Impact Behavior and Radiation Performance of a Structurally Integrated Antenna Array Conformed Around Cylindrical Bodies

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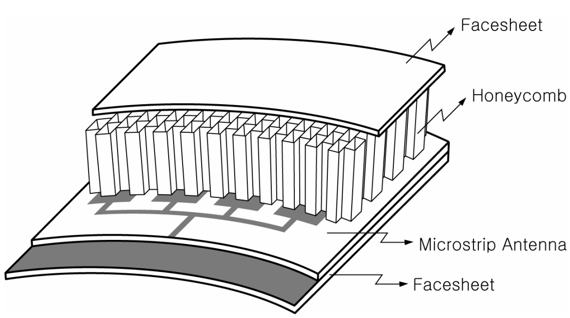
Abstract: In this paper, one structurally integrated composite antenna array conformed around cylindrical structures has been designed and fabricated. The experimental results show that the radiation pattern is strongly dependent on the cylinder curvature, while the array also exhibits high side-lobes and wider beamwidth. The results of impact test indicate that the value of the contact force decreases significantly and nonlinearly as the curvature increases due to the reduced density of curved honeycomb. These results suggest that the radius of curvature is an important structural parameter of conformal composite antennas.

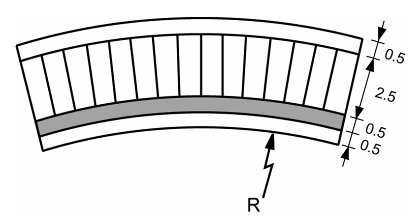
1. Introduction

The traditional separation between antenna and active electronic components design is eclipsing in favor of integrated active antenna systems and modules, where active and passive components are designed concurrently as parts of the same unit. These new antenna systems are, in turn, integrated into load-bearing structures of aerial vehicles, thereby resulting in unique multifunctional structures of hybrid composites. Good examples are conformal load bearing antenna structures (CLAS) which are embedded in the aerial vehicle structure with curvatures for aerodynamic reasons and which support the loads in addition to radiating or receiving electromagnetic energy [1-3].

In the present paper, one structurally integrated antenna array, termed *composite antenna* is proposed. A composite sandwich structure consisting of glass/epoxy facesheet and honeycomb core is used as a basic mechanical topology, in which an antenna array is embedded with curvature. To study the impact behavior caused by the foreign forces, the cylindrically curved panels are impacted using a drop-weight impact apparatus with an instrumented spherical tip. The radiation patterns of a benchmark array are measured in an anechoic chamber to investigate the effect of cylindrical geometry on antenna performance.



(a) Perspective view



(b) Cross section
(all dimensions are in millimeters.)

Fig. 1 Composite antenna geometry

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2. Design and Fabrication

The basic geometry of the composite antenna is a composite sandwich structure in which a microstrip antenna is embedded, as shown in Fig. 1(a). Sandwich construction involves two relatively dense and stiff facesheets that are bonded to either side of a low-density core. The facesheets carry bending-induced axial loads, and the core sustains shear stresses as well as compressive stresses normal to the plate. The presence of the core moves the facesheets away from the neutral axis, enhancing the bending resistance provided by the facesheets, the properties of which, despite being necessary to sustain the structural load, must not impair antenna performance. The upper facesheet must be thin so as to have only a small effect on the antenna characteristics, but its thickness must provide the necessary structural rigidity.

Glass/epoxy laminate (SK Chemicals) was used as a facesheet material, and non-metallic honeycomb of rectangular cell shape (Showa Industry) as a core material for the benchmarking prototype. The honeycomb was manufactured from high temperature resistant aramid paper, and coated with a phenolic resin. The combination of aramid paper and phenolic resin gives the superior strength, toughness and chemical resistance. The honeycomb cell shape is normally hexagonal for optimum mechanical properties, but it has a rectangular cell shape to provide improved drapeability for the production of curved parts. This honeycomb has an air-like dielectric properties, transparent to radio and radar waves. The RT/duroid 5880 (Rogers Corp.) is used for the antenna layer. The thickness of each layer is shown in Fig. 1(b). The cylindrical structures were designed with three radii of curvature, R, of 100, 150, and 200 mm.

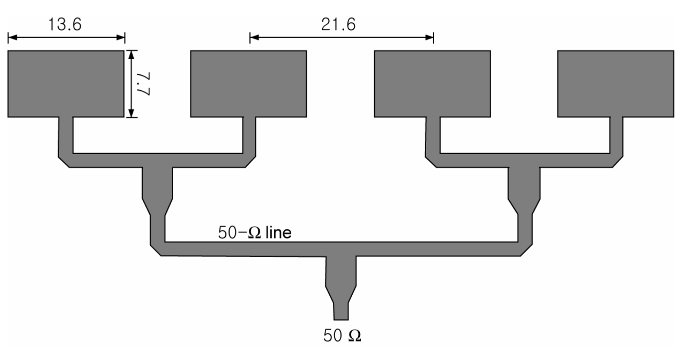

Fig. 2 Antenna element
(all dimensions are in millimeters.)

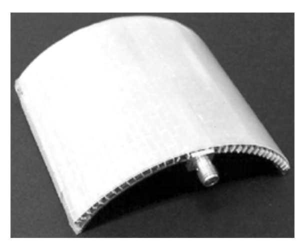

Fig. 3 Fabrication

The antenna elements were designed for a central frequency of 12.5 GHz. A computer-aided design tool (IE3D) was used to identify strongly interacting parameters through an integrated full-wave electromagnetic simulation leading to the geometry of Fig. 2. The array consists of 4×1 patches and the elements are all uniformly excited in amplitude. The rectangular patches have 0.9 wavelengths spacing between the centers of two adjacent elements. The antenna is embedded in the cylindrical composite panel with locating array elements on curved surface.

The manufacture of the composite array is a sequential process. The antenna layer is processed and the designed facesheets and honeycomb are then integrated, confirming the mechanical and electrical performances. For the facesheet of thickness 0.5 mm, glass/epoxy prepregs of 4 plies are symmetrically laid up with cross-ply, $[0/90]_2$. Each layer is bonded on the top or bottom of another one in a designed sequence, using epoxy film adhesive (EA9696). The assembly is performed on a cylindrical mold of designated radius, R. After being covered by a vacuum bag, the curved panel is cured in an autoclave according to the recommended curing cycle for this adhesive (125 °C for 90 minutes at a pressure of 3 kgf/cm^2). Fig. 3 shows the final assembly.

3. Antenna Performances

The H-plane radiation patterns measured in an anechoic chamber are shown in Fig. 4 for both flat and cylindrical deformed cases. The results show that the effect of the curvature is very strong in terms of the cylinder radius. The deformed array also exhibits high side-lobes, which can be reduced by making the element spacing smaller than the one required for the planar array [4]. Since the individual array elements on curved surfaces point in different directions, the element pattern cannot be separated any more from the array factor and it is necessary to compensate for the effect of the curvature of the structure in the phase of the excitation of each individual array element in order to get a well focused main beam from the array**.**

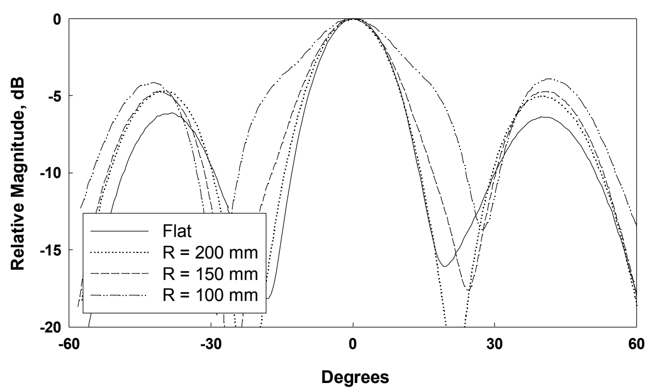

Fig. 4 Radiation patterns for planar and deformed arrays

4. Impact Behavior

Impact tests were carried out using a Dynatup 8250 drop-weight impact test machine in the set-up of Fig. 5. The impactor is cylindrical in shape, and is 140 mm in length and weighed 5.32 kg. Its contact part is hemispherical, and has a diameter of 12.7 mm. An air brake is installed to prevent more than one impact being applied to the specimen. The applied impact energy, 8.5 J is calibrated by adjusting the height of the impactor, H. Impact loads are acquired with a piezoelectric force transducer located on the impactor that contacts specimen. The position of the mass is recorded during the impact event with a non-contact linear displacement sensor that detects a metal target through inductive technology. By differentiating the displacement–time curve, the velocity of the drop mass is determined just before, during, and just after impact. The velocity and load data are used to calculate the impact energy.

The load history of each impact event is acquired and the peak force at each radius is obtained, as shown in Fig. 6. These results indicate that the value of the contact force decreases significantly by the curvature, which means decreased impact resistance due to the reduced density (expanded cell size) of curved honeycomb. The presented results suggest that the curved plates have a nonlinear response for radius, but contact force is thought to severely decrease at radii less than 100 mm.

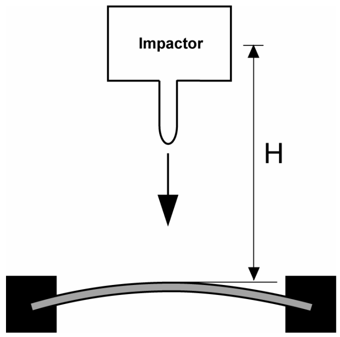

Fig. 5 Test set-up

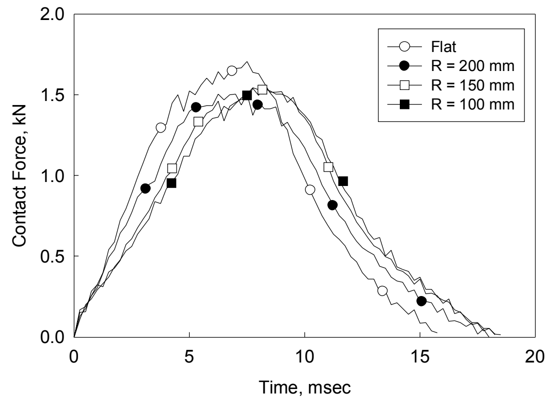

Fig. 6 Contact force

5. Conclusions

In this paper, one structurally integrated composite antenna array conformed around cylindrical structures has been designed and fabricated. A composite sandwich structure consisting of glass/epoxy facesheet and honeycomb core has been used as the fundamental mechanical topology, in which the microstrip antenna array has been embedded. The experimental results show that the radiation pattern is strongly dependent on the cylinder curvature for the transverse radiation pattern, while the array also exhibits high side-lobes and wider beamwidth. The elements must be located closer than in a broadside planar array in order to obtain reduced sidelobes. The results of impact test indicate that the value of the contact force decreases significantly and nonlinearly as the curvature increases, since the reduced density of curved honeycomb lowers the impact resistance of the composite antenna. These results suggest that the radius of curvature is an important structural parameter that must be considered when determining the mechanical and electrical characteristics of conformal composite antennas.

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