active FSS was designed to demonstrate its potential utility as a part of a rapid microwave imaging system. Preliminary results show that this could be an effective technique for rapid and dual-polarized microwave imaging systems. Further pertinent investigations are necessary to optimize this approach for robust MST measurements.

V. Acknowledgements & Future Plans

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