cbecimat26
26° Congresso Brasileiro de Engenharia e Ciência dos Materiais
22 a 26 de novembro de 2026
Costão do Santinho
Florianópolis-SC

Computational Design and Aircraft-level Integration of an FSS-Embedded Composite Radome for 24-27 GHz Communications

Oskar Banaszczyk [1,2,3], Sofia Essebti [1,2,3], Felipe de Moraes Yamamoto [3], Valéria Cristine de Oliveira [2], Mayara Martinez Boaro [4], Isaias Oliveira [3], Braulio Haruo Kondo Lopes [3,4], Rita de Cassia Mendonca Sales Contini [2], Maurício Ribeiro Baldan [3], and Jorge Tadao Matsushima [2]

[1] Inholland University of Applied Sciences, Delft, Zuid-Holland, The Netherlands
[2] FATEC São José dos Campos, São José dos Campos, São Paulo, Brazil
[3] Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil
[4] Universidade Federal de São Paulo, São José dos Campos, São Paulo, Brazil

1. Introduction

Aerospace communication systems operating in the 24–27 GHz mmWave band require high-speed data transmission and reliable electromagnetic performance [3]. Integrating frequency-selective surfaces (FSS) into glass fibre/epoxy composite radomes [2] offers a promising approach to combining structural protection with frequency-selective electromagnetic transmission [1], enabling in-band signal transmission and out-of-band attenuation [1, 3].

2. Objectives

This study optimizes baseline FSS unit-cell geometries in Altair FEKO for 24–27 GHz operation. It analyses the capacitive dielectric loading of glass/epoxy composite layers on transmission and reflection, and validates full-scale performance by modelling a 3D FSS radome in Siemens NX to evaluate far-field radiation patterns on an aircraft model.

3. Methodology

- **Unit-Cell Modelling:** Applied 2D Periodic Boundary Conditions and plane wave excitation across a 21–30 GHz frequency sweep.
- **Material Characterization:** Measured glass fibre ($\epsilon_r = 3.44$, $\tan\delta = 0.0248$) and epoxy resin ($\epsilon_r = 0.98$, $\tan\delta = 0.0089$) dielectric properties via VNA to establish realistic FEKO solver inputs.
- **System-Level Validation:** Integrated a $280\times250\times41$ mmcomposite radome onto an aircraft airframe over a 25.5 GHz horn antenna feed.

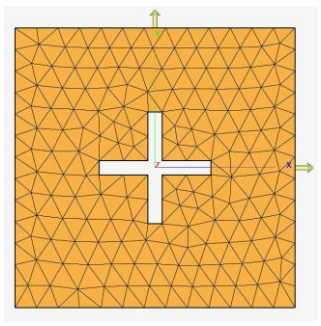


Figure 1. 2D CAD geometry of the Cross FSS unit cell modelled in Altair FEKO.

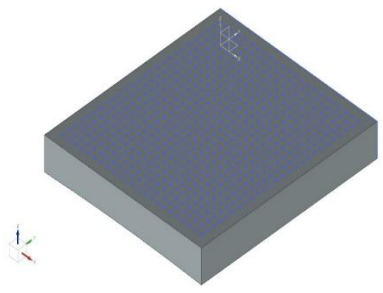
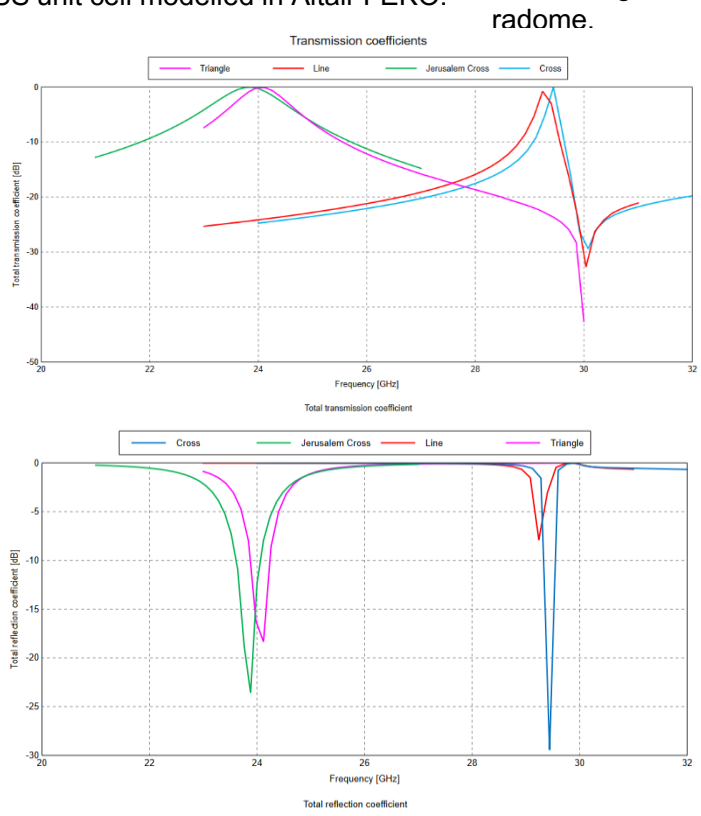


Figure 2. 3D CAD geometry of the rectangular composite radome.



(a)

(b)

Figure 3 Simulated free-space response for the Cross, Jerusalem Cross, Line, and Triangle FSS unit-cell geometries: (a) reflection coefficients (S11) and (b) transmission coefficients (S21).

4. Results and Discussion

Free-space unit-cell analysis identified the Cross FSS as the optimal configuration due to its sharp resonance peaking at 29.5 GHz, providing the higher-frequency baseline necessary to compensate for dielectric loading. Integrating the measured composite dielectric properties ($\epsilon_r = 3.44$ for glass fibre, $\epsilon_r = 0.98$ for epoxy) into FEKO demonstrated a strong capacitive loading interaction, shifting the resonant reflection minimum downward to 24.8 GHz ($S_{11} = -7.1$ dB, $S_{21} = -5.0$ dB) while the laminate loss tangent introduced moderate insertion loss. Macroscopic aircraft-level simulations at 25.5 GHz confirmed that the FSS radome preserves main-lobe directivity with a peak forward gain of 13.5 dB and suppresses back-lobe scattering to -15 dB. Far-field evaluations at out-of-band frequencies (22.5, 27.5, and 30.0 GHz) demonstrated clear gain attenuation and side-lobe perturbations, confirming that co-designing the unit-cell resonance with the composite's dielectric response enables effective airframe-level spatial filtering.

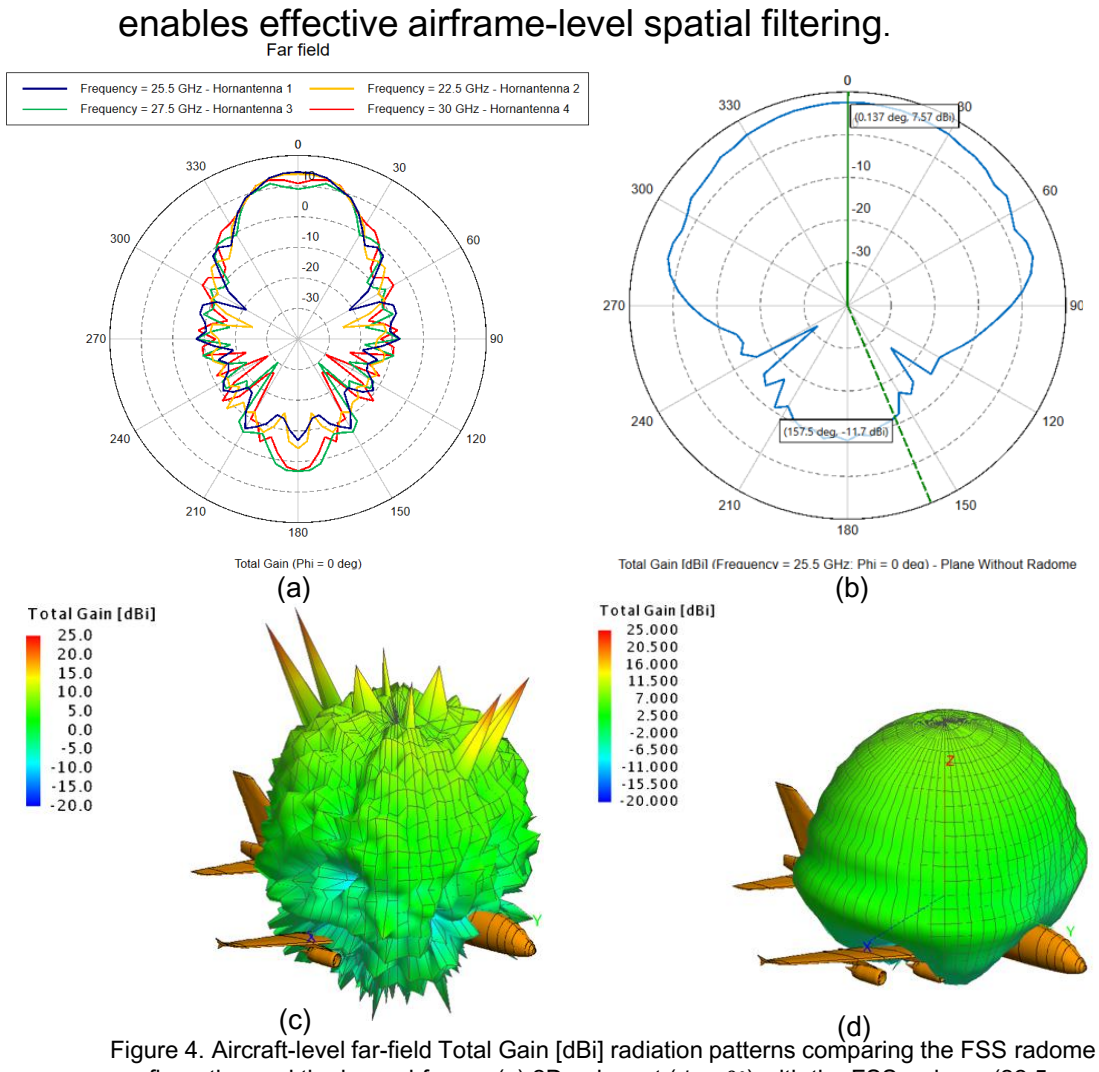


Figure 4. Aircraft-level far-field Total Gain [dBi] radiation patterns comparing the FSS radome configuration and the bare airframe: (a) 2D polar cut ($\phi = 0°$) with the FSS radome (22.5–30.0 GHz); (b) 2D polar cut ($\phi = 0°$) without a radome at 25.5 GHz; (c) 3D radiation pattern with the FSS radome; and (d) 3D radiation pattern without a radome.

5. Conclusion

Full-scale electromagnetic simulations demonstrate that 3D FSS-embedded composite radomes provide targeted spatial filtering within the 24–27 GHz band while maintaining broadside antenna performance. The modelling highlights that aligning unit-cell resonance with laminate dielectric properties is essential to mitigate dielectric damping and minimize insertion loss. This work establishes a baseline computational framework for future multi-layer element design and composite radome optimization.

6. Acknowledgments

CPRJI Comissão Permanente de Regime de Jornada Integral
CPS Centro Paula Souza
Fatec São José dos Campos Prof. Jessen Vidal
INPE
inholland university of applied sciences

7. References

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