IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, March 2026
Impact Factor: 8.2

Extension of Circular-Strip Loaded Cross- Dipole Frequency Selective Surface to VHF– UHF for Wideband EMI Shielding

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Abstract: *A compact, conformal, and wideband frequency selective surface (FSS) for electromagnetic interference (EMI) shielding in the VHF and UHF bands is presented. This paper presents the extension of a previously reported circular-strip loaded crossed-dipole frequency selective surface (FSS) topology to the VHF– UHF frequency range for wideband electromagnetic interference (EMI) shielding. Building upon the geometry reported in prior work, the unit-cell structure is adapted for VHF–UHF operation using a high-permittivity substrate and dual-layer complementary implementation. The unit cell measures only 10 mm × 10 mm (≈0.0167λ at 500 MHz) with a thickness of 25 mil. Full-wave simulations and experimental validation using a finite 20 × 20 element array demonstrate shielding effectiveness exceeding 20 dB over a wide frequency range with stable performance for both polarizations and for incidence angles up to 60°. The results experimentally validate the feasibility of extending GHz-band miniaturized FSS concepts to the VHF–UHF regime for conformal EMI shielding applications in spacecraft and other compact RF platforms.*

Keywords*:* Frequency selective surface, EMI shielding, VHF, UHF, miniaturization, conformal structures

I. INTRODUCTION

The increasing density of wireless and electronic subsystems in compact platforms such as spacecraft and airborne systems has intensified concerns related to electromagnetic interference (EMI). Conventional metallic enclosures and conductive meshes can deliver broadband attenuation; however, they typically do not provide band-selective behavior and may be difficult to implement on lightweight, flexible, or conformal surfaces. Frequency selective surfaces (FSS) provide a compelling alternative by enabling frequency-dependent transmission and reflection characteristics while maintaining low profile and mechanical flexibility [1].

The implementation of lightweight and conformal FSS is very desirable in case of miniaturized satellites like microsats, cubesats, Nanosats because of the challenging EMI environment inside the cuboid structure. Most reported FSS designs target microwave and millimeter-wave bands, where electrically small unit cells are easier to realize. In contrast, VHF and UHF operation which are likely operation bands in above mentioned satellites, requires aggressive miniaturization due to the long free-space wavelengths, making compact and conformal FSS designs particularly challenging. This work presents an experimental extension and validation of a previously reported miniaturized FSS topology into the VHF–UHF band, supported by full-wave simulations and finite-array measurements.

1.1 RELATED WORK

Circular-strip loaded crossed-dipole FSS structures have been reported for GHz-band electromagnetic shielding and wideband operation, demonstrating compact unit cells, angular stability, and flexible implementations. Other miniaturization approaches include fractal geometries, loop- based elements, resistive loading, and multi-layer stacking,

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primarily targeting microwave frequency ranges. Direct extension of such topologies to VHF–UHF bands is non- trivial due to the large free-space wavelengths and practical fabrication and measurement constraints.

II. THEORY AND DESIGN METHODOLOGY

An FSS can be modeled using an equivalent LC resonant circuit, where the metallic pattern contributes inductance and the inter-element gaps contribute capacitance. The resonance frequency [2][3]is given by

$$fr = 1/(2\pi\sqrt{LC})$$

To achieve resonance at low frequencies while maintaining a compact unit cell, the effective inductance and capacitance must be increased. In this work, a crossed-dipole element is selected as the baseline topology to ensure polarization- independent behavior. Open-ended circular metallic strips are used to increase the effective current path length and enhance capacitive coupling, thereby reducing the resonant frequency without increasing the physical dimensions. A complementary pattern is implemented on the opposite face of the substrate, and the topology is re-optimized and electrically scaled for VHF–UHF operation, where electrical miniaturization and finite-array effects are significantly more challenging. This top–bottom coupled configuration introduces multiple closely spaced resonances, resulting in a wide stopband suitable for broadband EMI shielding.

III. PROPOSED FSS STRUCTURE

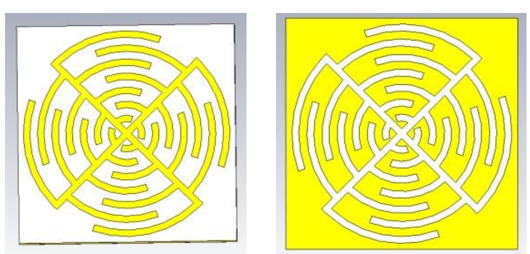
The unit cell geometry is adopted from the circular-strip loaded crossed-dipole topology reported in prior work [4] and is re-optimized here for VHF–UHF operation using a high-permittivity substrate and dual-layer complementary coupling to achieve extreme electrical miniaturization and wideband band-stop performance.

The final topology consists of a crossed dipole with circular- strip loading on one side and a complementary pattern on the opposite side, enabling strong electromagnetic coupling and wideband response within a compact footprint.

The key design parameters are summarized in Table I.

Table 1. Unit-Cell and Array Parameters

Unit-cell period	10 mm
Substrate material	Rogers RT6010LM
Relative permittivity	10.2
Substrate thickness	25 mil (0.635 mm)
Metallization	Copper on both faces (top and bottom are complementary pattern)
Array size	20 × 20 unit cells
Electrical size @ 500 MHz	0.0167λ



(a) (b)

Figure 1 (a) Top face (b) Bottom face

The array size is chosen such that overall dimension of FSS is < 20cm and it can be integrated over the panels of Microsat structure.

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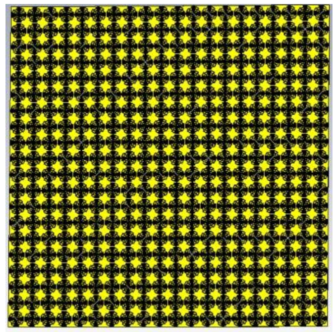

Figure 2 Simulated 20 x 20 Array

IV. SIMULATED RESULTS

Full-wave simulations are carried out using CST Microwave Studio [5] with Floquet periodic boundary conditions and two-port excitation.

4.1 Frequency Response

The simulated transmission (S21) and reflection (S11) coefficients exhibit a wide stopband across the VHF–UHF range. Multiple resonances merge to form a broadband attenuation region, with transmission levels below −20 dB over most of the operating band.

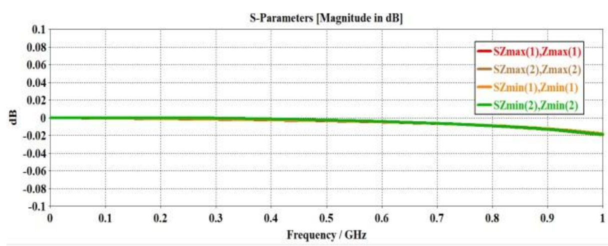

Figure 3 S-parameters- simulated of the proposed FSS unit cell

4.2 Shielding Effectiveness

Shielding effectiveness is computed as

$$SE(dB) = 10 \log10(P1/P2)$$

where P1 is the received power without the FSS and P2 is the received power with the FSS present.
The Simulated results indicate shielding effectiveness exceeding 20 dB over a wide frequency range.

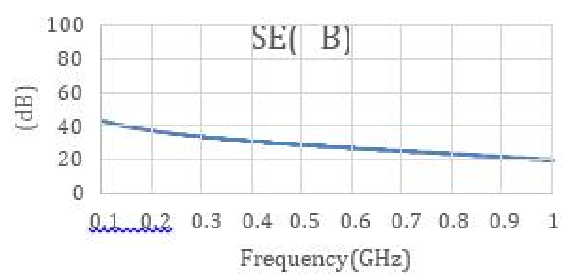

Figure 4 Simulated shielding effectiveness versus frequency

DOI: 10.48175/IJARSCT-31413

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4.3 Polarization and Angular Stability

The proposed FSS maintains stable shielding performance for both TE and TM polarizations and for incidence angles up to 60°, confirming its suitability for practical deployments where the angle of arrival may vary.

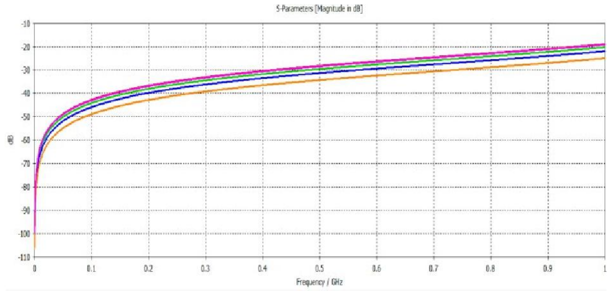

Figure 5 Angular stability for TE and TM modes for different incidence angles (0˚, 10˚, 30˚,45˚,60˚)

V. FABRICATION AND MEASUREMENT

A finite array consisting of 20 × 20 unit cells is fabricated using standard PCB photolithography on Rogers RT6010LM substrate. Additional margins are provided around the array to facilitate mounting during measurements.

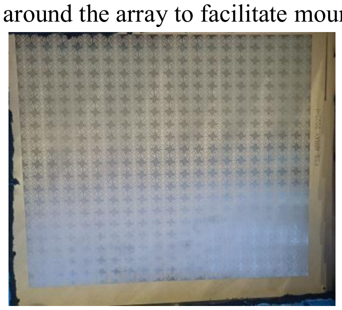

Figure 6 Fabricated FSS prototype 20 x 20 unit cell array

Measurements are carried out in an anechoic chamber using a vector network analyzer and two standard gain horn antennas. The FSS is placed between the transmit and receive antennas under normal incidence. The transmission coefficient is recorded with and without the FSS to evaluate shielding effectiveness.

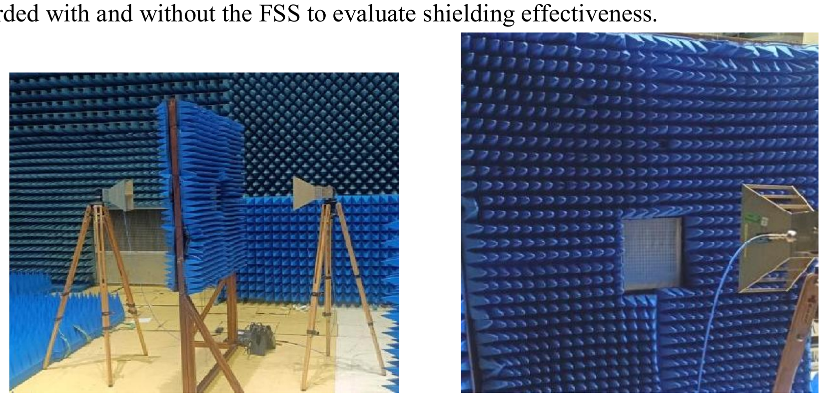

Figure 7 Anechoic chamber measurement setup using two standard gain horn antennas

Measured S-parameters and shielding effectiveness show good agreement with simulated results from 500MHz-1GHz band. Measurement in the lower frequency band couldn’t be completed due to the non-availability of test antennas of equivalent FSS aperture.

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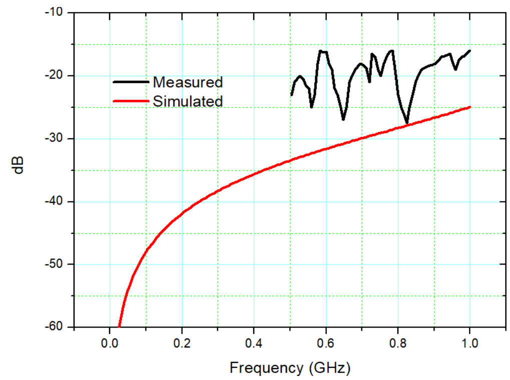

Figure 8 Simulated vs Measured result in 0.5-1GHz

Hence, an FSS array with bigger array size 80x 80 unit cell is considered for fabrication, by which FSS aperture will be almost equivalent to test antennas aperture for measuring the FSS performance in lower band. The measured shielding effectiveness exceeds 15 dB in the measurement range.

VI. DISCUSSION

Extension of GHz-band FSS topologies to the VHF–UHF regime introduces several practical challenges, including extreme electrical miniaturization, increased sensitivity to fabrication tolerances, finite-array effects, and practical measurement limitations at low frequencies. Despite these challenges, the presented results demonstrate that the topology can be successfully adapted to broadband shielding applications. These results confirm the robustness of the topology when scaled to long-wavelength operation and highlight its suitability for practical EMI shielding applications in large and complex RF environments such as spacecraft.

VII. CONCLUSION AND FUTURE WORK

This paper has presented an experimental extension of a circular-strip loaded crossed-dipole FSS topology to the VHF–UHF frequency range for wideband EMI shielding. Extreme electrical miniaturization, finite-array fabrication, and experimental validation have been demonstrated. The results confirm that GHz-band miniaturized FSS concepts can be successfully adapted for long-wavelength VHF–UHF operation, enabling practical, conformal, and lightweight EMI shielding solutions for spacecraft and other large RF platforms. The fabrication of FSS array for larger aperture size is under progress, after which a measurement campaign in lower frequency band is planned. The fabricated reflective FSS structure can be inducted in spacecraft applications as it is, by placing the FSS in the vicinity to emission source thereby shielding the other electronics from interference.

ACKNOWLEDGMENT

The authors express their gratitude to director URSC, for his encouragement and support during the work. We would like express gratitude to fabrication team URSC for their support in fabrication of the structure.

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