A Reconfigurable Dual-Band Metasurface for EMI Shielding of Specific Electromagnetic Wave Components

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***Abstract*—Metasurfaces are becoming more of an interest to the research community because of the unusual electromagnetic properties that can be achieved. This paper presents a reconfigurable metasurface for EMI shielding purposes. In particular, a dual-band Jersualem cross is developed and pin diodes are use to interconnect elements to control the specific polarization properties of the shield. It is shown that the response of the shield to specific field components can be controlled with simple control voltages. Simulations are validated with measurements throughout this work.**

I. INTRODUCTION

Without initial planning and proper design, electromagnetic shielding can be an unpredicted design component of a wireless or RF system. Traditionally, metallic shields are used to block against unwanted interference over wide bands of frequency [1] - [3]. In some cases, if this shield has an overall large area and thickness, the cost and weight can be impractical. Furthermore, if the noise sources are not very broadband, there may be bands in which the metallic shield may not be required to operate in.

Metamaterials are gaining popularity as an area of research for developing materials with electromagnetic properties not found in nature [4] - [10]. Within this area, metasurfaces or metafilms have also been developed [11] - [18]. In particular, the electromagnetic reflection of these structures have been a property of interest [11], [12] and [15]. It has been shown that by printing conductors on the surface of a printed circuit board (PCB) in particular patterns, a compact and light-weight metasurface can be developed to block particular frequency bands of interest and pass others [11]. The result is a compact and light-weight frequency selective shield. The work in [11] has been extended in [12] to include other operating bands and tunability by embedding voltage controllable varactor diodes within the design of the shield.

A more recent area of research associated with metamaterials is reconfigurability. Reconfigurable structures have several advantages over tunable structures such as higher frequencies of operation, simple control voltages (i.e., there is not the requirement of a precision controlled voltage source) and are a more efficient solution to shielding applications for multiple frequencies. Some of the initial work on reconfigurable metamaterial transmission lines was reported in [19]. This involved a reconfigurable composite right-/left-handed (CRLH) transmission line [4] with pin diodes embedded into the design. It was shown that the zero-phase frequency can be quickly changed between two values with a simple control voltage.

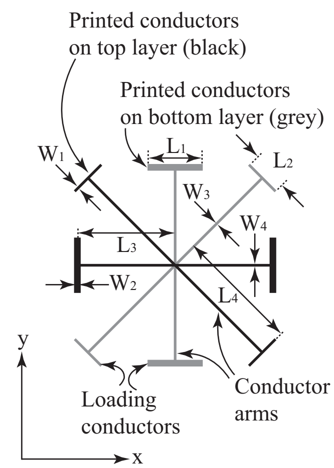

Fig. 1. Layout of the dual-band Jerusalem cross.

The objective of this work is to combine the compact and light-weight features of the dual-band metasurface with the simple control methods of the reconfigurable structures. The metasurface proposed in this paper consists of 48 of the individual dual-band Jerusalem crosses shown in Fig. 1 in the 8×6 layout configuration shown in Fig. 2. The cross has four conducting arms and each arm is loaded with conductors. The horizontal and one of the diagonal conducting bars is

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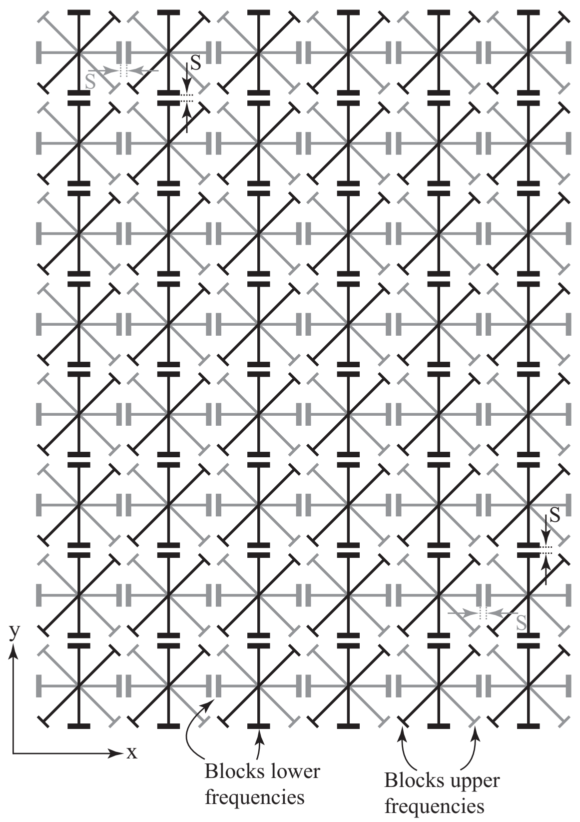


Fig. 2. Layout of the dual-band metasurface shield without reconfigurability.

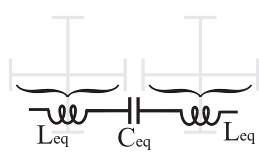


Fig. 3. Equivalent circuit of the Jerusalem crosses embedded into the reconfigurable dual-band metasurface shield.

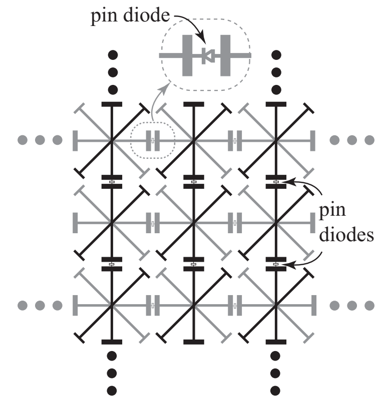


Fig. 4. Drawing showing the pin diodes in a small section of the reconfigurable shield.

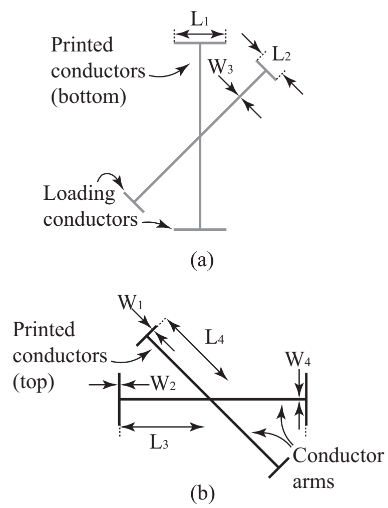


Fig. 5. (a) Layout of the printed conductors on the bottom layer and (b) layout of the printed conductors on the top layer.

printed on the top layer and the vertical and the alternate diagonal conducting bar is printed on the bottom layer. The top conductors are drawn with black lines and the conductors on the bottom layer are shown in grey.

II. The Two-Layer Reconfurable Dual-Band Metasurface EMI Shield

The Metasurface with the Jerusalem crosses presented in [11] have been adopted for this work. To achieve dual-band operation, two crosses for two different frequency bands were designed. The result of this effort is shown in Fig. 1. The cross with the horizontal and vertical conducting bars was designed to block the lower frequencies and the rotated cross was designed to block the upper frequencies (indicated in Fig. 2). Then, the dual-band crosses were orientated in the manner shown in Fig. 2 to create the dual-band shield.

The blocking frequencies of each cross can be computed by considering the equivalent circuit in Fig. 3. Each conducting bar is modeled as a series inductance L_{eq} and the capacitance between adjacent crosses is modeled as C_{eq}. Then the blocking frequency can be computed using $1/(2\pi\sqrt{L_{eq}C_{eq}})$.

Next, to implement the reconfigurable aspect of the shield, pin diodes were used to connect adjacent loading bars between crosses. A drawing of the proposed configuration is shown in Fig. 4. When the pin diode is off, the adjacent crosses are coupled through the capacitance and when the diode is on (biased), the adjacent cells are directly connected and the capacitance between neighboring cells is reduced; which in result reduces the shielding effectiveness. This ability to control the shielding effectiveness of the surface can be used for reconfigurability of particular polarizations. To implement the ability to control individual polarizations, the voltage controlling the diodes on the horizontal conductors must be different and isolated from the voltage controlling the diodes on the vertical conductors. To isolate these voltages, each dual-band cross in Fig. 1 was split into two sections and printed on separate layers. A drawing of the conductors on each layer are shown in Fig. 5. Fig. 5(a) shows the layout of each cross on

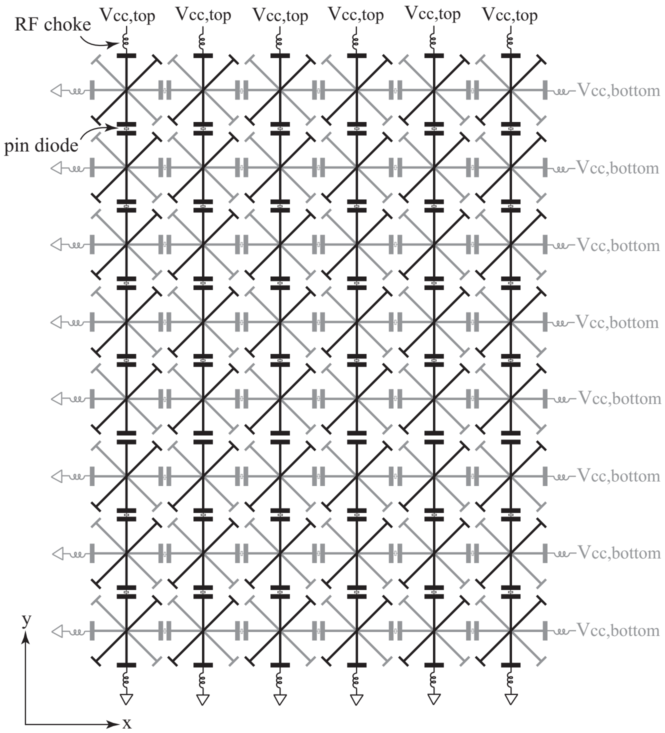


Fig. 6. Layout of the reconfigurable dual-band metasurface shield.

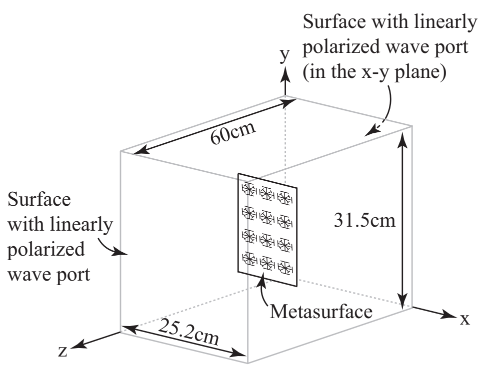


Fig. 7. Drawing of the simulation definition in HFSS.

the bottom layer of the shield and Fig. 5(b) shows the layout of the top layer.

This two layer design then resulted in the reconfigurable metasurface shield shown in Fig. 6. The pin diodes were connected to the horizontal and vertical conducting bars shielding the lower frequency only. The control voltages $V_{cc,top}$ (in black) at the top of the shield controlled the diodes on the vertical conducting bars and the control voltages $V_{cc,bottom}$ (in grey) on the right-side of the shield controlled the diodes on the horizontal conductors. Each voltage and reference were connected to the shield using RF chokes to isolate the source from the RF shield. Therefore, $V_{cc,top}$ can then be used to control the shielding effectiveness of the surface for y-polarized waves (vertical polarization) and the $V_{cc,bottom}$ can be used to control the shielding effectiveness of the surface

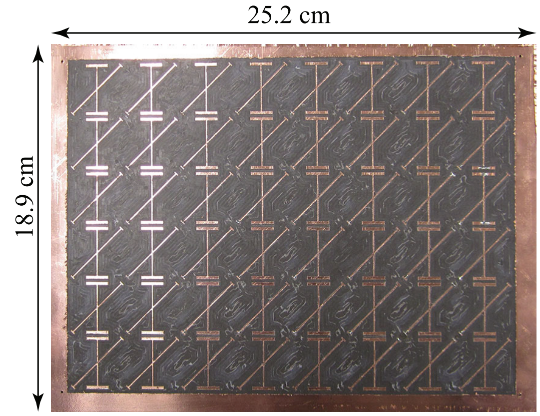


Fig. 8. Picture of the manufactured prototype shield without the pin diodes (L_1 = 13.0 mm, L_2 = 3.0 mm, L_3 = 13.0 mm, L_4 = 19.3 mm, W_1 = 1.0 mm, W_2 = 2.0 mm, W_3 = 1.0 mm, W_4 = 1.0 mm and S = 1.5 mm).

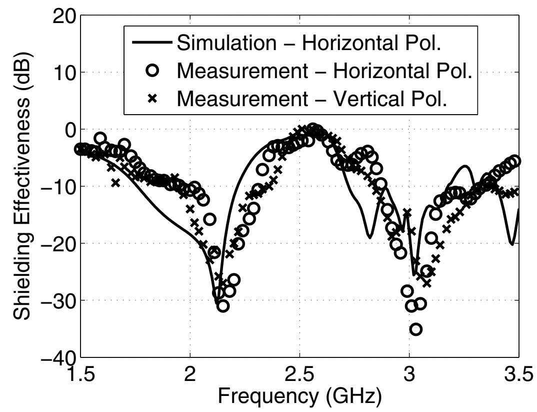


Fig. 9. Simulated and measured shielding effectiveness results for a x- and y-polarized wave (horizontal and vertical) for the surface without the pin diodes.

for x-polarized waves (horizontal polarization) individually.

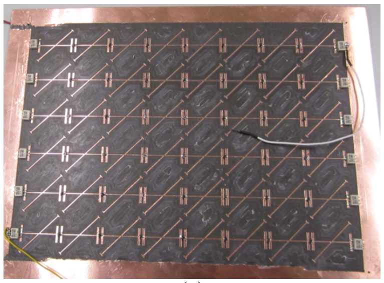
III. Simulation and Measurement Results

Initially, the dual-band metasurface was simulated and designed in HFSS [20] without the pin diodes in place. These steps were taken first to explore the shielding properties of the surface for conductors on two layers. The substrate was a Rogers RT/Duroid 5880 [21] (ε_r = 2.2 and $\tan\delta$ = 0.0009) with a thickness of 1.57 mm. A drawing of the simulation definition along with the dimensions is shown in Fig. 7 and a picture of the manufactured prototype shield without the pin diodes is shown in Fig. 8. The shielding effectiveness was then measured in an anechoic chamber and compared to simulations where SE was computed using the following [1]:

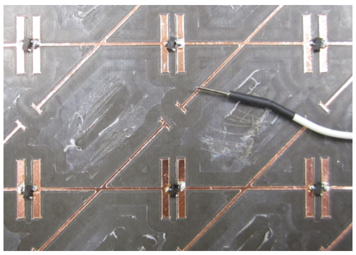
$$SE_{dB} = S_{21,withoutshield} - S_{21,withshield}. \tag{1}$$

These results are shown to agree in Fig. 9.

For the horizontal polarization, the lower and upper bands in which the SE was above 15dB was measured to be a 170 MHz and 320 MHz, respectively. Then the horn was rotated



(a)



(b)

Fig. 10. (a) Picture of the manufactured reconfigurable prototype shield and (b) closer image of the pin diodes.

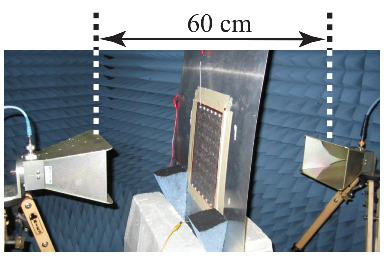


Fig. 11. Picture of the reconfigurable prototype shield being measured in the anechoic chamber.

by 90 degrees for vertical polarization and similar 15 dB SE properties were observed. These results are shown to agree in Fig. 9.

Next, the pin diodes manufactured by Skyworks [22] were attached to the vertical and horizontal printed conductors of the shield in Fig. 8 in the manner shown in Fig. 6 and the RF chokes used were manufactured by Minicircuits [23]. A picture of the manufactured prototype reconfigurable metasurface is shown in Fig. 10(a) and a closer image of the pin diodes soldered to the conductors is shown in Fig. 10(b). The reconfigurable metasurface was then placed in the anechoic chamber and the shielding effectiveness was measured for the x- and y-polarizations. A picture of the shield being measured is shown in Fig. 11 and the measurement results are depicted in Figs. 12 and 13. From these results it can be noted that the lower frequency has been shifted down after the addition of the pin diodes whereas the upper frequency remains unchanged. This is thought to be due to the fact that each pin diode is presenting an additional series inductance of 1.5 nH to the crosses blocking the lower frequency band thus increasing the overall inductance and lowering the blocking frequency.

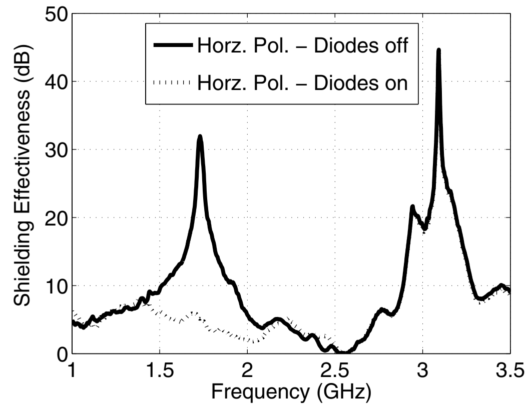


Fig. 12. Measured shielding effectiveness of the reconfigurable shield for the x-component (horizontal polarization).

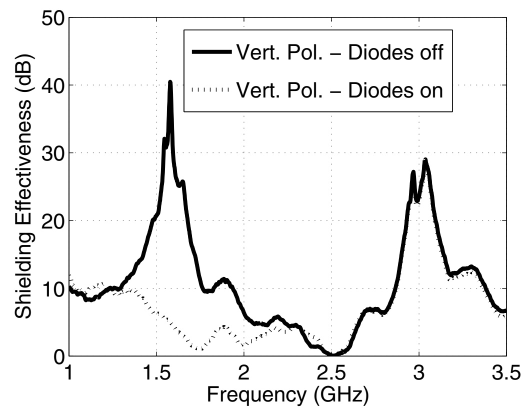


Fig. 13. Measured shielding effectiveness of the reconfigurable shield for the y-component (vertical polarization).

IV. Discussion

Several unique comments can be made about the previous results. The related results reported in [12] are for a dual-band metasurface with printed conductors on a single layer and varactor diodes used to control the coupling between adjacent crosses. The design in Fig. 2 and the measurement results in Fig. 9 show that a dual-band shield can be designed on two different conducting layers.

The reconfigurable results in Figs. 12 and 13 show that the polarization of the shield can be controlled individually. In particular, the results in Fig. 12 show that the horizontal polarization of the shield can be turned on and off with the pin diodes in the lower band without affecting the upper band. Similarly, the results in Fig. 13 show that the vertical polarization of the shield can be turned on and off with the pin diodes in the lower band without affecting the upper band. This feature makes this shield useful for applications that require unique and precisely controllable shields.

V. Conclusion

A new reconfigurable dual-band measurface EMI shield has been designed, manufactured and tested. Initially, it was shown that the metasurface can be printed on two conducting layers with dual-band characteristics. Then, pin diodes were attached to the dual-band metasurface and individual control voltages were used to control the diodes. These diodes were then used to control the individual polarizations of the shield in the lower band without affecting the upper band. In principle, it was shown that simulations agreed with measurements.

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