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A Switchable and Tunable Multifunctional Reconfigurable Frequency Selective Surface

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This paper presents a novel multifunctional reconfigurable frequency selective surface (MRFSS) capable of switching between three important electromagnetic (EM) operations, including reflection, transmission, and absorption, while simultaneously offering frequency tunability. The design features metallic patterns on both sides of a single-layer FR4 substrate, integrated with varactors on the top side and p-i-n diodes on both the top and bottom sides to achieve desired switching and tuning characteristics. By articulately regulating the bias conditions of the p-i-n diodes, different functions can be realized under different bias voltages, whereas the frequency tunability can be achieved in each state by adjusting the reverse bias voltage of the varactor diode.

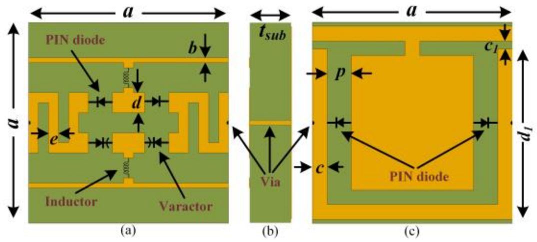

Figure 1. Design of the proposed MRFSS unit cell geometry. (a) Top view. (b) Side view. (c) Bottom view.

The design involves two different metallic configurations periodically arranged on the top and bottom layers, whose unit cell configuration is presented in Figure 1. The top layer features a meander pattern, where varactors and p-i-n diodes are connected in parallel. The bottom layer comprises a central patch and metal lines, which are joined through p-i-n diodes. A metallic via is placed at the center of the unit cell, establishing a common biasing node for both layers. FR4 serves as the dielectric medium. The design has been conceptualized such that the bottom side topology exhibits either transmission or reflection through the switching activity of the diode. On the other hand, the top layer pattern, owing to a combination of the resonators and electronic components, displays selective transmission (1.64-2.53 GHz, 0.71-0.93 dB) and reflection (2.49-4.48 GHz, reflection > -2.5 dB) characteristics at different frequencies. While combining these top-layer functions with the bottom-layer operations, the overall geometry achieves four EM operations under different conditions. Under the OFF (top layer p-i-n diode)-OFF (bottom layer p-i-n diode) state of the p-i-n diodes, the MRFSS demonstrates a bandpass transmission response, tuning from 1.68 to 2.56 GHz (under different bias voltages of the varactor) with an insertion loss of around 1.8-2.9 dB. The OFF-ON state exhibits a narrowband absorption behavior, ranging from 1.84 to 2.85 GHz, with absorptivity values lying between 84.3% and 96.5%. The ON-ON state features the reflection mode with a reflection coefficient of -1.5 dB, tuning from 2.55 to 4.62 GHz. The fourth mode (ON-OFF) displays a selective reflection behavior between 2.48 and 4.43 GHz.

The circuit modeling approach has been performed for the proposed design, and the scattering parameter values have been derived using Advanced Design System (ADS) software, by comparing with full-wave simulations for all modes. The topology is polarization-selective, and operates when the electric field is oriented parallel to the diode elements and the meander pattern. However, the response deteriorates with other polarizations. The design has also been examined for various incident angles, and the analysis reveals highly stable responses at different incident angles, confirming its angular stability behavior till 60^{o} for all EM operations.

Thus, the paper provides a detailed analysis of an MRFSS structure presenting different EM operations under various electronic conditions. One pair of p-i-n diode and varactor have been mounted on the top layer, whereas another pair of p-i-n diode has been used in the bottom layer. The combination of p-i-n diodes from both layers exhibit four different conditions (ON-ON, ON-OFF, OFF-ON, and OFF-OFF), and each state exhibits one particular EM operations, like reflection, transmission, and absorption. While tuning the varactor diode voltage for each case, the response further tunes over a wide frequency range, thereby facilitating both switching and tuning characteristics from a single MRFSS structure. The design has also been investigated through a step-by-step methodology, equivalent circuit modeling, and oblique incidence response. Such MRFSS structures, capable of exhibiting multiple switching and tuning characteristics, can be used for radar cross section reduction, EM shielding, and other defense applications.