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Optically transparent frequency selective surface for ultrawideband applications

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Abstract

A multilayer ultra-wideband frequency selective surface (FSS), which filters the frequency range between 3.38 and 4.66 GHz is presented. The proposed structure having a transparent substrate allows the light pass through itself, while it filters the electromagnetic waves at the frequency band of interest; and it has a bandwidth of 1.28 GHz. For the FSS structure, a transparency level of 52.5% obtained with a fractional bandwidth value of 32%. The structure is examined layer by layer; and the proposed FSS structures are evaluated in terms of bandwidth and transparency level.

KEYWORDS

dual-band, frequency selective surface, multiband, ultra-wideband, visible spectrum

1 | INTRODUCTION

Fundamental principles of frequency selective surfaces (FSSs) were directly evolved by the American physicist David Rittenhouse and documented by an engaging scientific exchange between Francis Hopkinson and Rittenhouse published in 1786.[1] The principle of it has directly evolved from the investigation of diffraction gratings in optics, which are used to decompose a beam of non-monochromatic light into its spectral orders. Since then, there have been significant research on FSSs, consisting of periodically placed patches or slots that show different transmission characteristics in microwave and optical regions.[2–7]

There are some regulations to use frequency spectrum, includes microwave and optical regions, fairly and efficiently. Examples for mentioned regulations include Industrial Scientific Medical (ISM) band communication, wireless sensor networks, and ultra wideband (UWB) communications. UWB signals have been defined by the U.S. Federal Communication Commission (FCC), allocated a 3.1 to 10.6 GHz block of radio spectrum for unlicensed UWB transmission, with an instantaneous spectral occupancy of a fractional bandwidth of 20% or more.[8] Billions of electronic devices thereby exhibit many desirable properties for UWB applications, thereby FSSs have begun to use to reduce or increase the effectiveness of these devices. However, because of the resonant characteristics of patches or slots, bandwidth of such surfaces are quite narrow which leaded the researchers to focus on alternative designs for achieving multiband and/or ultra-wideband designs.[9–16]

FSS designs have widespread application area coverage including the efficiency of the smart houses which are getting popular since people demand on amenity and comfort last few decades. The houses are evolved to incorporate advanced automation systems to provide the inhabitants with sophisticated monitoring and control over the buildings'

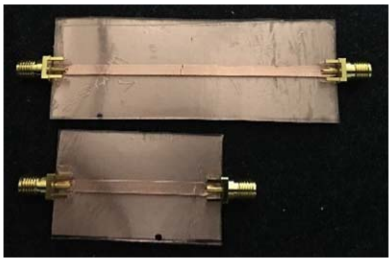

FIGURE 1 Permittivity measurement set-up of the transparent substrate material. [Color figure can be viewed at wileyonlinelibrary.com]

functions. However, these controlling and monitoring devices contribute to the electromagnetic pollution that already has a level of intensity due to Wi-Fi, mobile phones, and so forth. Therefore, a demand is created to filter the electromagnetic pollution in such houses, not only for eliminating the interference between devices but also for clearing the air in terms of health doubts about electromagnetic pollution.[17–19] To fulfil these expectations, designing FSS and metasurfaces are widely used.

In this letter, we consider this requirement and design FSS for filtering the electromagnetic waves for single-band, dual-band, and ultra-wideband operations. Bandwidth enhancement is achieved by designing multilayered topology with a substrate of transparent nylon. The proposed topology that is transparent for visible spectrum but filters a certain frequency band in microwave region has a frequency interval of 3.38 to 4.66 GHz having a bandwidth of 1.28 GHz having a fractional bandwidth of 32%.

2 | PERMITTIVITY MEASUREMENT

Permittivity of a substrate is one of the most important parameters for designing 2D microwave components. To design an engineered surface in an accurate manner, the determination of the permittivity value has a crucial effect as it has a significant impact on S_{21} resonance value.[20] Measured value of ε_{eff} (attendantly ε_r) can be calculated via a method which considers two microstrip lines (Figure 1) and extraction of the effective permittivity value by using the phase difference ($\nabla\varphi$), difference of physical length (∇l_p) frequency (f) values with the relation $\nabla\varphi = \left(2\pi f\left(\nabla l_p\right)\sqrt{\varepsilon_{eff}}\right)/c$.[21] For considering a frequency band of interest, Table 1 presents a set of ε_{eff} values which are the measured values by using the measurement set-up.

TABLE 1 Measurement of using the two microstrip lines for transparent substrate material

f (GHz)	$\nabla\varphi$ (measured)	ε_{eff} (calculated)
3.0	190.1	2.2
3.5	216.4	2.1
4.0	250.0	2.2
4.5	284.3	2.2
5.0	314.5	2.2

3 | PROPOSED DESIGN AND RESULTS

The proposed multilayer structure, which consists of square SRRs for each layer, has a simulation set up seen in Figure 2A. Measurement set up is demonstrated in Figure 2B and the manufactured sample given in Figure 2C. A WR229 waveguide is used for measurements, and corresponding simulations are conducted by using CST Microwave Studio with WR229 waveguide dimensions. The substrate of the FSS are transparent nylon ($\varepsilon_r \sim 2.77$) having a thickness of 1.48 mm and the conductor is copper having a thickness of 0.035 mm. Other parameters for the proposed structure are as follows; l_1 = 27.1 mm, l_2 = 25.2 mm, l_3 = 23.7 mm, g_1 = 3 mm, g_2 = 5 mm, g_3 = 5 mm, $x_1 = x_2 = x_3$ = 3 mm, $d_1 = d_2$ = 1.52 mm. The SRRs are excited electrically and each layer filters a separate frequency band. Increasing the number of the layers causes other S_{21} resonances, so that multiple and ultra-wideband filtering becomes possible.

To evaluate the response of a single layer without the couplings resulting from the other layers, the manufactured structures are examined and the resonance characteristics (Figure 3) are obtained one by one. The corresponding S_{21} resonance frequencies for each individual are as follows: f_1 = 3.75 GHz, f_2 = 4.42 GHz, and f_3 = 4.85 GHz for Layer 1, Layer 2, and Layer 3, respectively.

Double-layer structures consists of several combinations of each individual layers are examined. Dual S_{21} resonance obtained for three different combinations. The SRR structures for each layer cause another resonance as they have different physical size. The lower frequency occurs from mainly due to the larger SRR and the higher frequency is affected from the small SRR. The frequencies for the double layer structure is f_1 = 3.508 GHz, f_2 = 4.198 GHz for the first combination (Layer 1 and Layer 2). Due to the increase of the mutual capacitance value between two layers, the S_{21} resonance frequency tends to decrease. It should be noted that for the discussions in this letter, we are considering the LC resonance where $f_0 \sim (C_{total} L_{total})^{-1/2}$ and neglecting the higher frequency values which are called dipolar resonances. As expected, the other combinations also satisfy the trend lead to a reduction in resonance frequencies which we confirmed by both simulation and measurement. Subsequently, for the second combination (Layer 1 and Layer 3) and the

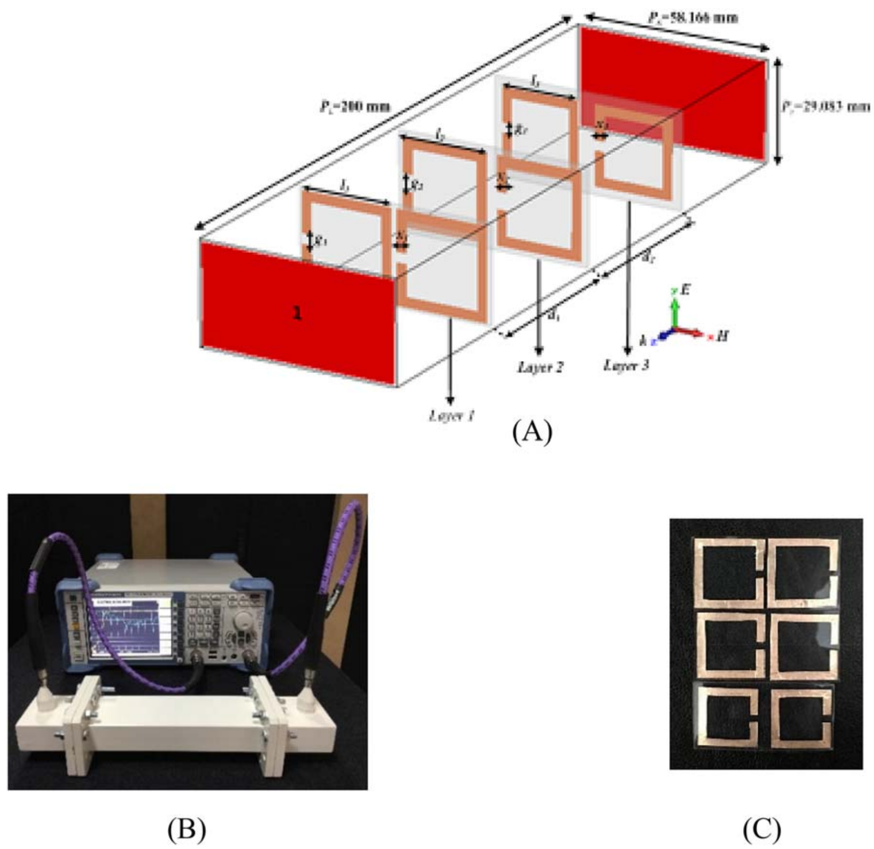

FIGURE 2 Proposed design. A, Simulation set-up of the multilayered ultra-wideband engineered surface. B, Measurement set-up of the multilayered ultra-wideband engineered surface. C, Manufactured sample. [Color figure can be viewed at wileyonlinelibrary.com]

third combination (Layer 2 and Layer 3), the measured frequencies are f_1 = 3.721 GHz, f_3 = 4.715 GHz, and f_2 = 4.108 GHz, f_3 = 4.67 GHz (Figure 4).

Multilayered (three-layer) FSS structure with the combination of Layer 1, Layer 2, and Layer 3 presents three band stop peaks at 3.51, 3.73, and 4.32 GHz in measurement and 3.51, 3.72, and 4.35 GHz in simulations (Figure 5). As in all single- and double-layer cases, increasing the layer number lead us to have a third band stop peak. Apart from other individual designs, by optimizing the band-stop resonance frequency to become closer, an ultra-wide bandwidth of 1.28 GHz between the frequency bands of 3.38 and

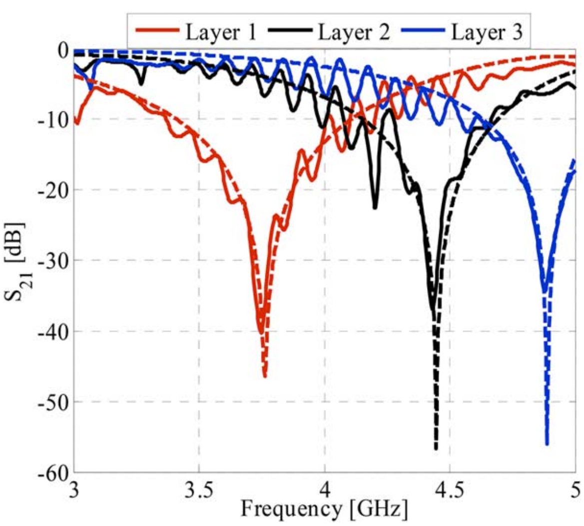

FIGURE 3 Simulation (---) and measurement (—) results for single layer. [Color figure can be viewed at wileyonlinelibrary.com]

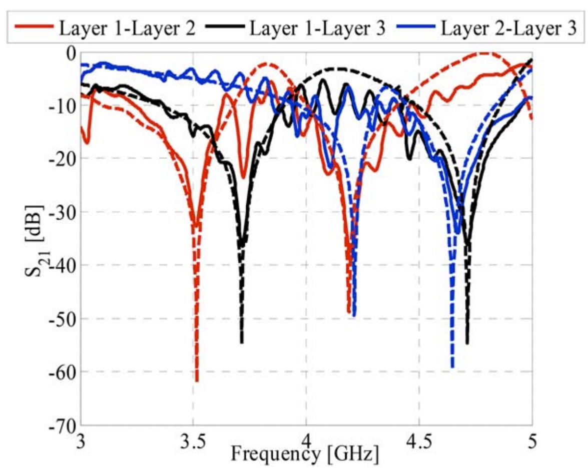

FIGURE 4 Simulation (---) and measurement (—) results for double-layer structures. [Color figure can be viewed at wileyonlinelibrary.com]

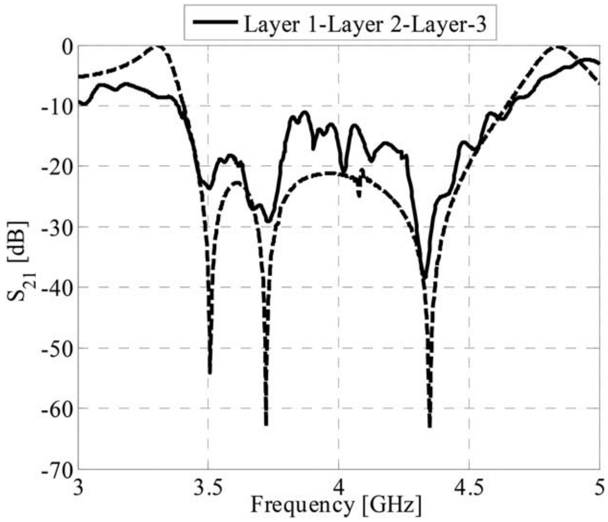

FIGURE 5 Simulation (---) and measurement (—) results for double-layer structures.

4.66 GHz is obtained. The simulation results have a satisfactory agreement with the measured values.

We also examined the transparency level of three-layered ultra-wideband FSS structure and we obtained a ratio of transparent area of the unit cell to the total area of unit cell as 52.5%. For one-layer structure, this transparency is 66.87%, 70.28%, and 72.41% for Layer 1, Layer 2, and Layer 3, respectively.

4 | CONCLUSION

In this study, single-, double-, and three-layered FSS structures are designed, fabricated, and measured. All designs are simulated and validated by experiments with satisfactory agreement. The proposed structure having a transparent substrate allows the light pass through the structure while it filters the electromagnetic waves at the frequency band of interest and has a bandwidth of 1.28 GHz. The designed structure has the advantage of suppressing electromagnetic while passing the light.

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Minimized multi-layer substrate integrated waveguide 3-dB small aperture coupler

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Abstract

A multi-layer 3-dB substrate integrated waveguide coupler is presented in this article. As a promising technique, the multi-layer substrate integrated waveguide has been widely used in microwave and millimeter circuits and systems for its decrease in size. This design combines the Bethe hole coupling theory with the SIW technology to reduce the height and integrate with other planar circuits. More importantly, the strong coupling (3-dB) coupler presented in this article utilizes the higher frequency band of TE_{10} mode to get a relatively bigger radius of aperture and in turn reduce the number of coupling sections, which significantly decrease the size of the coupler. The simulated results are in good agreement with the measured data.

KEYWORDS

aperture coupling, coupler, multi-layer SIW

1 | INTRODUCTION

Waveguide has been widely used in microwave and millimeter wave systems and circuits as a kind of classical transmission line. For its large power capacity and small attenuation, the waveguide has many irreplaceable applications in high-power systems, millimeter systems and some precision measurements. In recent years, with the developing demands on the size reduction and the integration of microwave and millimeter components and systems, a new planar waveguide structure called SIW is presented and has been applied in numerous high quality microwave and millimeter components. Moreover, multi-layer SIW has been a promising technique in size reduction of the circuits. The SIW operating as a transmission line not only possesses the advantages of easy integration and mass-productive, but also have higher Q, less loss and larger power capacity. Figure 1 illustrates the structure of SIW.

Because of the similarity with waveguide, a lot of theories have been transmitted into SIW and get a further development. Coupler is a key passive component and has been widely used in transceiver or phase-array antennas. Numerous of couplers basing on the narrow wall aperture coupling theory have been put forward these years.[1,2] However, the single-layer structure obviously occupies more area than the multi-layer one, which makes multi-layer structure a promising technique in circuit miniaturization. Moreover, in comparison with the narrow wall couplers, the study on broad wall couplers is much weaker and only a few strong coupling couplers were mentioned. Researches on the multi-layer

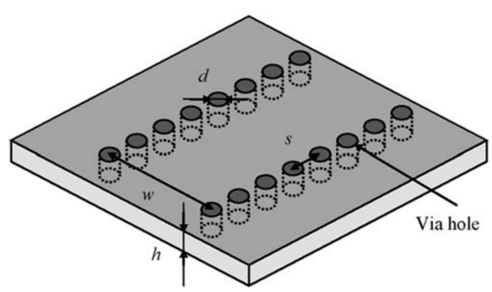

FIGURE 1 Configuration of an SIW structure synthesized using metallic via-hole arrays