01 Jan 2023

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2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI) | 978-1-6654-4228-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/USNC-URSI52151.2023.10237897

PCB Based Modulated Scatter with Enhanced Modulation Depth

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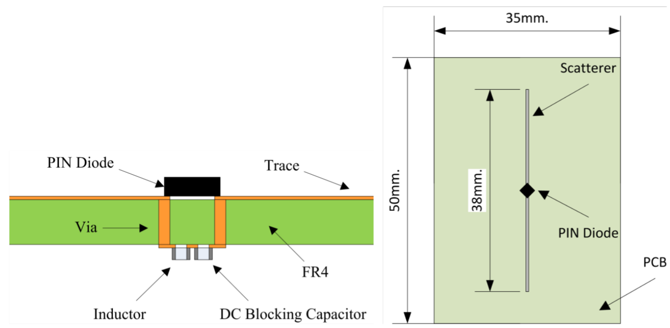
***Abstract*—The modulated scatterer technique (MST) has shown promise for applications in microwave imaging, electric field mapping, and materials characterization. Traditionally, MST scatterers are dipoles centrally loaded with an element capable of modulation (e.g., a PIN diode). By modulating the load element state, the scattered fields are also modulated. However, due to the small size of such scatterers, it can be difficult to reliably detect the response. Increasing the modulation depth (MD) of the scattered signal may improve detectability. This paper presents simulations and measurements of PCB-based MST elements that, through reactive loading, are designed to be electrically invisible during the reverse bias state of the modulated element (a PIN diode in this case) while producing detectable scattering during the forward bias state. The results show a significant (>90%) improvement in the MD of the scattered signal when compared to a traditional MST scatterer.**



(a) Side view (b) Top view

Fig. 1: Diagram of the PCB-based modulated scatterer design.

I. Introduction

The modulated scatterer technique (MST) [1] consists of illuminating a small scatterer (typically a resonant dipole centrally loaded with a PIN diode) with an electromagnetic wave. This incident wave induces a current on the dipole, corresponding to its geometry and local environment, which subsequently causes scattering [2]. The scattering may then be modulated—and thus uniquely distinguished from other signals—by changing the state of the scatterer load, e.g, a PIN diode. This technique has shown potential for microwave imaging, electric field mapping, and materials characterization applications [1]–[4].

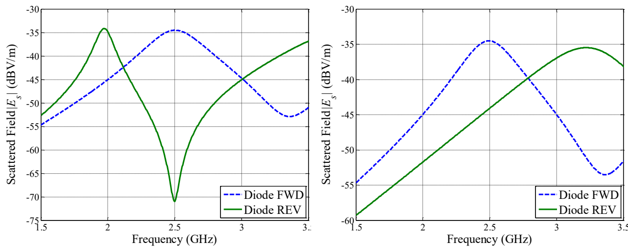
Recently, it was proposed to improve the modulation depth (MD) of MST scatterers by adding reactive elements to the scatterer load in order to reduce scatting in the reverse bias state [5]. Here the MD is considered as the difference in scattered electric field magnitude between the forward and reverse bias states of the active load [5]. However, results were obtained using scatting elements that were constructed of wires with the loads soldered in the middle (to create a loaded dipole antenna). This design resulted in a mechanically weak structure susceptible to breaking. In this work, we propose a similar scattering structure that is implemented on a printed circuit board (PCB) substrate in order to provide a more mechanically robust scatterer suitable for practical MST applications. Furthermore, PCB-implemented scatterers are better suited for precise tolerances and mass production.

II. Modulated Scatterer Design

The basic design of the PCB-implemented scatterer with improved MD is shown in Fig. 1. As shown, vias are used to connect the scatterer on the top layer of the PCB to the inductive load on the bottom layer of the board underneath the pin diode. In this way, the design places the loads in parallel. It is well-known that vias are a source of parasitic inductance [6], which is usually unwanted in board designs. However, in this case, inductive loading is desired [5]. Therefore, the use of vias results in a reduced value of lumped element inductance required for maximizing the MD.

The scatterer length was optimized to achieve maximum scattering at the design frequency of 2.5 GHz, which resulted in a total length of 38 mm. The trace width was set to 0.511 mm. Simulations revealed that minimum scattering during the reverse bias state of the diode is achieved with a 6 nH inductor. A capacitor was included in series to block the PIN diode DC biasing currents from shorting through the inductor. A relatively high capacitance of 0.22 μF was chosen so that the impedance of the capacitor would be negligible at the measurement frequencies (0.3 mΩ at 2.5 GHz).

Full wave simulations of the PCB-implemented scatterer were conducted using CST Microwave Studio [7] in order to fully capture the parasitic effects of the vias as well as any effects of the substrate. The simulated broadside scattering, under plane wave illumination, from this design is shown in Fig. 2a for both forward and reverse bias states of the PIN diode. The simulated results show an MD of 97%. A similarly designed (PCB-based) traditional MST element was also simulated and analyzed for comparison. The structure was identical to that depicted in Fig. 1, sans the vias and parallel elements. The simulated scattering from the traditional element is plotted in Fig. 2b and achieves a 50% MD at 2.5 GHz.



(a) PIN diode and inductor (b) PIN diode only

Fig. 2: Simulated broadside scattered fields produced by plane-wave excitation of the PCB scatterers.

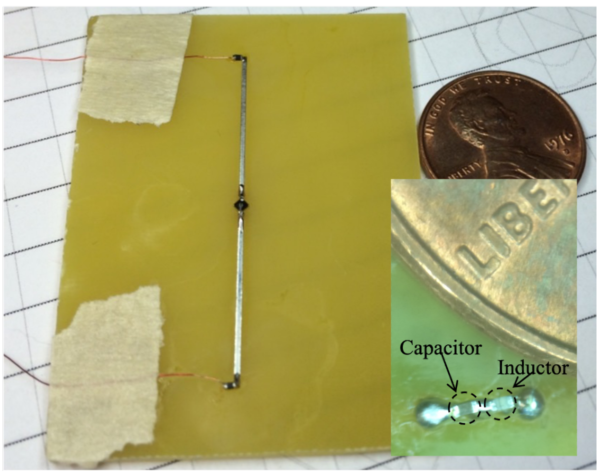


Fig. 3: Photograph of the PCB-based modulated scatterer design.

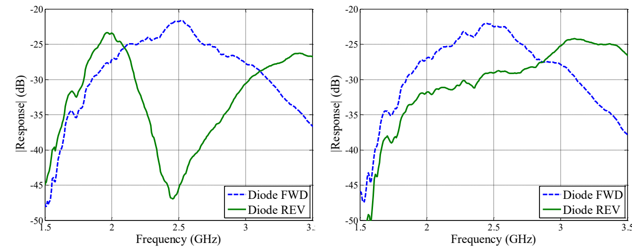
III. Measurements

The PCB-based MST element designed above was fabricated for measurement verification. A photograph of the fabricated scatterer is shown in Fig. 3, which also depicts the DC biasing wires for the PIN diode and surface mount inductors used as RF blocks connected at the ends of the scatterer. The photo inset shows the back of the scatterer with the inductor and capacitor—both are 0201 package size—soldered into place. The surface-mounted components used are listed in Table I. For comparison, a traditional MST element was also fabricated, which consisted of the same top layer (PIN diode and traces) but without the vias and reactive elements on the bottom layer.

The PCB scatterers were measured inside a semi-anechoic chamber approximately 0.5 m from the aperture of two 1-4 GHz ridged horn antennas—each connected to a calibrated port of an Agilent 8753E Vector Network Analyzer. A bistatic setup was chosen for better measurement sensitivity. The setup was measured with and without the scatterer present to isolate the scatterer response from that of the measurement setup using coherent background subtraction. Additional measurement details are provided in [8].

TABLE I: Surface mount components

	Manufacturer	Part Number	Value
PIN Diode	Microsemi	GC4270	N/A
Inductor	TDK	MLK0603L6N2ST	6.2 nH
Capacitor	Panasonic	ECJ-ZEB0J224M	0.22 μF



(a) PIN diode and inductor (b) PIN diode only

Fig. 4: Measured broadside response produced by plane-wave like illumination of the fabricated PCB scatterers.

The post-processed response of both PCB-based scatterers (improved and original) are presented in Fig. 4. At the design frequency of 2.5 GHz, the improved scatterer design provides an MD of 88% compared to the traditional design that achieves 36%. The measured results also show a good correlation with the simulated data provided in Fig. 2.

IV. Conclusion

In this work, an MST element with improved MD implemented on a PCB substrate was presented. The design is based on the concept presented in [5] but extended to PCB manufacturing for a more mechanically robust design. Experiments show the new design which uses reactive elements in parallel with the PIN diode significantly (>90%) improves the MD when compared to the traditional design of using a diode only.

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