

# Design and Development of Satcom Panel with Good Electromagnetic Transparency and Mechanical Strength

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**Abstract** - Satellite communication (SATCOM) systems rely on radome structures that must simultaneously ensure efficient electromagnetic wave transmission and adequate mechanical protection. The present study focuses on the design and evaluation of polymer matrix composite panels capable of achieving this dual functionality. Two composite configurations, namely Glass Fiber Reinforced Polymer (GFRP) and hybrid Glass/Kevlar/Epoxy laminates, were developed and analyzed. The mechanical performance of these composites was investigated using ANSYS ACP through static structural analysis, while electromagnetic transparency was evaluated using ANSYS HFSS by analyzing transmission characteristics over a frequency range of 1–18 GHz. The results indicate that Kevlar-based composites exhibit superior mechanical strength with reduced deformation, whereas glass fiber composites demonstrate better electromagnetic transparency. The hybrid composite configuration provides an optimal balance between these conflicting requirements, making it suitable for SATCOM panel applications in aerospace systems)

**Key Words:** Satellite Communication, Radome Design, Hybrid Composites, Dielectric Properties, Electromagnetic Transmission, Structural Analysis

## 1. INTRODUCTION

Satellite communication plays a critical role in modern aerospace systems by enabling navigation, real-time data transfer, and global connectivity. A key component of these systems is the SATCOM panel or radome, which serves as a protective enclosure for antennas while allowing electromagnetic waves to pass through with minimal attenuation. This dual functionality imposes stringent requirements on material selection, as the panel must possess both high structural integrity and excellent electromagnetic transparency.

Electromagnetic performance of materials is primarily governed by dielectric properties such as dielectric constant and loss tangent. Materials with low dielectric constant reduce signal reflection, while low loss tangent ensures minimal energy dissipation during wave transmission. Glass Fiber Reinforced Polymer (GFRP) is

widely used due to its favourable dielectric properties, typically exhibiting a dielectric constant in the range of 4 to 5 with low loss characteristics. However, its mechanical performance may not always meet the demanding conditions of aerospace applications.

To overcome this limitation, hybrid composites incorporating Kevlar fibers are considered. Kevlar offers high tensile strength, impact resistance, and relatively low dielectric properties, making it suitable for structural reinforcement without significantly compromising electromagnetic performance. The present work investigates the feasibility of hybrid composite panels to achieve an optimal trade-off between structural strength and electromagnetic transparency.

## 2. Literature Review

Recent studies have emphasized the importance of material selection in achieving electromagnetic transparency in radome applications. Fiber-reinforced composites such as quartz, glass, and aramid fibers have been extensively explored due to their low dielectric properties and structural efficiency. Quartz fiber composites have been shown to significantly reduce dielectric constant and improve wave transmission, while maintaining thermal stability under extreme conditions.

Hybrid composite systems combining glass and aramid fibers have gained considerable attention due to their ability to balance mechanical and electromagnetic properties. Previous research indicates that glass fibers enhance electromagnetic transparency, whereas aramid fibers contribute to improved tensile strength and impact resistance. However, a trade-off between these properties is often observed, necessitating careful optimization of material composition and stacking sequence.

In addition to experimental investigations, numerical simulation tools such as ANSYS HFSS and ACP have been widely adopted to evaluate electromagnetic and structural performance. These tools enable detailed analysis of wave propagation and stress distribution, thereby reducing the need for extensive physical testing. Despite significant advancements, limited studies have focused on integrating

both mechanical and electromagnetic analyses for SATCOM panel design, highlighting the relevance of the present work.

### 3. Materials and Methodology

#### 3.1 Material Selection

Polymer Matrix Composites (PMCs) were selected for the SATCOM panel due to their ability to provide both electromagnetic transparency and mechanical strength. These materials exhibit low dielectric constant and low loss tangent, which are essential for minimizing signal reflection and energy loss during microwave transmission. In addition, PMCs offer high strength-to-weight ratio, good resistance to aerodynamic loads, and environmental stability, making them suitable for aerospace applications. Reinforcements such as E-glass fiber and Kevlar fiber were chosen due to their complementary properties, where glass fiber enhances electromagnetic transparency and Kevlar improves structural strength. Hence, hybrid combinations enable an effective balance between functional and mechanical requirements.

#### 3.2 Composite Fabrication

The composite laminates were fabricated using a compression moulding technique to ensure uniform thickness, proper fiber-matrix bonding, and minimal void formation. In this process, fiber layers were stacked with epoxy resin and subjected to controlled temperature and pressure conditions. The method was selected because it produces high-quality laminates with improved mechanical properties and surface finish. The fabricated panels included GFRP (glass/epoxy) and hybrid (glass + Kevlar/epoxy) composites with a total of 10 layers. The process ensured consistent material properties, making the specimens suitable for further simulation and experimental analysis.

#### 3.3 Structural Analysis using ANSYS ACP

ANSYS ACP (Composite PrepPost) is a specialized tool used for modeling and analyzing layered composite structures. It allows accurate definition of fiber orientation, stacking sequence, and material properties, which are critical in predicting composite behavior. In this study, ACP was used to simulate tensile loading conditions by fixing one end of the laminate and applying load on the other, replicating real-world conditions.

The analysis provided stress, strain, and deformation results, helping identify material performance and failure-prone regions. Among all materials, the Kevlar/epoxy composite exhibited the highest strength (236 MPa) and lowest deformation, indicating superior mechanical performance. Hybrid composites showed balanced

behavior, whereas glass fiber composites exhibited higher deformation. Thus, ACP analysis confirms that Kevlar-based and hybrid composites are more suitable for structural applications in SATCOM panels.

#### Specimen 1 – E-Glass/epoxy

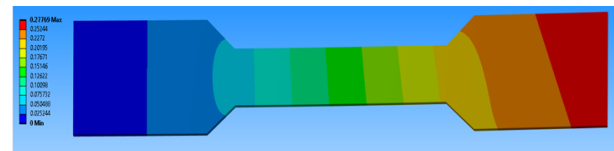


Fig-1: Directional Deformation of specimen 1

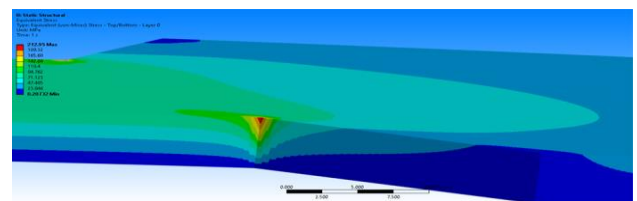


Fig-2: Maximum stress Distribution of specimen 1

#### Specimen 2 – HYBRID Glass/Kevlar/epoxy

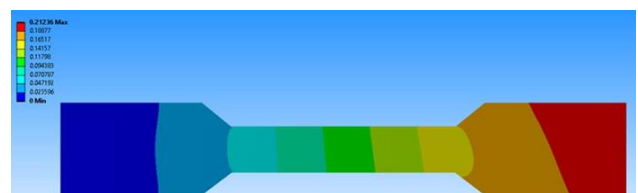


Fig-3: Directional Deformation of specimen 2

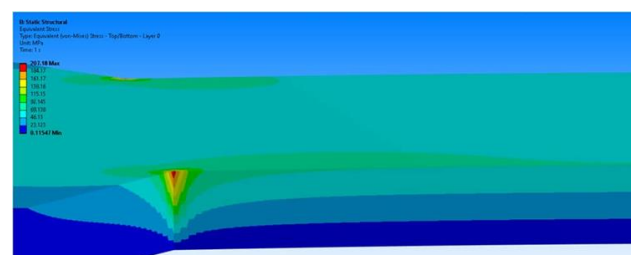


Fig-4: Maximum stress Distribution of specimen 2

#### Specimen 3 – Quartz/epoxy

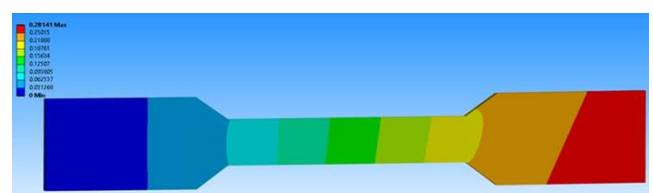


Fig-5: Directional Deformation of specimen 3

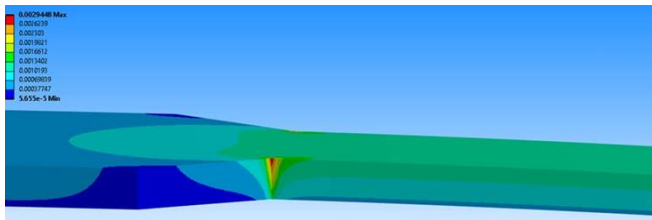


Fig -6: Maximum stress Distribution of specimen 3

**Specimen 4 -HYBRID - GLASS/Quartz/epoxy**

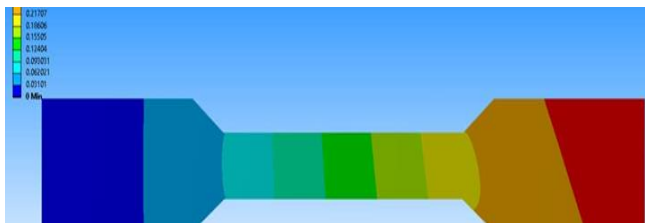


Fig -7: Directional Deformation of specimen 4

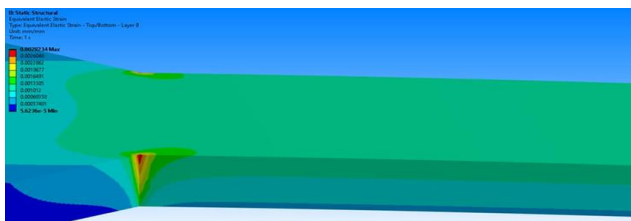


Fig -8: Maximum stress Distribution of specimen 4

**Specimen 5 -Kevlar/epoxy**

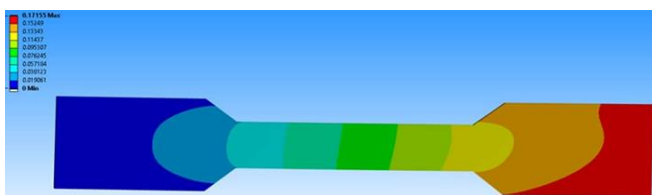


Fig -9: Directional Deformation of specimen 5

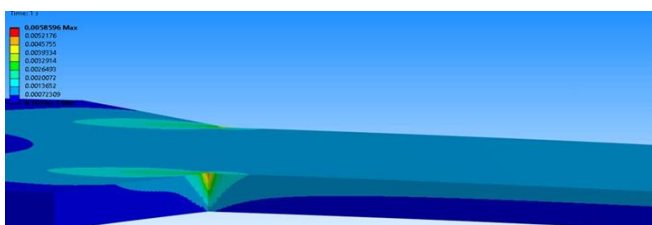


Fig -10: Maximum stress Distribution of specimen 5

**3.4 Electromagnetic Analysis using ANSYS HFSS**

ANSYS HFSS (High Frequency Structure Simulator) is an advanced electromagnetic simulation tool used to analyze

wave propagation through materials. It is based on the Finite Element Method (FEM) and is widely used in antenna and radome design. In this study, HFSS was used to evaluate the electromagnetic transparency of composite panels by modeling them as dielectric slabs of 2 mm thickness.

The simulation was conducted over a frequency range of 1–18 GHz, and the transmission coefficient (S21) was used to measure wave transmission. A validation study was performed by comparing simulation results with experimental data, showing a low error of approximately 2.2%, confirming the reliability of the model. The results indicate that materials with lower dielectric constant and loss tangent exhibit higher transparency, with different composites performing better in different frequency bands. Thus, HFSS analysis validates the suitability of selected materials for SATCOM applications.

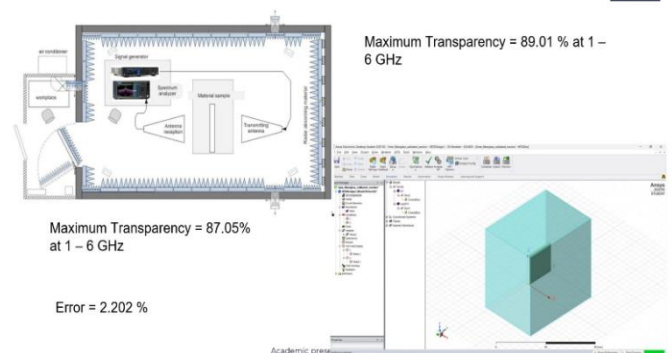


Fig -11: HFSS Setup window

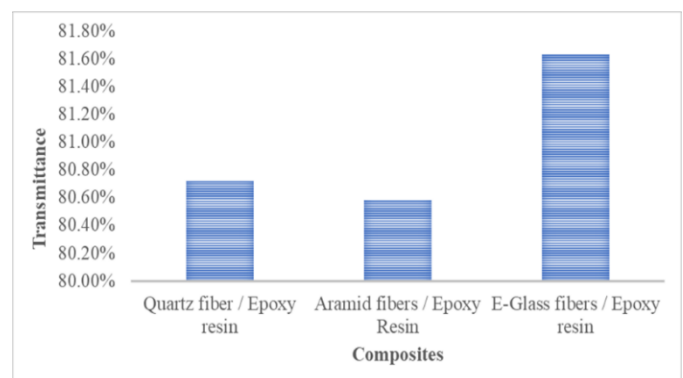


Fig -12: Comparison chart for L-Band

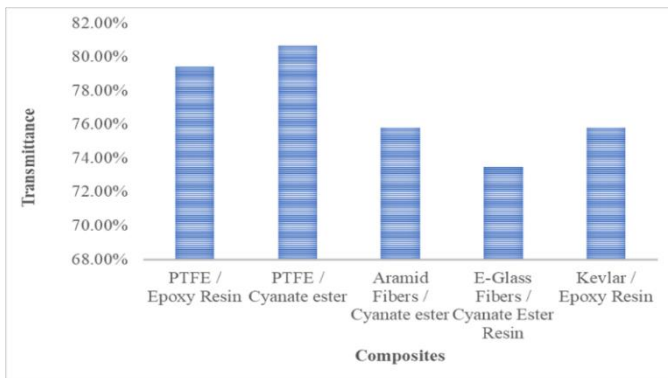


Fig -13: Comparison chart for L-Band

### 3.5 Fabrication and Specimen Preparation

The fabricated composite panels were further processed into standard test specimens using water jet cutting. This technique uses a high-pressure water stream to cut materials without generating heat, thereby preventing damage such as fiber breakage or matrix degradation. The specimens were prepared according to ASTM standards to ensure accuracy and consistency during testing. This step is essential to maintain the original material properties and obtain reliable experimental results.

### 3.6 Mechanical Testing (Tensile Test)

Tensile testing was performed to evaluate the mechanical performance of the fabricated composites under axial loading conditions. The test measures key properties such as ultimate strength, displacement, strain behavior, and failure characteristics. The results showed that hybrid composites (glass + Kevlar) exhibit improved ductility, toughness, and energy absorption compared to pure glass fiber composites.

While glass fiber composites showed relatively higher stiffness, they failed in a brittle manner with lower deformation. In contrast, hybrid composites demonstrated higher load-bearing capacity and greater deformation before failure, indicating better resistance to mechanical damage. Therefore, tensile testing confirms that hybrid composites provide a more reliable and durable solution for SATCOM panel applications.



Fig -14: Tested Specimen 1



15: Tested Specimen 2



Fig -16: Tested Specimen 3



Fig -17: Tested Specimen 4

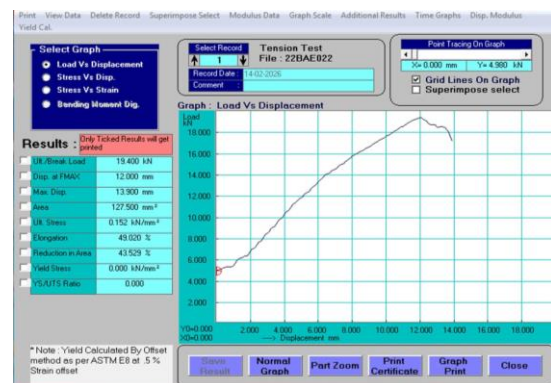


Fig -18: Load vs Displacement graph of Tested specimen 1

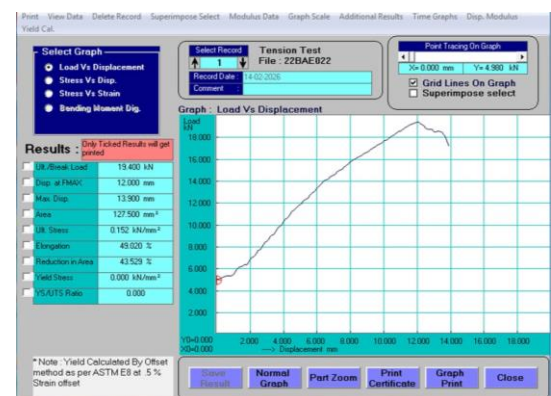


Fig -19: Load vs Displacement graph of Tested specimen 1

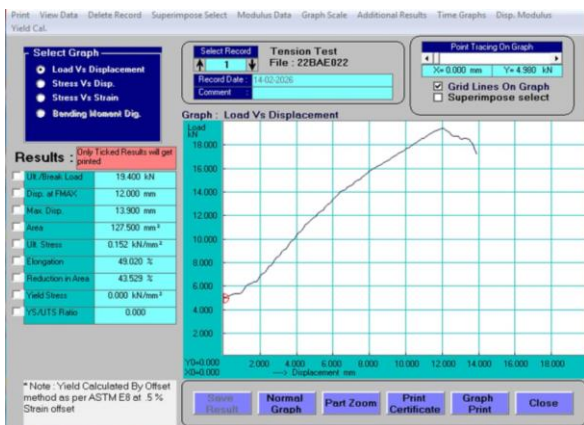


Fig -20: Load vs Displacement graph of Tested specimen 1

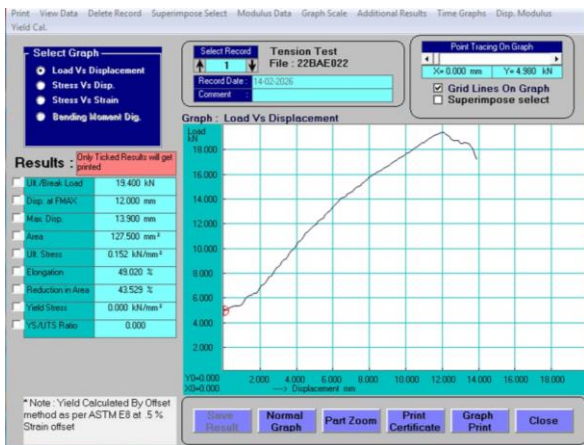


Fig -21: Load vs Displacement graph of Tested specimen 1

#### 4. Results and Discussion

The structural analysis results obtained from ANSYS ACP reveal significant differences in the mechanical behavior of the composite materials. Among the tested configurations, the Kevlar/epoxy composite demonstrates the highest load-bearing capacity, with a maximum equivalent stress of approximately 236 MPa and the lowest deformation of about 7.18 mm. This indicates superior stiffness and resistance to mechanical loading. In contrast, glass fiber composites exhibit higher deformation values, suggesting lower stiffness despite their adequate strength.

Hybrid composites consisting of glass and Kevlar fibers show intermediate behavior, offering a balance between strength and deformation. Although their mechanical performance is slightly lower than pure Kevlar composites, they provide improved structural characteristics compared to GFRP.

Electromagnetic simulation results indicate that glass fiber composites exhibit better wave transmission due to their lower dielectric losses. Kevlar composites, while mechanically superior, show relatively reduced electromagnetic transparency. The hybrid composite configuration effectively balances these properties by

maintaining acceptable transmission characteristics while enhancing mechanical strength.

The results clearly demonstrate that no single material can independently satisfy both mechanical and electromagnetic requirements. However, hybridization provides a practical solution by combining the advantages of individual materials. This makes hybrid Glass/Kevlar composites a promising candidate for SATCOM panel applications.

Table -1: Comparison Table for ACP results

PROPERTIES	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3	SPECIMEN 4
ULTIMATE BREAK LOAD(KN)	19.4	18.44	17.7	22.20
DISPLACEMENT AT FMAX (mm)	12	6.1	12	12.5
MAXIMUM DISPLACEMENT (mm)	13.9	9.1	16.4	16.8
ULTIMATE STRESS (KN/mm <sup>2</sup> )	0.152	0.145	0.109	0.137
Yield stress (KN/mm <sup>2</sup> )	0	0.089	0.189	0.133

**Table -2:** Comparison Table for HFSS results

Properties	Glass/Epoxy	Kevlar/Epoxy	Quartz/Epoxy	Hybrid-Glass/Kevlar/Epoxy	Hybrid-Glass/Quartz/Epoxy
Total Deformation(mm)-Max	12.1265	7.18132	12.294	9.1418	9.1418
Directional deformation (mm) -Max	0.27769	0.17155	0.28141	0.21236	0.27909
Equivalent Elastic strain-Max	0.002922	0.0058596	0.0029448	0.0028509	0.0029234
Equivalent stress (von mises) (MPa)-Max	212.95	236.01	211.71	207.18	213.06

### 5. Conclusion

This study presents the design and evaluation of composite materials for SATCOM panel applications with a focus on achieving both electromagnetic transparency and mechanical strength. The results indicate that Kevlar-based composites provide superior structural performance, whereas glass fiber composites offer better electromagnetic characteristics. Hybrid composites successfully bridge this gap by delivering a balanced combination of both properties.

The integration of structural and electromagnetic simulations using ANSYS tools has proven effective in evaluating material performance and reducing experimental efforts. Based on the findings, hybrid Glass/Kevlar/Epoxy composites are recommended for SATCOM panels in aerospace applications, as they meet the functional requirements of strength, durability, and efficient signal transmission.

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### BIOGRAPHIES



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