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A SINGLE-LAYER FSS FOR S-, C-, X-, Ku- AND K-BAND APPLICATIONS

ENOJNA PLAST FREKVENČNO SELEKTIVNE POVRŠINE ZA UPORABO S-, C-, X-, Ku- IN K-PASOV

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This research introduces an ultra-wideband frequency-selective surface (FSS) that offers a very good bandwidth for insulation and communication applications. It consists of two layers: a dielectric substrate layer and a metal layer. The basal layer, which is the substrate, is made of FR4; and the top patch, which is the metal, is made of copper. The FSS is constructed without using several layers or several resonators in a single unit cell. This single-sheet, planar-structure-based FSS has an ultra-level bandwidth of 20.3 GHz, ranging from 2.3 GHz to 22.6 GHz. It will be employed in microwave applications in the S-, C-, X-, Ku-, and K-bands, with a centre frequency of 10.6 GHz. The polarisation and angle stability of the transverse electric (TE) and transverse magnetic (TM) modes are examined, and it was found that they are insensitive up to 90 degrees. Plots depicting the distribution of the magnetic field, surface current, and electric field are used to analyse the structure's physical mechanism. The performances from previous studies are compared and contrasted with that of the current work.

Keywords: ultra-wideband, frequency-selective surface, high bandwidth, polarization insensitive

V raziskavi je predstavljena ultra-široka pasovna, frekvenčno selektivna površina (FSS; angl.: frequency selective surface), ki ponuja zelo dobro pasovno širino za izolacijske in komunikacijske aplikacije. Sestavljena je iz dveh plasti oziroma dveh slojev: dielektrične podlage in kovinske plasti. Osnovna plast, ki je podlaga, je izdelana iz materiala FR4 (kompozitni laminatni s steklom ojačani epoksidni material), na vrhu nje pa je tanka kovinska plast iz bakra. Predlagana FSS je enovita, in ni sestavljena iz posameznih plasti ali več resonatorjev v celični enoti. Ta enojna plast na osnovi ploskovne FSS strukture ima pasovno širino na frekvenčni ravni 20,3 GHz v območju med 2,3 GHz in 22,6 GHz. Uporabna bo za mikrovalovne aplikacije v S-, C-, X-, Ku-, in K-pasovih z osnovno frekvenco pri 10,6 GHz. Preučevana je bila polarizacija ter kotna stabilnost transverzalnega električnega (TE) in magnetnega polja (TM). Ugotovljeno je bilo, da sta le-ti lastnosti neobčutljivi do 90 stopinj. Izdelane slike podajajo porazdelitev magnetnega polja, površinskega toka in električnega polja, ki so jih uporabili za analizo strukturnih fizikalnih mehanizmov. V članku je tudi predstavljena primerjava med v članku predstavljeno raziskavo in kakovost naprave s predhodno opravljenim delom oziroma raziskavo.

Ključne besede: ultraširoki pas, frekvenčno selektivna površina, visoka širina pasu, polarizacijska neobčutljivost

1 INTRODUCTION

A frequency-selective surface (FSS) is a sequential structure with band-stop or passband (transmitting or reflecting coefficient) features that is printed in a single-, double-, or tri-array on a dielectric substrate.[1]

It is used in many applications including absorbers, digital circuits (CA), geographical filters, filters, radios, band-pass filters or wideband filters, monitors, mirrors, and attenuators for nanotechnology.[2] Its important purpose is to inhibit the response at particular frequencies in electromagnetic (EM) shielding. Due to the recent development of numerous power devices for both wireless and wired communication technologies, research in the EM-shielding sector has increased. These devices are easily impacted by other electronic and electrical equipment because of their size reductions and high voltage-regulation requirements.[3–5]

Electromagnetic interference (EMI) issues due to radiation from different sources can prohibit the gadget from working properly. An ultra-wideband (UWB) frequency is employed in imaging applications as the wide frequency range improves the image resolution.[6] Highly advanced UWB FSS is deployed for shielding to minimise interference and boost the efficiency of the UWB antennas. The literature contains numerous reports of UWB FSS. In one investigation, a dielectric substrate was sandwiched between two metallic layers of specified FSS, producing 7.5 GHz of ultra-wide bandwidth and spanning the resonant frequency between 6.5 GHz and 14 GHz.[7] However, owing to fringes effects, there was a broadband drop of up to 50 % for different orientations, which is a significant drawback.

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In another method, a few levered square cycles were created and isolated by a length (width) of 'K' using a customizable FSS device. The device was used to directly alter the K^{th} position. This system had a communication range of 3.5–8 GHz and was very expensive. Besides, the system also developed shimmering chambers when the separation 'K' was adjusted past a certain point.[8] Some other models included switching devices positioned crosswise for each corner and varied shapes of loops joined together by outstretched arms. The FSS were programmable for up to four GHz width with diodes, and the inverter's operation might change the band.[9] Three major compounds were used in a multilayer FSS to generate a wideband frequency for the S, C, and X-bands, but creating it was tedious and the performance was subpar.[10]

FSSs have been utilised most frequently in prism mirrors, passband or concert filters, circuit analogue absorbers, combination radomes, and household appliances. A pair of multi FSSs that operate as a multichannel transmit array with a simple design at 13.5 GHz are appropriate for double or circularly polarised purposes.[11] The multilevel FSS stack used as the crystal structure in the described architecture retains its large capacity and is promising in terms of productivity, despite its small profile.[12] When there are no active devices, the classical control device that regulates the distance with bevel gears offers a wide resonant frequency.

The infinitely customizable FSS is increasingly used for broadband sheltering. A broad FSS incorporated with a biasing system for radio frequency (EM) shielding in several bands was proposed for its use.[13] Rectifiers are added, which cause the concert reaction to change from lower to higher frequency. For the S and C areas, a super (UWB) FSS made of hexagonal rings offers EM filtering. Metal vias are used to join the areas on the top and basal layers of the 2.5-D octagonal layout. Major compounds are used in a continuous multiple layer FSS to display the transition between several radio frequencies. Air separators are used in the construction of the layers, thus creating a multi-layered structure. It is possible to tailor impedance FSS to achieve both minimal and wideband absorption. Both the X and Ka frequencies are EM shielded by a separate FSS. The FSS unit cell's two printed parts are coupled in a way that displays band-stop reaction. By altering the traditional loops type, a small UWB bandpass filter was previously created. By altering the traditional circuit type FSS, a smaller wide-band FSS was constructed to shift the overall band-stop reaction with the insertion of a rectifier. Greater bandwidth and complex physical response are produced by the metal plate layers when they are split with a dielectric material. Uninvestigated up to this point is a small UWB FSS with a concert response.[14,15]

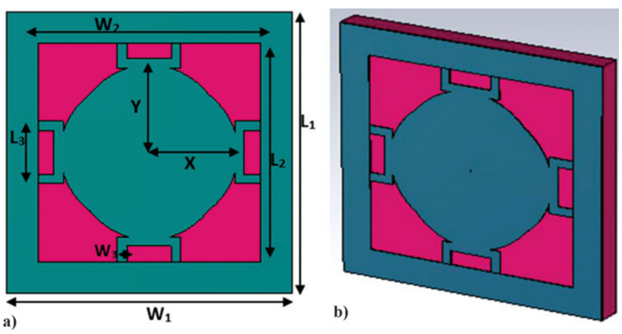

Figure 1: Planned FSS structure: a) forward-facing view and b) perspective view

The following are the proposed design's primary goals:

1. To obtain an ultra-high-bandwidth frequency response, ranging from 2.3 GHz to 22.6 GHz, encompassing S-, C-, X-, Ku-, and K-band frequency response, and to develop an ultra-thin-dimension-based one layer and planar patch structure.

2. To create a straightforward structure with outstanding polarisation and angle insensitivity for a 20.3-GHz-wide bandwidth.

2 PROPOSED FSS MODEL

Figures 1a and **1b** show the planned FSS's unit cell structure. The structure is a single metal plate imposed on a 0.8-mm-high, FR4 (Flame Retardant fibre glass epoxy) dielectric substrate material. The 0.035-mm-thick metallic patch is created in two shapes, including a square and an eclipse.

Figures 1a and **1b** show the planned FSS's unit-cell structure. The structure is a single metal plate imposed on a 0.8-mm-high, FR4 (Flame Retardant fibre-glass epoxy) dielectric substrate material. The 0.035-mm-thick metallic patch is created in two shapes, including a square and an eclipse. All the dimensions of the suggested FSS framework are given in **Table 1**. The transmission coefficient (S12) and the reflection coefficient (S11) of the S-parameter characteristics of the planned FSS structure model section is examined. The properties of the transmission and reflection coefficients, respectively, exhibit band stop and bandpass responses. S11 is the S-reflection parameter's coefficient, and S12 is its transmission coefficient.

Table 1: Parameters and their respective values used to design the FSS

Parameters	Values (mm)
Substrate length and width (L × W)	9 × 9
Top patch outer square length and width ($L_1 \times W_1$)	8.98 × 8.98
Top patch inner square length and width ($L_2 \times W_2$)	7 × 7
Ellipse X-radius and Y-radius (x, y)	2.5, 2.8
Length and width of the small square ($L_3 \times W_3$)	2 × 0.8
Height of the patch	0.035
Height of the substrate	0.8

3 RESULTS AND DISCUSSION

3.1 Different stages of the frequency-selective surface unit cell

The planned Frequency Selective Surface is developed and simulated using the widely available Computer Simulation Technology (CST) Microwave Studio Software. **Figure 2** depicts the suggested FSS structure's many stages of operation along with the corresponding transmission coefficient. The way the FSS design with TE modes works at each level has been explained. In Stage 1, a basic square patch PEC material was applied over a square-shaped substrate layer to achieve a 3-GHz resonance with a 50-dB transmission coefficient. In Stage 2, an eclipse structure with a small square is placed alongside the Stage 1 structure. This helps to obtain a single frequency band at 20 GHz, and an associated transmittance of 32 dB. In Stage 3, the unique FSS structure proposed in the current study is created. It has an eclipse shape encircled by four square arms and an outer square metallic layer. It supports an ultra-level bandwidth of 20.3 GHz, in an extremely broad band ranging from 2.3 GHz to 22.6 GHz. It has a transmission coefficient of 55 db, which is exceptionally high in comparison to that of earlier studies. This suggests that the proposed FSS structure is promising for creating a small structure with a high bandwidth and transmission coefficient.

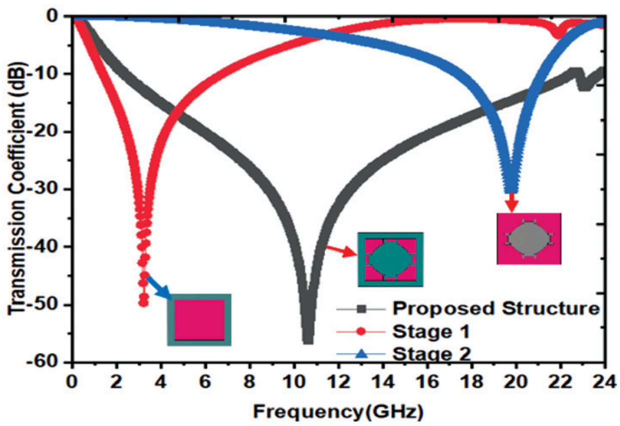

Figure 2: Different evolving phases of the proposed FSS structure

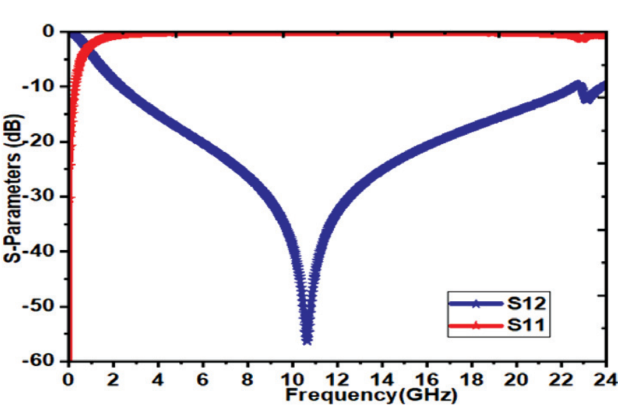

Figure 3: Outcomes of the recommended FSS structure using S parameters to explain S11 and S12

3.2 Transmission and reflection coefficient

The transmission coefficient (S12) describes how the wire transmits the signal, and the reflection coefficient (S11) refers to the amount of electromagnetic wave reflected back due to the transmission's insertion loss or impedance discontinuity. It is typically characterized as the coefficient of reflection between the point frequency and the channel's frequency response, shown in **Figure 3**.

3.3 Transmission coefficient for transverse electric and transverse magnetic mode polarization

The transmission coefficient (S12) value was analysed for both the transverse electric and transverse magnetic modes. The frequency of operation is the same for both modes. The insertion and the return loss values are also the same. This implies that the structure has polarization-independent characteristics Shown in **Figure 4.**

3.4 Polarization (φ) and incident angle (θ) stability

By varying the angles between 0 and 90 degrees, the polarisation angle (φ) and the obliquely incident angle (θ) of the structure are computed. The proposed FSS, which is seen in **Figure 5**, is polarisation- and inclination-angle independent in nature since the theta and pi values remained constant while the angles changed.

3.5 Electric field (E), magnetic field (M) and surface-current distribution plots

Plots of the surface, magnetic field, and electric field current distribution are used to examine the physical operations of the structure. The suggested FSS ranges in frequency between 2.3 GHz and 22.6 GHz, and its centre

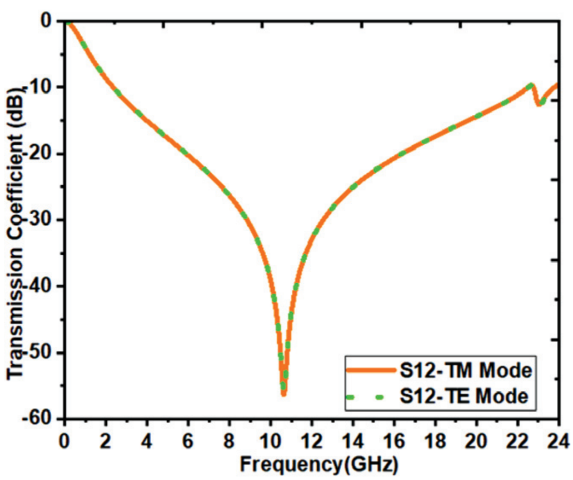

Figure 4: Outcomes of the suggested FSS simulated for TE and TM mode polarization stages

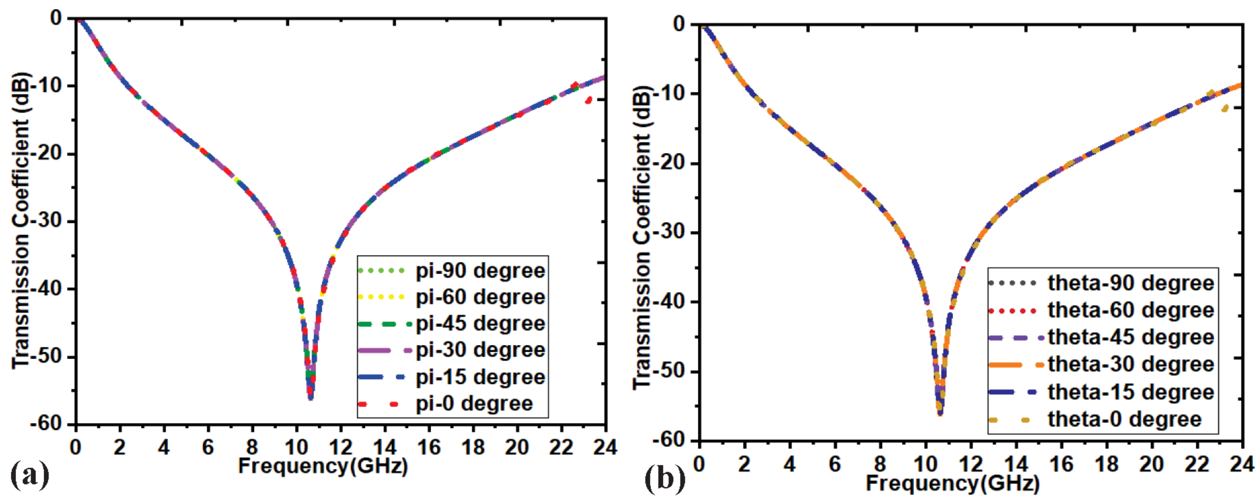

Figure 5: Transmission coefficient (S12) of TE mode: a) polarization angle (φ) and b) various angles of incidence (θ) up to 90 degrees

frequency is 10.6 GHz. **Figure 6** shows the current distribution plots on the surface, magnetic field, and electric field at 10.6 GHz. **Figure 6a** shows the electric field distribution, with the patch structure and a few other locations on the dielectric surface showing the strongest electric field distribution. The magnetic field distribution is given in **Figure 6b**. The patch resonator structure and a few locations on the dielectric surface where the field is the strongest. The surface current distribution plot at the centre frequency of 10.6 GHz is given in **Figure 6c**. The surface current flow is a maximum at the patch structure's top and basal parts and at the dielectric layer's surface.

The comparisons are shown in **Table 2.** The dielectric materials and their constant values, bandwidth, covering bands, dimensions and number of layers, etc. have been compared there. This helps in studying and observing the proposed FSS work with that of previous studies.

4 CONCLUSIONS

This study contributes towards electro-magnetic shielding in wireless and wired communication technologies. It proposes, fabricates, and studies an Ultra-Wideband Frequency-Selective Surface with an ultra-level bandwidth of 20.3 GHz, encompassing an extremely broad band ranging between 2.3 GHz and 22.6 GHz. The top patch of the structure is composed of copper and the basal patch is made of a substrate from Flame-Retardant fibre glass epoxy. Thus, the proposed FSS is designed without using multiple layers or multiple resonators in one single unit cell. Its performance is analysed in S-, C-, X-, Ku- and K-band applications in the microwave regime with its centre frequency at 10.6 GHz. The polarization and angle stability for transverse electric and transverse magnetic modes were examined using the Computer Simulation Technology Microwave Studio Software. Simulation outcomes show that the polarization and angle stability are insensitive up to 90 degrees. The physical operation of the structure is

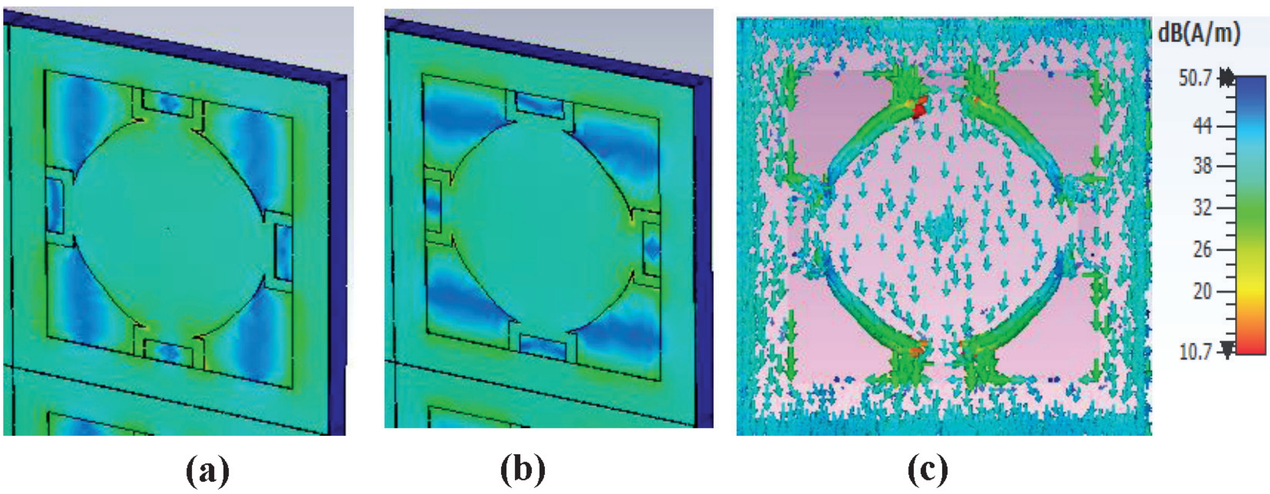

Figure 6: Distribution plots at 10.6 GHz for: a) electric field current, b) magnetic field current and c) surface current distribution

Table 2: Assessment of the outputs of the proposed approach with that of the previous outputs

Ref. No.	Dimension (mm × mm)	No. of layers	Covering band MW	Frequency range (GHz)	Bandwidth (GHz)	Polarization Stability	Angle Stability	Dielectric and dielectric constant value
16	4.6 × 4.6	One side	S, C, X	3.05–10.73	7.68	Insensitive up to 60^0	Insensitive up to 60^0	FR4(6.15)
17	7.5 × 7.5	Two Sides	X, Ku	8–18	10	Insensitive up to 60^0	Insensitive up to 60^0	F4B-2 board (2.65)
18	6 × 6	Two Sides	C, X, Ku, K	6.0–19.25	13.25	Insensitive up to 30^0	Insensitive up to 30^0	F4B-2 (2.65)
19	4.98 × 4.98	Two Sides	S-, C-, X- and Ku	2–13	11	Insensitive for 0 and 85 degrees	Insensitive for 0 and 85 degrees	RO3210 (10)
20	15 × 15	Metallization on both sides of FR4	L, S, C, X, Ku	1.75–15.44	13.69	Insensitive up to 60^0	Insensitive up to 60^0	FR4 (4.3)
21	10 × 10	One side	X, Ku	8–18	10	Insensitive up to 60^0	Insensitive up to 60^0	Arlon CuClad (2.17)
22	30 × 30	Metallization on both sides of FR4	S, C, X, Ku	2.19–13.49	11.3	Insensitive up to 45^0	Insensitive up to 45^0	FR-4 (4.4)
23	10 × 10	One side	S, C	Dual stop band freq.	4, 5.5	Insensitive up to 60^0	Insensitive up to 60^0	FR-4 (4.4)
24	7.5 × 7.5	One side	X, Ku, K, Ka	6 Resonances	10.47, 14.74, 19.08, 23.59, 27.86, and 28.74	Insensitive up to 45^0	Insensitive up to 45^0	Rogers R04003C (3.55)
25	10 × 10	One side	S, C, X, Ku	3.1–13.3	10.2	Insensitive up to 45^0	Insensitive up to 45^0	FR4 (4.3)
26	6.79 × 6.79	One side	X	8–12	4	Insensitive up to 60^0	Insensitive up to 60^0	Rogers 5880 (2.2)
Proposed work	9 × 9	One side	S, C, X, Ku, K	2.3–22.6	20.3	Insensitive up to 90^0	Insensitive up to 90^0	FR-4 (4.3)

analysed by surface, magnetic field, and electric field current distribution plots and the outcomes are compared with that of the previous works. The proposed approach is found to be better and therefore promising for use in shielding and communication applications.

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