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SMART SKIN FOR AEW AIRCRAFT

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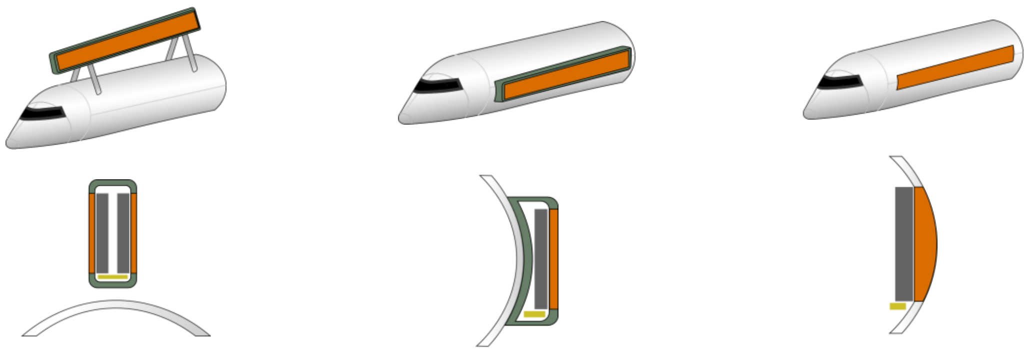
Abstract

A multifunctional fuselage structure has been developed. It provides the structural integrity necessary for smaller aircraft and permits the transmission of high-power microwave radiation characteristics for long-range surveillance radars. In particular, the solution permits a straightforward integration and allows for a curvature that improves buckling performance. A 700 mm × 700 mm fuselage demonstrator was manufactured to verify its performance via measurements. The demonstrator exhibits good antenna performance (good RF coupling and good radiation beam shape) as well as good stiffness and load-carrying capability. It also performed well in vibration tests showing low dynamic response which is useful in dynamic environments.

Keywords: Antenna array, fuselage integration, multi-functional fuselage, radar antenna and smart skin.

1. Introduction

Airborne Early Warning (AEW) radars generate high-power electromagnetic radiation in order to detect distant airborne objects and allow defences to be alerted as early as possible before the intruder reaches its target. Traditionally, AEW aircraft have a large, mechanically rotating antenna a rotodome mounted either beneath or on top of the aircraft´s fuselage [1]. However, in recent times physically fixed body long Active, Electronically Scanned Antenna (AESA) arrays are gaining interest, mainly due to their electronic beam steering capabilities and relatively simple mechanical integration. Additionally, body long antenna can be integrated into smaller platforms compared to the rotodome antenna (for the same sized antenna aperture) [2], which can help reduce the operating cost of the platform.



(a) (b) (c)

Figure 1 – Antenna configurations on the airborne early warning platform. (a) dorsal mounted, (b) side-mounted and (c) fuselage integrated.

The fixed body long AESAs can be integrated in various ways, see Figure 1. The first two (dorsal mounted and side-mounted, Figure 1a and 1b) are the most common, c.f. the Saab Erieye [3] and Elta ELW-2085 [4] respectively. A major advantage of these configurations is that they can be installed on existing aircraft without major modifications. However, these antennas create protrusions on the fuselage affecting the aerodynamic performance of the aircraft by creating additional drag as well as increasing the aircraft weight due to additional structural build-ups and support structures required for these antennas [5]. Antenna protrusions are also subject to extreme temperature variations and humidity, severe stresses at the integration points, bird strikes and lightning. Integrating the antenna sensor into the fuselage as shown in Figure 1c would avoid the antenna protrusions and address these problems.

Aircraft fuselages carry bending moments, shear forces, and torsional loads. Integrating a large AESA by simply making a “Cut-out” in the fuselage (i.e., without the structural integration) produce discontinuities in the otherwise continuous shell structure, redistributing the loads in the vicinity of the cut-out which requires heavily reinforced cut-out, resulting in unavoidable weight increase and structurally inefficient fuselage [6]. Therefore, the fuselage integration of a large AESA such as that of an AEW aircraft must be done by redesigning the fuselage as a multifunctional structure meeting both mechanical and electromagnetic requirements.

Integration of AESA arrays in planar structures for AEW application was explored previously in [7,8]. Although exhibiting good RF transmission properties and intrinsic material strength, the force transfer between the fuselage and the radar electronics restricted the applicability to a subset of low-stress applications in addition to complicating the service procedures. In this work, we developed a new design that fulfils the electrical requirements over the entire mechanical load envelope as well as simplifies the service procedures.

2. Antenna design

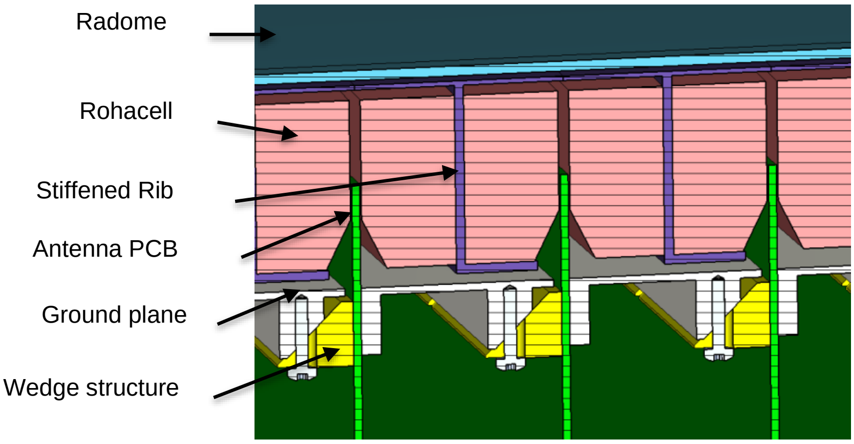


Figure 2 – Cross-section view of the antenna array

The cross-section of the antenna array is shown in Figure 2. The antenna elements are etched on vertically running Printed Circuit Boards (PCBs). The ground plane is a part of the antenna structure and incorporates wedge-like structures which help to accurately mount the PCBs. The ratio of the PCB protrusion above the ground plane and its thickness is small enough to be sufficiently rigid against vibrations. The fuselage is curved with R_0 = 300 cm in one direction and fits with ribs.

Figure 3 shows the fuselage integrated antenna array assembly. The antenna array is geometrically inserted into the load-carrying fuselage in such a way that it can be easily dismounted for maintenance and repairs. The antenna PCBs do not come in direct contact with the fuselage, hence reducing the probability of antenna failure. Improved antenna reliability together with the ability to dismount the array in a simple manner address the limitations of the earlier design in [4].

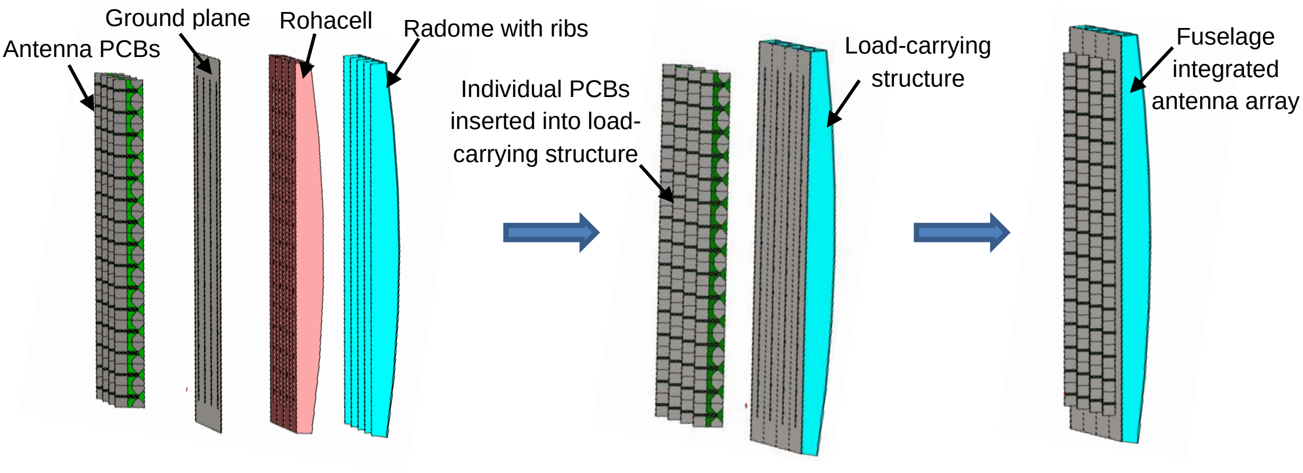
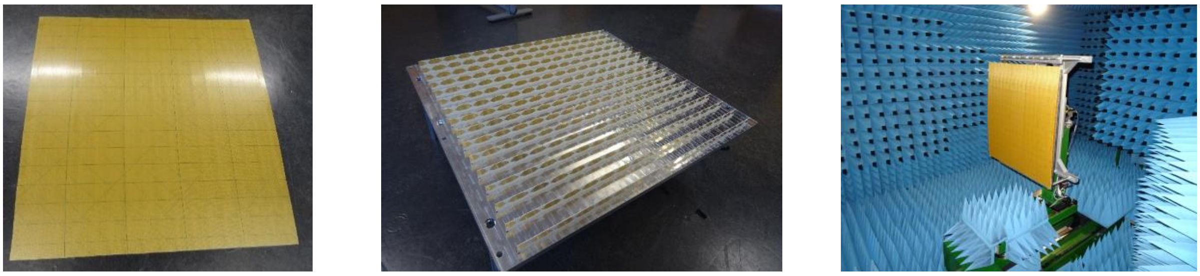


Figure 3 – Fuselage integrated antenna array and its assembly



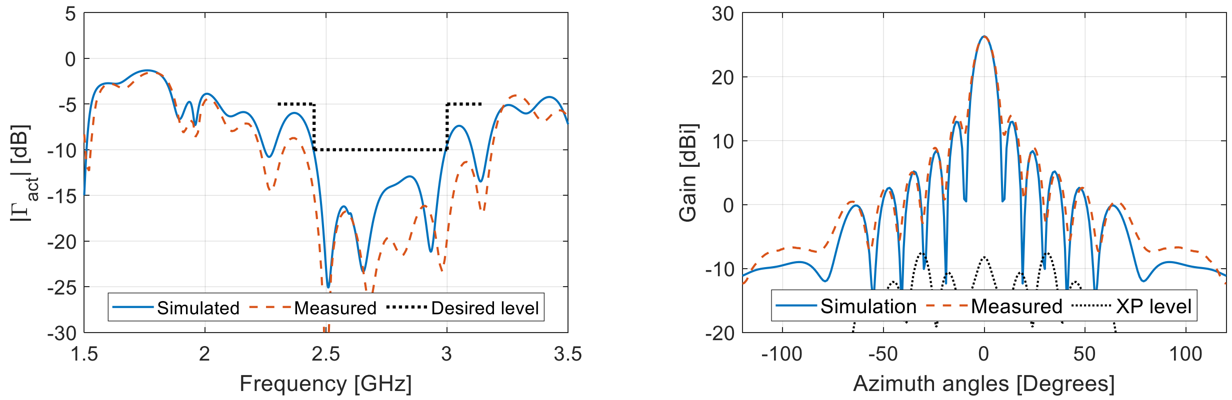
(a) (b) (c)

Figure 4 – Pictures of the 16×16 elements antenna array demonstrator. Antenna array (a) with radome, (b) without radome and (c) in the measurement chamber.

A 16×16 element antenna array was built in order to demonstrate the fuselage integrated antenna array concept, see Figure 4. The measurements were done in an anechoic chamber at the Chalmers University of Technology.

Figure 5 shows the measured and simulated total active reflection and radiation patterns of the antenna array demonstrator. The active reflection shows how much of the input power is being reflected back to the input power source from the antenna. In practice, the perfect power coupling between the source and the antenna array is not possible and the reflection of less than or equal to 10% (i.e., $|\Gamma_{act}| \leq -10$ dB) is acceptable. In Figure 5a, we can see that the antenna demonstrator achieves this level of reflection for 20% of the frequency bandwidth.

The radiation pattern shows the quality of the focused beam and the sidelobe levels. In Figure 5b, we can clearly see (i) a well-formed antenna beam with the peak gain of 26 dBi, (ii) the 13.2 dB sidelobe level characteristic of a rectangular antenna array, and (iii) a very good match between measurements and electromagnetic simulations.

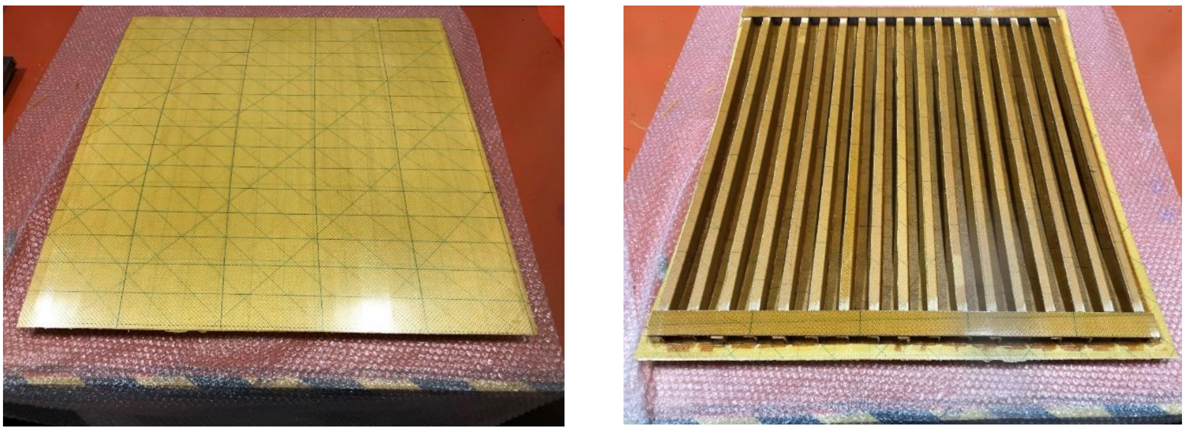


(a) (b)

Figure 5 – The performance of the 16×16 elements antenna array demonstrator when the main beam is at broadside. Measurement and simulation results of (a) total active reflection coefficients and (b) radiation patterns at 2.7 GHz.

3. Radome manufacturing

The aim of the study was to integrate the antenna elements into a fuselage design. Several design concepts, including sandwich and monolithic composite structures were considered. In the first part of the study, a planar bowtie element was evaluated. However, for the demonstrator vertical elements were chosen. The three main drivers behind this choice were: (i) bending and torsion of the fuselage during in-flight conditions without force transfer to the antenna, (ii) slack required for service and repair, and (iii) manufacturability. The chosen design concept was a 700 mm × 700 mm rib stiffened monolithic composite panel with space for a 16 × 16 array, including antenna elements between the ribs, see Figure 6. A fuselage tool for a mid-range aircraft fuselage were used for lay-up. The tools were pre-distorted to compensate for shape distortion during curing to achieve nominal tolerances and to avoid residual stresses.



(a) (b)

Figure 6 – 700 x 700 mm rib-stiffened monolithic composite fuselage-integrated radome. (a) top and (b) bottom views

The material used in the antenna radome was an aerospace graded aramid fibre/epoxy woven fabric prepreg. An adhesive film was used between ribs and skin. The same adhesive film was also used as radius filler.

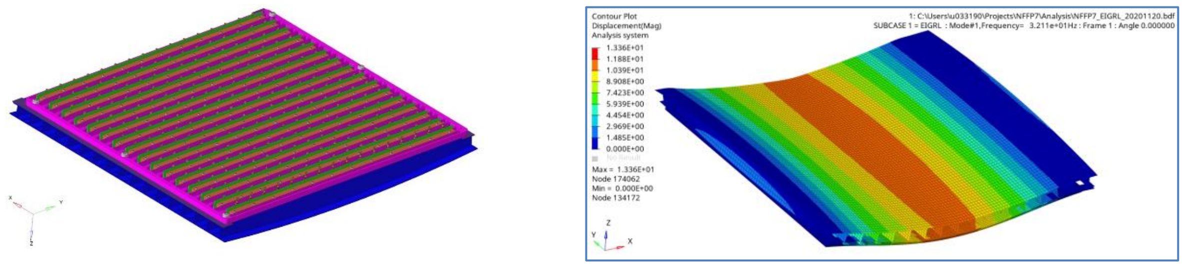
17 ribs were prefabricated with a 180°C cure cycle for 2 h at 6 bar pressure, i.e. typical for aeronautical applications. A 4 layer skin was laid upon a 3700 mm radius concave tool. Position tools were used for accurately placing the ribs in the co-bonding assembly. The ribs were first dry-mounted and overlapping material of the ribs´ upper flanges was marked and machined away for best fit to the assembly. By using the position tools, the ribs achieved very accurate exact placement before they were co-bonded to the skin with adhesive film. The co-bonding used the same cure cycle (180°C for 2 h and 3 bar) as for the ribs. The heat-up rate was 2°C/min and the cool-down rate was 3°C/min. The principles for the final cross-section was a [0/90, 45/135, 0/90, 45/135] lay-up with a cure ply thickness of 1.8 mm.

The composite design above was easy for the operator to lay up and form. The concept was also well suited for more automated serial manufacturing.

4. Fuselage Integration

The curved, rib-stiffened fuselage also serves as a radome. This implies, among other things, that the material must be strong and RF transparent. Aramid Fibre Reinforced Plastic (AFRP) fulfils these requirements and has in particular been qualified for aerostructure design. Hence, AFRP was chosen for the demonstrator.

Finite element analysis and vibration tests have been performed on the demonstrator in order to establish a connection between tests and simulations and to prepare for computer-aided design taking e.g. the structural integrity and reliability into account.

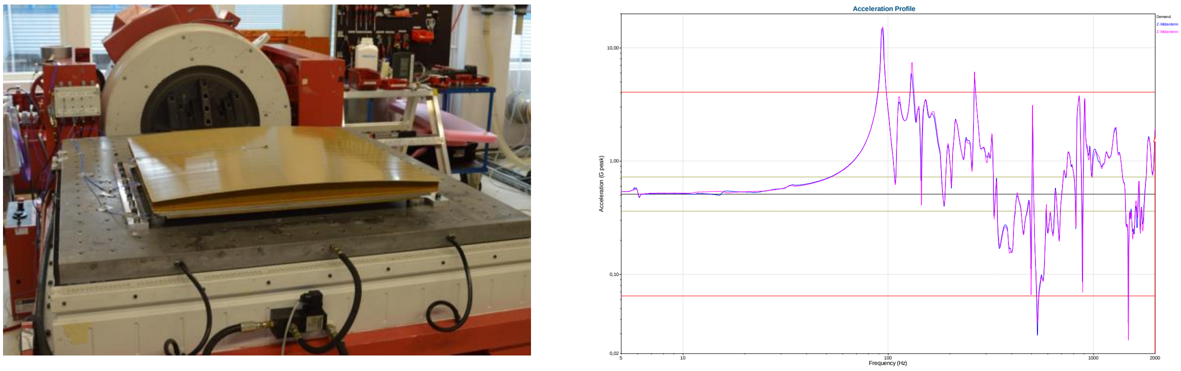


(a) (b)

Figure 7 – FE-model and the mode shape. (a) FEM simulation model and (b) Lowest order eigenmode

In the finite element analysis, the natural frequencies and the modal effective mass were calculated, see Figure 7. Since the mass of the antenna is moderate and the fuselage structure is very stiff, the design concept has good stiffness and load-carrying capacity. Moreover, the design is scalable and can easily be adapted to different applications e.g. by modifying the number of attachment joints and the radome skin thickness.

In the vibration test, both sinusoidal sweep and random loads were applied in all directions, see Figure 8. The sinusoidal sweep was used to establish the natural frequencies and the dynamic response of all parts of the demonstrator, while the random vibration test was performed to test the mechanical integrity and robustness. The test levels were for simplicity taken from those used for the larger GlobalEye AEW. The results show that the curved fuselage has a low dynamic response, which is an advantage in dynamic environments. The demonstrator was inspected before and after the vibration test, there were neither loosened screws nor wear on the parts.



(a) (b)

Figure 8 – Vibration test. (a) Picture of the rig set-up and (b) Dynamic response in a sinusoidal sweep.

5. Conclusion

The paper demonstrates the structural integration of an AESA antenna in the fuselage structure. The integrated fuselage structure is designed to fulfil the electrical requirements of an airborne antenna sensor as well as the mechanical requirements of a load-carrying aircraft fuselage. The antenna array demonstrator performed well in both electrical and mechanical measurements. It demonstrated low input reflection (i.e., RF coupling between antenna and input power source), good radiation pattern with high gain and low sidelobe level as well as exhibits good stiffness and load-carrying capability required for an aircraft fuselage. The antenna demonstrator also showed enough rigidity against dynamic in-flight vibrations.

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8. Copyright Statement

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