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MICROSTRIP ANTENNA FOR SAR APPLICATION WITH MICROWAVE COMPOSITE LAMINATES AND HONEYCOMB CORES

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SUMMARY: Microstrip antenna for the application in synthetic aperture radar (SAR) system was designed at 5.3 GHz with microwave composite laminates and Nomex honeycomb cores to make this antenna have a good structural rigidity and electrical performance applying to aircraft structural skin. Its design was focused on a wide bandwidth, a high polarization purity, a low loss and a good structural rigidity. This study demonstrated design procedure, fabrication and its structural/electrical performances. For validating structural rigidity, the flexural behavior under 3-point bending test was experimentally observed comparing with that of composite sandwich beams. The electrical measurements of fabricated antenna structure were in good agreement with its simulation results and it was shown that complex antenna structure has a good flexural characteristics.

KEYWORDS: Microstrip Antenna, Composite Laminate, Nomex Honeycomb, SAR

1. INTRODUCTION

The future technology of multifunction shared apertures conformal to the aircraft outer skin (sometimes referred to "smart skin") coupled with smart structures offer enormous payoffs. At the overall vehicle performance level, these include: advantages for reduction in vehicle size, weight, life cycle cost, improved fault tolerance, reconfigurability and survivability, modularity and improved reliability and maintainability[1]. The embedment of radio frequency(RF) antennas in loadbearing aircraft skin is an entirely new approach to integration of antennas into aircraft structure. CLAS(conformal load-bearing antenna structure) emerged from the need to improve structural efficiency and antenna performance and demands integrated product development from the disparate technologies of structures, avionics, material and manufacturing to ensure an optimal producible design. Avionics technology is developing and providing very thin conformal antenna elements that can be embedded in the plies of laminated composite structural materials, which must have electromagnetic properties required for optimal antenna performance in addition to the traditional attributes of high strength and stiffness, damage tolerance and durability[2]. CLAS is currently being developed in an exploratory program addressing all of the salient manufacturing and design issues associated with embedding antenna within load-bearing structures. Locker el al.[3] fabricated a structurally effective 36 by 36 inch curved multifunction antenna component panel of 0.15 to 2.2 GHz frequency regimes and validated its structural and electrical performances.

The objective of this work is to design and fabricate microstrip antenna for SAR application using sandwich construction and demonstrate the structural and electrical performance.

2. DESIGN PROCEDURES

2.1 Design concept

The fundamental design concept for the complex antenna structure is a composite multiplayer sandwich panel which is composed of dual polarized SSFIP(Strip-Slot-Foam-Inverted Patch) elements on microwave composite laminates, Nomex honeycombs and shielded plane. The primary concern is to ensure that the face sheet properties required to sustain the structural load was not excessive for antenna performance. Therefore, face sheets must carry a significant portion of the in-plane loads as well as have a low dielectric constant required for electrical performance, and honeycomb cores transmit shear between face sheets induced from bending loads and provide air gap required for the antenna.

2.2 Antenna requirements for SAR system

SAR is the system to survey a configuration of the ground or an object using microwave ,which is named from obtaining data about a larger ground than the aperture of real antenna. The most significant element in determining overall system performance is the antenna. Future requirements for advanced SAR antennas include the need for dual-frequency or dual-polarization operation[8].

Table 1. Antenna requirements for SAR system

Parameter	Requirements
Frequency	5.3 GHz
Bandwidth	100 MHz
Beamwidth	± 10 ° for elevation plane ± 5 ° for azimuth plane
Polarization	Dual-linear
Cross-polarization	< -20 Db
Gain	> 20 dBi

Design of complex antenna structure described in this paper was focused dual-polarization operation at a frequency. Table 1 shows the antenna requirements for SAR system.

2.3 Description of complex antenna structure

The construction of complex antenna is the application of composite sandwich structure and SSFIP antenna. Microstrip antenna presents significant advantages in terms of size, ease of fabrication and compatibility with printed circuits, but also a number of drawbacks, ranging from narrow bandwidth to low efficiency.

Taking all these factors into consideration a new global concept, the SSFIP(strip-slot-foam-inverted patch) antenna, has been developed. The composite materials are used, the substrate(composite laminate) being a low loss, low-permittivity foam(Nomex honeycomb) to prevent surface wave propagation and to increase the bandwidth. The radiating patches are deposited on the underside of a substrate that also serves as protective cover. They are fed via wide coupling slots by a microstrip line located on a high-quality dielectric substrate underneath the ground plane[6]. The shielding plane located at the bottom side is used to reduce the back radiation unwanted [Figure 1]

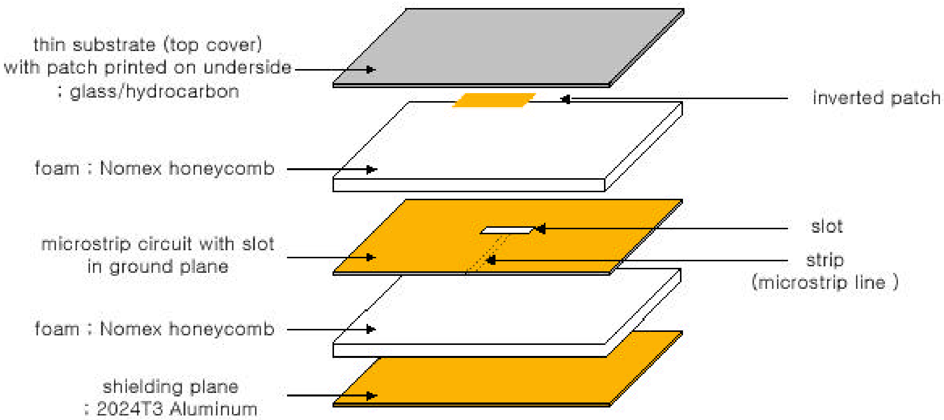
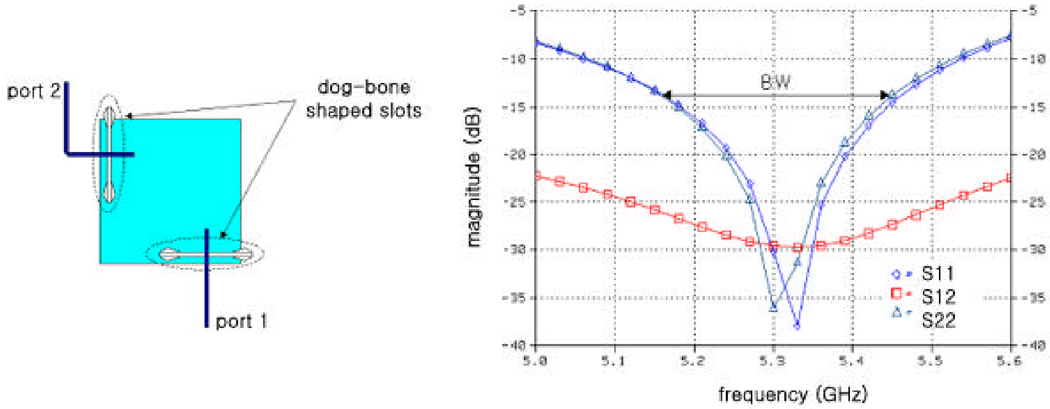


Figure 1. Exploded view of the complex antenna structure

2.4 Design of antenna elements

Single elements

In this paper, two slots are put orthogonal to each other for the dual-polarization so that they cross and are designed with the shape of dog-bone which can have coupling between feed and slot improve with the proper slot distance and not widening the slot[Figure 1 (a)]. Figure 2 (b) shows single antenna element resonates at 5.3 GHz, having a bandwidth of 300 MHz at 1.5:1 VSWR level and isolation of –30dB between two ports.



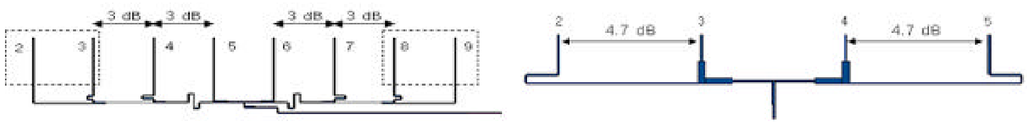
(a) Geometry of a dual-polarized single antenna

(b) Return loss

Figure 2. Dual-polarized slot coupled patch antenna

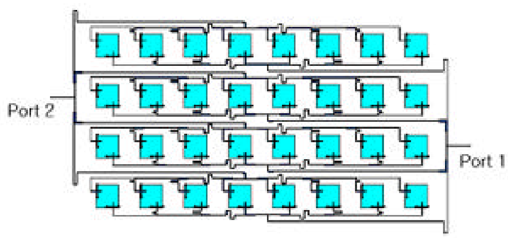
8x4 array antenna

The whole antenna elements are organized into four linear sub-arrays of 8x1 array antenna at intervals of 0.8 λ in elevation.



(a) 8X1 feed network

(b) 4X1 feed network



(c) 8X4 array antenna elements

Figure 3. Design of feed network

3. FABRICATION

3.1 Materials

In order to meet electrical and structural performance, it is necessary to select appropriate materials. The substrate is glass/hydrocarbon laminate with dielectric constant of 3.38 and thickness of 0.5mm which allows the design and fabrication of high frequency circuit with superior electrical and mechanical properties and is a low loss material. Nomex honeycomb used as a foam is lightweight, strong and have a low dielectric constant (about 1.1). These properties allow it to be used structurally in microwave applications. Nomex honeycombs of thickness of 2.54 and 13 mm were inserted underneath the patch and feedline, respectively. 2024 T3 aluminum of 0.5mm thickness was used as a shielding plane.

3.2 Fabrication of complex antenna structure

Manufacturing of complex antenna is a sequential process : 1) fabrication of radiating sheet (top layer), 2) layer for aperture and feedline (middle layer), 3) bonding of honeycomb and each layer with shielding plane(inserting adhesive film and autoclave curing).

The layers were bonded to the top and bottom of the honeycomb cores with AF126 film adhesive and the assembly was cured under pressure in an autoclave following the recommended curing cycle for the adhesive. The final demonstration article is structurally 400 x 300 x 17.5 mm flat antenna panel [Figure 4].

4. EXPERIMENTAL RESULTS OF ANTENNA PERFORMANCE

Figure 5 shows the VSWR characteristics between 5.1 and 5.5 GHz. The VSWR of about -33dB at 5.3GHz was observed at both port 1 and port 2 giving a dual-polarization operation. The bandwidth of port 2 is narrower than that of port 1 and antenna finally give about 80MHz bandwidth at VSWR of 1.5, which is considered that port 2 consists of more curved feedline than port1. In Figure 6, the isolation of –40 dB is shown between two ports ,which means they do not affect each other.

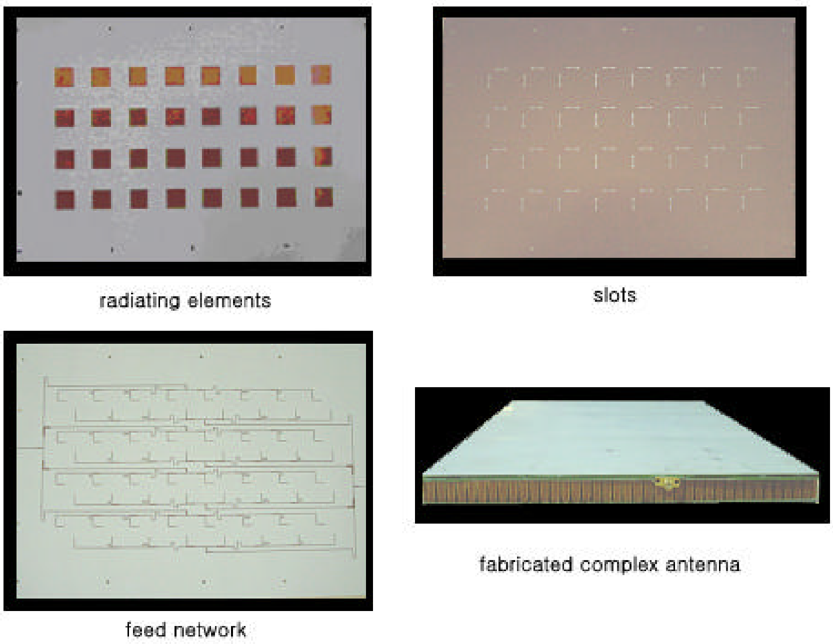


Figure 4. Appearance of each layer and complex antenna structure

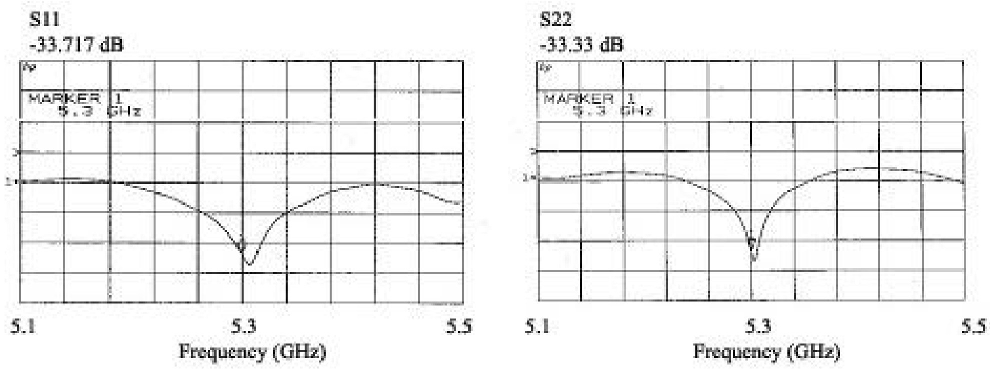


Figure 5. Measured return loss

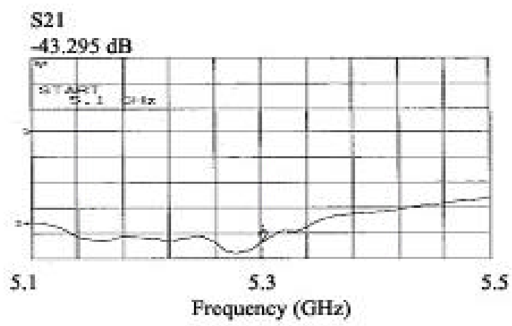


Figure 6. Isolation characteristics between two ports

The radiation patterns of co-polarization and cross-polarization, measured in POSTECH anechoic chamber, are shown in Figure 7 and Figure 8 for azimuth and elevation plane, respectively at the center frequency of 5.3 GHz with the termination of the other port.

In Figure 7 the radiation patterns for eight element of azimuth plane, beamwidth of 10° shows a good agreement with theoretical predictions created with commercial software with low cross-polar level (worst case : -25dB) and low front-to-back ratio (worst case : -20 dB). In Figure 8; the radiation patterns for four element of elevation plane, beamwidth of 20° satisfy the antenna requirements with low cross-polar level and SLL which reduces range ambiguity in SAR system.

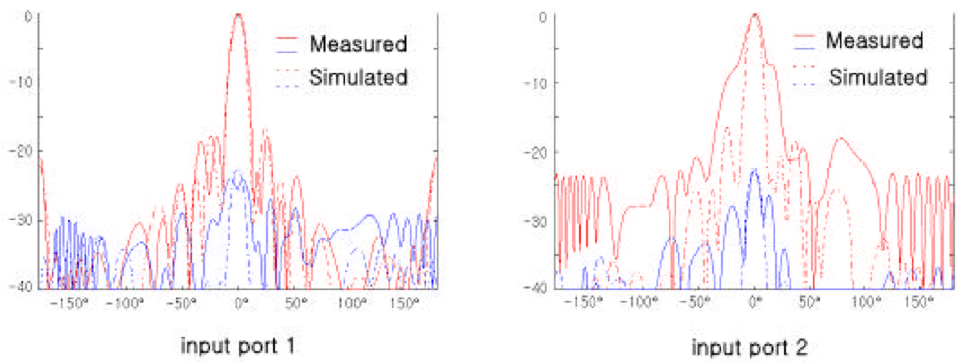


Figure 7. Radiation patterns for azimuth plane

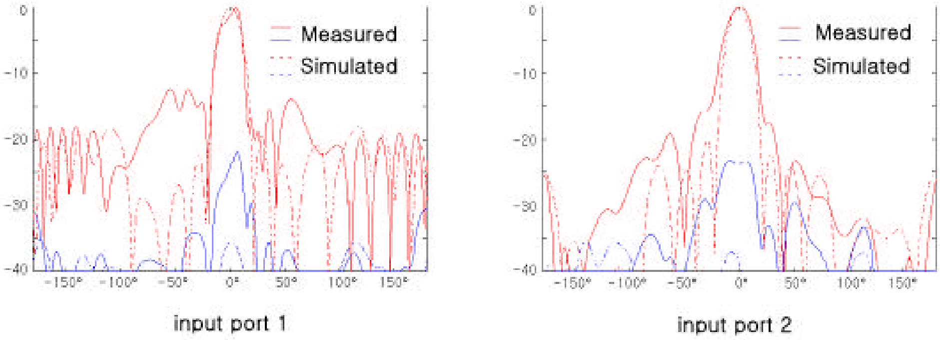
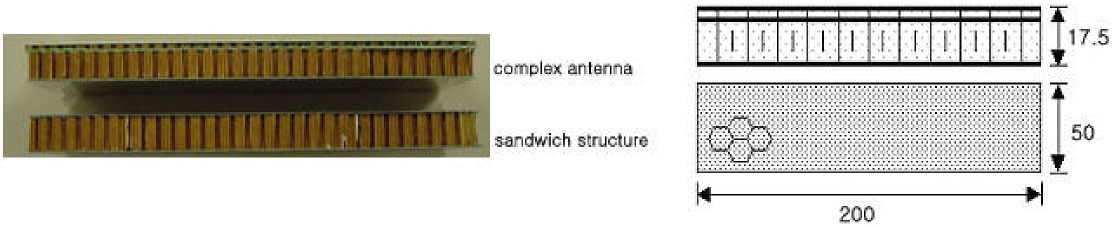


Figure 8. Radiation patterns for elevation plane

5. STRUCTURAL EXPERIMENT

Sandwich construction for high efficiency and performance of aircraft structures utilize GFRP or CFRP for the facing materials and honeycomb or rigid foams for cores. In this paper, the mechanical behavior of complex antenna structure under 3-point bending test was investigated and compared experimentally with the sandwich structures of same thickness using CFRP and GFRP facing materials.



No.	Construction	Face thickness (mm)	Core depth (mm)	Total thickness (mm)	Density (Kg/m^3)
1	Same as antenna structure	0.5	2.54 / 13	17.5	3.4×10^5
2	CFRP ([0/90]s) /Nomex honeycomb	0.5	16	17.5	2.0×10^5
3	GFRP (woven cloth) /Nomex honeycomb	0.5	16	17.5	1.8×10^5

Figure 9. Details of complex antenna and sandwich structure test specimens

5.1 Fabrication of specimens

Complex antenna specimen was made of two glass/hydrocarbon laminates, 2024 T3 aluminum and two honeycomb cores, which has a same construction as a complex antenna structure. Experimentally comparing the mechanical behavior, two types of sandwich beams were considered. They were made from CFRP and GFRP skin of a same thickness as a substrate, respectively. Figure 9 presents details of three types of specimens. The core material used in this study was Nomex honeycomb HRH-10-1/8-5(Hexcel co., BMS 7-124 : Type 5, Class 4, Grade 5). The adhesive used to bond the face sheet to the core was AF126 film adhesive(3M co.,Type 2, Class1A, Grade 5) and the assembly was cured under pressure in an autoclave. The basic properties of the materials used are tabulated in Table 2.

Table 2. Mechanical properties of materials

Property	Substrate G/hydrocarbon	CFRP [0/90]s	GFRP (woven cloth)	Shielding plane 2024 Al T3
Elastic modulus (Mpa)	26,889	74,150	22,800	72,400
Tensile strength (Mpa)	141	1147.5	427	482

Property	Nomex honeycomb (HRH-10-1/8-5)
Density (kg/m^3)	80.1
Compressive strength (Mpa)	4.83
L-shear strength (Mpa)	2.24
W-shear strength (Mpa)	1.21

5.2 Testing procedure

The flexural behaviors were measured under three-point bending in general accordance with ASTM C393-94. The general lay-out of the bending test is shown in Figure 10, with the specimens tested at a cross-head speed of 3mm/min in center-point loading using support span of 150 mm. An experimental test-rig was designed and manufactured in order to realize the support and loading conditions corresponding to symmetrical three-point bending.

Because skin is very thin and brittle, It is predicted that failure occur in the top skin due to face yielding or inward wrinkling of the top skin at the vicinity of the central load. Allen[4] gives the critical compressive stress σ_{fw} that result in wrinkling of the top skin as

$$\sigma_{fw} = \frac{3}{\{12(3-\nu_{cxz})^2(1+\nu_{cxz})^2\}^{-1/3}} E_{fx}^{1/3} E_3^{2/3}$$

where ν_{cxz} is the out-of-plane Poisson's ratio and E_3 and E_{fx} is the out-of-plane Young's modulus of the honeycomb core and in-plane Young's modulus of the face sheet, respectively.

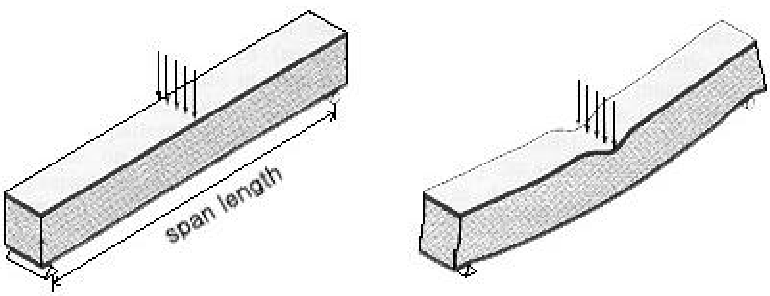


Figure 10. Layout of three-point bending

5.3 Results

The load-deflection curves of 3-point bending test are shown in Figure 11 which indicates failure of the complex antenna specimen(No. 1) occurred in a brittle manner with little non-linearity before first failure and a sharp drop in load of 1.93 kN. First drop means failure of middle layer for aperture and feedline (face yielding) and as load is increased, inward wrinkling of the top skin occurred in the vicinity of the central load with core crushing. In the case of other specimens, specimen 2 (made from CFRP skin) failed at the 1.68 kN and specimen 3 (made from GFRP skin) at the 1.67 kN, both equating to 87% of the complex antenna. The dominant failure mode was all inward winkling of the top skin under the loading point with core crushing, which is same as the behavior of complex antenna structure. Face wrinkling is a buckling mode of the skin with a wavelength greater than the cell width of the honeycomb. This flexural behavior is due to the thin and brittle face as predicted.

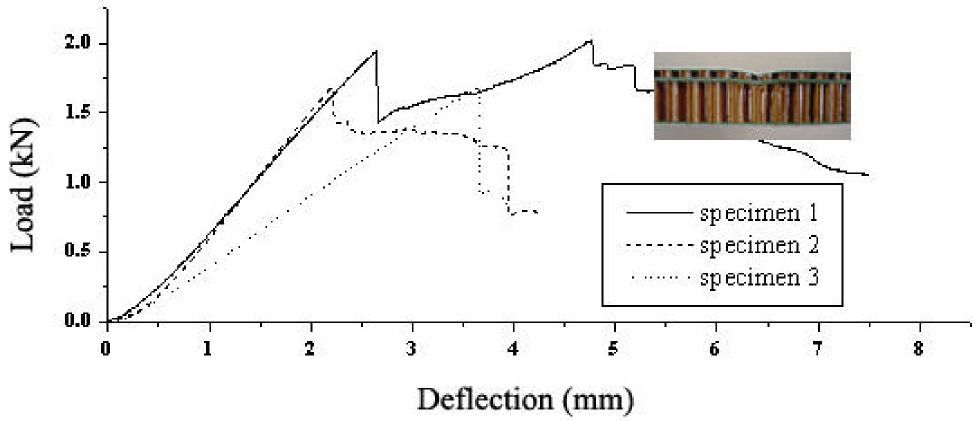


Figure 11. Load versus deflection under three-point bending

6. SUMMARY AND CONCLUSION

In this paper, dual-polarized microstrip antenna for SAR system was designed and fabricated using sandwich construction to improve both structural and electrical performance. In the design of antenna elements, slot of the dog-born shape was used to improve polarization purity. The shielding plane of 2024 Al T3 reduces the front-to-back ratio of beam pattern as well as increases in-plane and flexural stiffness of the complex antenna structure. The final demonstration article is structurally 400 x 300 x 17.5 mm flat antenna panel.

The measured results of this antenna structure; reflection coefficients, radiation patterns, cross-polarization level and the isolation between two ports, were in good agreement with the theoretical model prediction and satisfied the antenna requirements for SAR system.

A structural study of complex antenna structure was experimentally conducted on the comparison of composite sandwich beams under three-point bending. The bending behaviors of face wrinkling and core crushing were observed in all specimens. In antenna structure, this behavior is due to unsymmetrical faces. In other words, Al alloy on bottom that is stiffer than substrate on top supports in-plane tensile load until core failure after first load drop. The flexural behavior of composite sandwich having CFRP and GFRP faces is identical with antenna structure. With a symmetrical beam the stress is the same in the tension and compression faces. For composite face materials, the compressive face is generally the critical one. The load point of antenna structure at failure was higher than that of sandwich structure. But, the density of the latter is lower than that of the former.

Consequently, The complex antenna structure presented showed a good combination of structural efficiency and antenna performances.

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