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Designing a Tunable Frequency Selective Surface with Active Components / Pescari, Catalin; Silaghi, Andrei-Marius; De Sabata, Aldo; Matekovits, Ladislau; Mir, Farzad. - ELETTRONICO. - (2024), pp. 1707-1708. (Intervento presentato al convegno IEEE International Symposium on Antennas and Propagation and INC/USNCURSI Radio Science Meeting (AP-S/INC-USNC-URSI) tenutosi a Firenze (Italy) nel 14-19 July 2024) [10.1109/ap-s/inc-usnc-ursi52054.2024.10685885].

Availability:
This version is available at: 11583/2994243 since: 2024-11-07T15:51:03Z

Publisher:
IEEE

Published
DOI:10.1109/ap-s/inc-usnc-ursi52054.2024.10685885

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19 March 2025

Designing a Tunable Frequency Selective Surface with Active Components

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***Abstract*—In accordance with the increasing demand for tunable devices in present-day communication systems, two design suggestions for a tunable Frequency Selective Surface are made in this work. We used active devices (diodes for tuning reasons) and a control network (to bias the active devices) in our simulations of metallic structures. Electromagnetic simulation has been used to assess the proposed designs. By utilizing the square-shaped unit cells 18 mm edge length and periodicity, distinct filtering bands can be produced below 12 GHz.**

I. INTRODUCTION

Two-dimensional periodic structures known as frequency selective surfaces (FSSs) are used for polarization conversion, shielding, and spatial filtering [1]. These designs naturally evolve to become adaptable, thus designers are frequently introducing lumped elements into structures in order to create tunable FSSs. There are two basic ways to do this: employing PIN or varactor diodes [2, 3]. In addition, in structures containing active components, a DC bias network (Control network-CN) needs to be included [3, 4].

The structure of this paper is as follows. Section 2 provides a brief discussion of the suggested solutions including diodes and CN. In Section 3, an electromagnetic simulation is used to evaluate the operation. Parametric modifications are also covered in this part to show how the structures can be tuned. Field images are taken, documented, and discussed for the structures and CN lines to further enhance the investigations depth.

II. DESIGN OF THE PROPOSED STRUCTURE

We started our designs from the cut-slot structure introduced by some of the authors in [5] and placed diodes in the cut-slots in order to obtain controllable geometry (Fig. 1a). The dimensions of the structure are identical to those described in [5] (more details will be given in the presentation). In Fig. 1b it is visible that three parallel CN microstrip lines are linked to the main FSS structure in this region by means of via holes (one via hole links one CN line) [5]. Studies regarding the use of CN were undergone previously [5].

Moving forward, the bias voltage provided to the structure controls the PIN diode's behavior, which in turn controls the FSS's behavior. An almost short circuit is shown by the PIN diode's behavior, which correlates to a low R (ON state) when the bias network is provided a high voltage. On the other hand, when small power is provided to the structure, PIN diodes function as a capacitor (OFF state) [5].

Fig. 2 displays the equivalent circuits for the ON and OFF states of the PIN diodes. When the structure operates as an RL circuit (ON state), the nominal values for the lumped elements are: R_s = 7 Ω *and* L = 30 pH, whereas when the PIN diodes act as an LC circuit (in the OFF state) the nominal values are: L= 30 pH, C_s = 28 fF, and R_s = 30 kΩ [3].

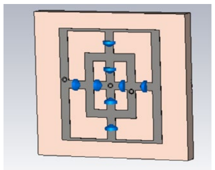

Figure 1a. Structure with PIN diodes present.

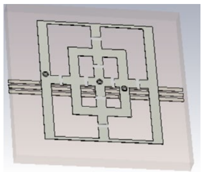

Figure 1b. Position of CN lines.

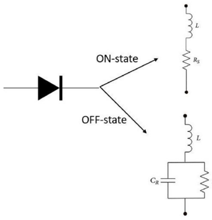

Figure 2. Equivalent circuit of PIN diodes in ON and OFF states [3].

III. SIMULATION RESULTS

A. Initial simulations

Next, we calculated the transmission coefficients in normal incidence, obtained with the help of the simulation program [6] for the diode structure in both OFF and ON states. Firstly, in Fig. 3 we can observe the transmittance for the diode structure in OFF state for both TE mode (blue color) and TM mode (red color). Resonances appear at 4.67 GHz, 9.8 and 11.9 GHz for the TE mode, respectively at 2.76 GHz, 6.36 GHz and 11.1 GHz for the TM mode. Secondly, in Fig. 4 we can observe the transmittance for the diode structure in the ON state, for the TE mode. For the case of TE incidence, a stopband of −10 dB between 6.51 GHz and 9.86 GHz with a resonance centered at 8.6 GHz can be observed. Furthermore, two smaller bands appear between 10.18 GHz and 10.49 GHz and between 11.38 GHz and 11.71 GHz.

Subsequently, parametric evaluations were performed to examine the transmittance modifications with angle theta for both designs. Initially, for the diode structure in ON state, a parametric analysis in TE incidence was carried out. From 0 to

45 degrees, the theta angle was changed in increments of 15 degrees. The most significant notch is shifted to lower frequencies when this parameter is increased, based on the results shown in Fig. 5. There are more notches at higher frequencies. For the diode in OFF state, the parametric study shows consistency (more details will be given at the presentation moment).

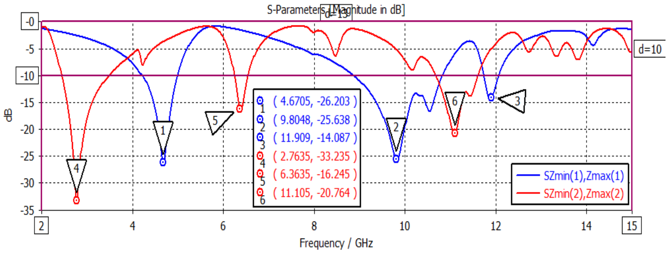

Figure 3. Transmission result for OFF structure (TE and TM modes).

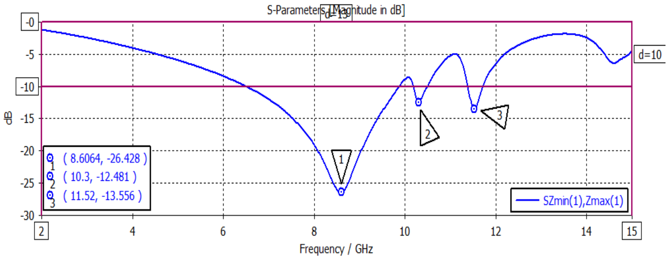

Figure 4. Transmission result for ON structure (TE mode).

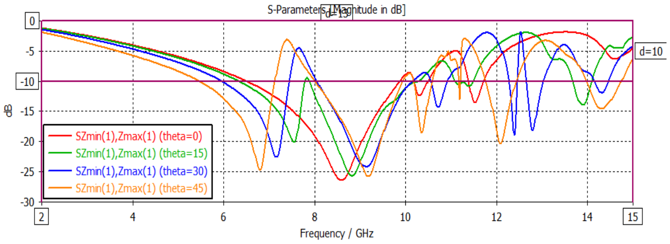

Figure 5. Transmission results for ON structure (TE mode), for different theta values.

B. *Field images*

To elaborate on the previous findings with the presence of the CN and the diodes, field images of surface current density are provided for each design, with diodes in both OFF and ON states. Next, the OFF structure is discussed. Since the primary resonances in TE mode are concentrated at frequencies of 4.67 GHz and 9.8 GHz, these frequencies were selected for field image computation (Fig. 6a and Fig. 6b). Firstly, Fig. 6a illustrates the maximum magnetic field of 30 A/m at 4.67 GHz with an excitation of 1 V/m. The biggest surface currents in this design are found on the exterior of the structure, which shows that the resonance sources come from the big rectangle dimensions. Secondly, the occurrence of the second resonance (9.8 GHz) can be attributed to the design's small interior rectangle dimensions, as seen in Fig. 6b.

Surface currents were also computed on the other side of the design in order to illustrate how the CN lines influenced the appearance of the resonances (for example, for the ON structure in Fig. 8). Surface currents at 4.67 GHz (Fig. 7a) and at 8.6 GHz (Fig. 8) have extremely low levels on the CN lines side, whereas surface currents at 9.8 GHz have significant levels (Fig. 7b) on the CN lines face. Thus, it may be concluded that the 9.8 GHz resonance's manifestation is influenced by the CN lines.

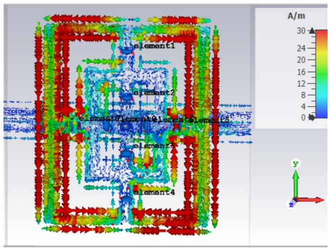

Figure 6a. Field image for OFF structure, 4.67 GHz.

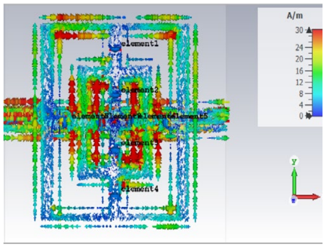

Figure 6b. Field image for OFF structure, 9.8 GHz.

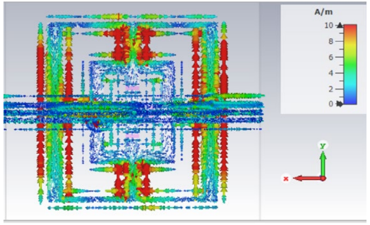

Figure 7. Field image for ON structure, 8.6 GHz, at CN lines.

IV. CONCLUSIONS

This work proposes a tunable FSS that has multiple configurations that acts as a band-stop spatial filter for frequencies below 12 GHz. Two structures with diodes in OFF and ON states, and a control network exhibit filtering. A parametric analysis for the colatitude angle (using electromagnetic simulation) has demonstrated the tunability of the proposed designs. Lastly, to confirm the simulation results, field images of surface current density are supplied.

ACKNOWLEDGMENT

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS - UEFISCDI, project number PN-III-P1-1.1-PD-2021-0010, within PNCDI III.

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