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INVITED PAPER

Microwaves in Airborne Surveillance

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ABSTRACT

The use of microwave spectrum is widespread due to its convenience. Therefore, enormous amount of information is available in the free space channel. Obviously, mining this channel for surveillance is quite common. Airborne surveillance offers significant advantages in military operations. This paper talks of the usage of microwaves in airborne surveillance systems, in general, and in the Indian airborne early warning and control (AEW&C) System, in particular. It brings out the multiple sub-systems onboard the aircraft comprising the AEW&C system and their spectral coverage. Co-location of several systems has its own problems and resolving them in terms of geometric location, frequency band and time of operation are covered. AEW&C, being an airborne system, has several other requirements including minimal weight, volume and power considerations, lightning protection, streamlining, structural integrity, thermal management, vibration tolerance, corrosion prevention, erosion resistance, static charge discharge capability, bird strike resilience, etc. The methods adopted to cater to all these requirements in the microwave systems that are used in the AEW&C system are discussed. Paper ultimately speaks of the microwave systems that are designed and developed for the Indian AEW&C system to surmount these unusual constraints.

Keywords: Airborne warning system, control system, microwaves, airborne surveillance

1. INTRODUCTION

Utilisation of microwaves in recent years has increased exponentially due to the easy and convenient usage of free space as the channel. However, the free space channel is prone to tapping of information despite several evasive methods. Therefore, the surveillance methods should adopt themselves to make use of this provision. Airborne surveillance system is one where the sensors are placed onboard an aircraft to get the height advantage so that the microwave rays could be picked up directly without any blockage due to buildings or other obstructions.

2. AEW&C SYSTEM DESCRIPTION

Airborne early warning and control (AEW&C) system is having several sensors onboard the aircraft and the sensors are able to get the connectivity to their source of information through a direct microwave path. Blockages due to buildings or other man-made and natural objects are eliminated in airborne surveillance due to unobstructed line-of-sight. The ill effects of multi-paths are also minimized.

The AEW&C system is a system of systems having primary radar (PR), secondary surveillance radar (SSR), electronic support measure, communication support measure (CSM), ‘C’- Band Data Link (CBDL), ‘Ku’- Band SATCOM data link (KBDL), V/UHF communication link working in the microwave region. These subsystems are mounted onboard a passenger aircraft as shown in Figs. 1 and 2. As can be seen from Table 1, the Indian AEW&C system is versatile in choice of the sub-systems and its capabilities.

Figure 1. AEW&C Indian system.

Table 1. AEW&C systems on EMB-145 aircraft

Systems on board	AEW&C on EMB-145 platform				
	Sweden	Brazil	Greece	Mexico	India
Primary radar	Yes	Yes	Yes	Yes	Yes (with elevation scan)
IFF	No	Yes	No	No	Yes
ESM	No	Yes	Yes	No	Yes
CSM	No	Yes	No	No	Yes
C-Band data link	No*	No*	No*	No*	Yes
Ku-Band SATCOM	No	No	No	No	Yes
V/UHF	NK	NK	7 V/UHF	3 V/UHF	7 V/UHF (data & voice)
Self protection	No	No	Yes	No	Yes
No. of OWS	NK	4	5	4	5
IFR	No	No	No	No	Yes
Additional seats	3	3	3	3	5

Figure 2. AEW&C India sub-systems.

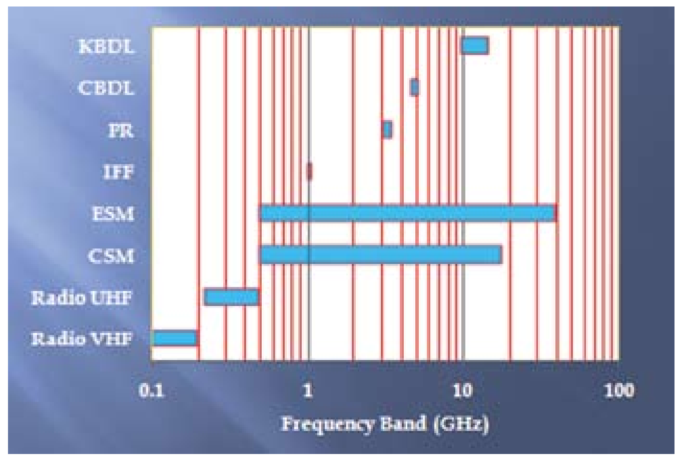

Figure 3. AEW&C spectral coverage.

3. AEW&C SPECTRAL COVERAGE

The conventional microwave spreads from 1 GHz to 100 GHz or 300 mm to 3 mm wave length. In case of the AEW&C, the subsystems cover frequencies from VHF to 'Ku'-band as shown in Fig. 3. The figure depicts the actual frequency spectrum in use. It can also be seen that there are regions with overlapping frequencies, which means that the concerned systems should function without interference while operating simultaneously. In addition, there would be a number of unwanted frequencies generated as by-product in the subsystems in spite of the best efforts for spectral purity and these frequencies will interfere with each other.

4. ANTENNA SPATIAL SEPARATION

In the case of AEW&C, the real estate available on board the aircraft is limited and hence antennae are to be kept in close proximity to each other. On the exterior of the AEW&C aircraft shown in Fig. 4, there are 89 antennae and sensors located in a cramped condition. In addition, aircraft body being metallic, the individual antenna radiation pattern gets distorted due to 'body effect'. Hence, prior knowledge of the individual antenna radiation pattern alone cannot help while selecting suitable locations on the exterior of the aircraft for various antennae. Moreover, aircraft safety being of the highest priority, the ideal location requirement from antenna radiation pattern point of view has to take a back seat.

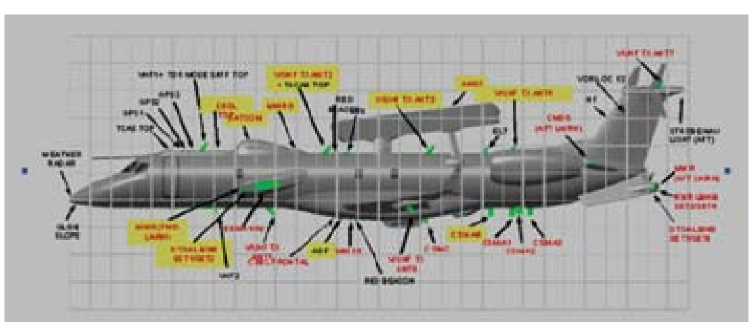

Figure 4. Antenna spatial separation.

5. PATTERN PREDICTION WITH 'BODY EFFECTS'

The first step toward location identification is to predict the antenna radiation pattern with 'body effects'. For this, one has to resort to any of the computational electro-magnetic methods. Commercial tools such as E-Mind have been used and the patterns obtained are shown in Figs. 5 and 6. This exercise is recitative and time consuming. Depending upon the number of locations tried for each antenna, one generates voluminous data.

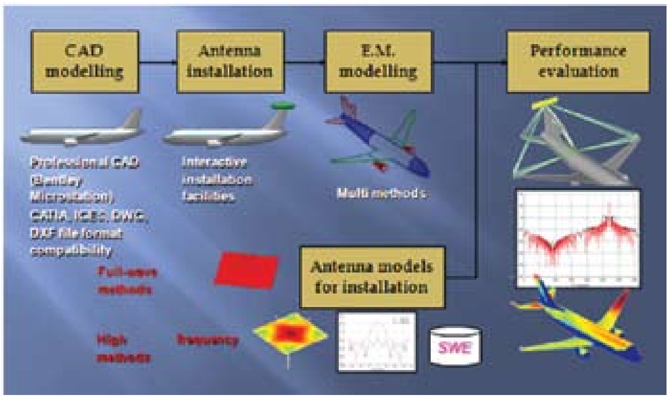

Figure 5. Antenna siting optimisation.

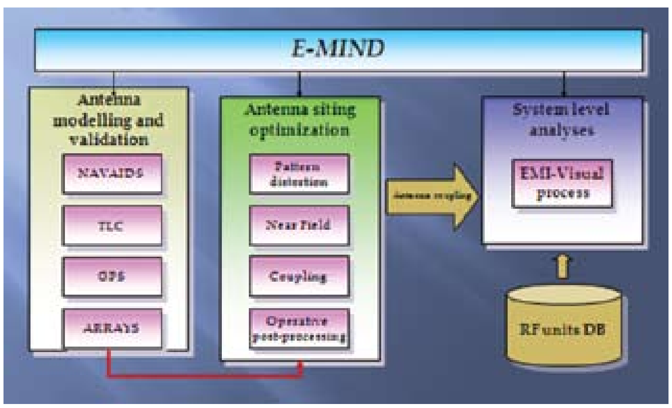

Figure 6. Approach to EMI Problem.

6. ANTENNA LOCATION SELECTION PROCESS

In general the antenna location process goes through the following steps:

a. No location on the control surfaces
b. No location that affects air flow over the control surfaces
c. No location that blocks the air in-take
d. No location that leads debris into the engine during bird strike
e. No location that interferes with aircraft controls.
f. No location that does not have structure to support the antenna
g. No location that burns the other mission system front-end
h. Preferably locations not affecting the cooling for other mission systems
i. Preferably locations not affecting field of view of other mission systems
j. Preferably locations not affecting the performance of other systems.

Fig. 7 shows the location of the SATCOM radome adjusted forward to allow sufficient air for the active antenna array unit (AAAU) located in the rear under all 'angle-of-attack' conditions. Similarly, the AAAU itself was moved forward to avoid damage from a possible broken engine blade leading to a flight hazard. Additional fins had to be added to stabilize the aircraft under 'side-slip' conditions as there was a blockage of air to the control surface. Once these essential conditions are met, the decision is to have a location which is best from point of view of electromagnetic performance. Thus, the design is an iterative exercise with multi-disciplinary considerations before the final decision is taken. Obviously, the resulting outcome is only an optimum one and not the ultimate solution from electromagnetic point of view.

Figure 7. Locating SATCOM Radome and AAAU from aerodynamic and engine considerations.

7. ACTIVE ELECTRONICALLY SCANNED ARRAY RADAR

The primary radar is active electronically scanned array (AESA)-based radar having more than 1,000 elements producing several tens of kilo watts of power. The complete AESA is located outside the aircraft in a dorsal configuration known as active array antenna unit (AAAU) as shown in Figs. 7 and 8. This design, using ram air for cooling the electronics inside the AAAU, drastically reduces the burden on the cooling system virtually to one third and consequently the power that is required for cooling is also reduced.

The fundamental advantage of the AESA over mechanically scanned array (MSA) is inertia less scanning, energy management and graceful degradation. Unlike the American E-3C or E-2D AWACS systems, the Indian AEW&C is based on AESA as shown in Fig. 7. The basic configuration of the AESA is shown in Fig. 9.

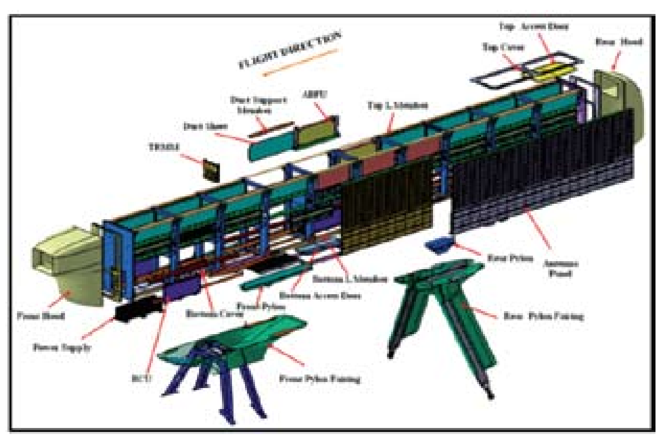

Figure 8. AAAU exploded view.

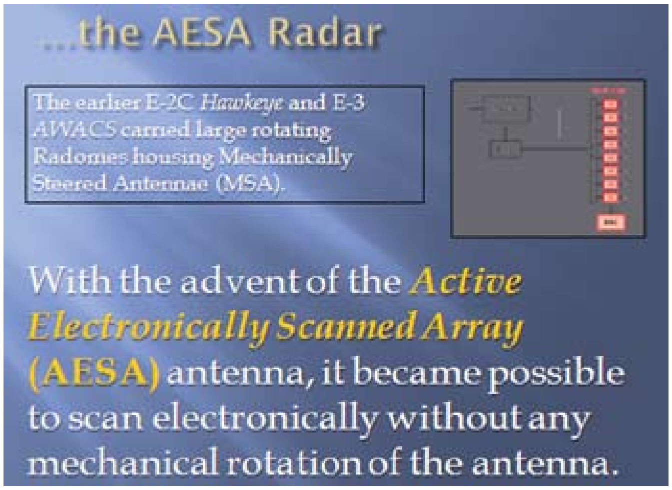

Figure 9. AESA radar.

8. AIR FLOW REQUIREMENT

The construction details of the AAAU can be seen in Fig. 8. The bottom portion of the AAAU contains the Multi-output power supplies (MOPS) that require more cooling than the TR modules that are placed in the middle. The internal airflow for each of the 160 Transmit-receive multi-modules (TRMM) should be not less than 15 CFM even under blockage conditions due to the presence of SATCOM radome under all pitch- and yaw-conditions. To assess the required quantum of airflow, wind tunnel tests were carried out apart from CFD analysis (Figs.10 and 11). As can be seen in Fig.12, the system has about 2 km length of RF cables in the air passage and the air-flow analysis model should take this into account and ensure adequate margins in the flow of cooling air.

Figure 10. Wind Tunnel Test.

9. BIRD STRIKE REQUIREMENT

Safety against bird strikes is another vital requirement for AAAU being a large airborne antenna system. This calls for selection of proper material and structural design for the AAAU. The criteria are such that after the bird strike, there should not be a cause for any flight-safety concern. The debris from a damaged antenna beyond a certain size, for example, should not be able to enter the engine. The carbon composite front hood with aluminum mesh and the aluminum slotted

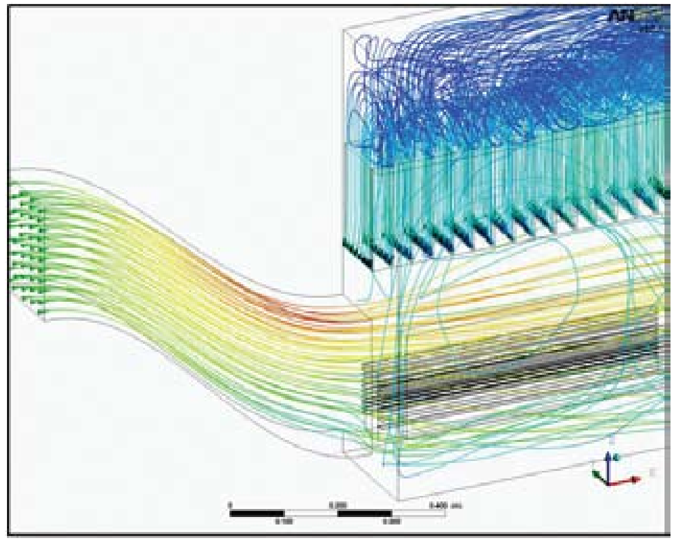

Figure 11. Airflow through AAAU – CFD analysis.

Figure 12. RF Cables in the AAAU.

array are designed for such a criterion. Apart from transient analysis, actual test is also conducted with frozen bird of 4-pound weight, as per defence standards. See Fig. 13.

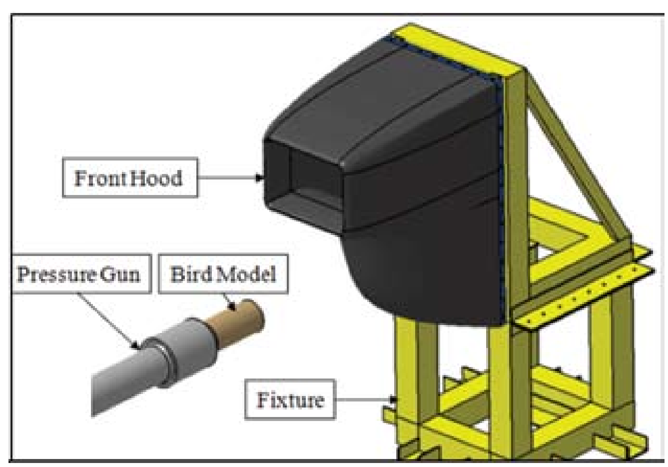

Figure 13. Bird-proofing front hood of AAAU.

10. LIGHTNING REQUIREMENT

Another special requirement for the airborne antenna is that it has to pass the lightning test for both direct and indirect effects. After zonal analysis, the lightning attachment points are identified and provided with paths for lightning to pass through without causing any structural damage. The indirect effects can be equally damaging like direct effects on items like the TRMM with sensitive electronics. The lightning must be discharged as much as possible by limiting the current flow in the skin. The waveguide slot array is best suited for this environment. A truncated AAAU being subjected to lightning test is shown in Fig.14.

Similarly, the SATCOM radome in the lightning prone zone has button/strip type lightning conductors to retard the lightning effect as shown in Fig.15.

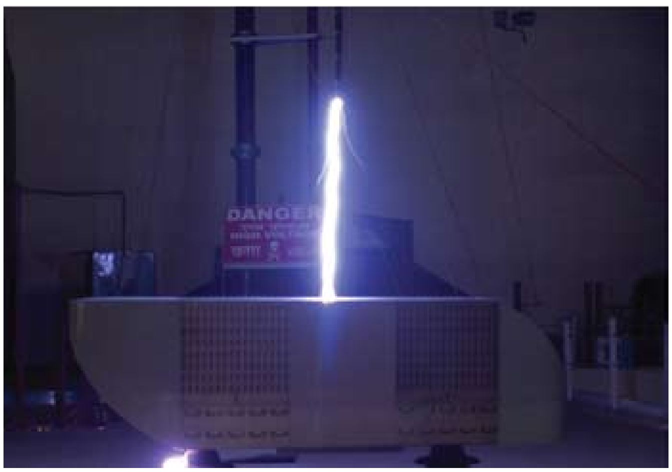

Figure 14. Lightning test on AAAU.

Figure 15. Lightning protection for SATCOM Radome

11. RADIATING ARRAY REQUIREMENTS

In order to get electronic scanning up to 60 degrees on either side, the element should have beam-width of more than 120 degrees. The waveguide or cavity backed slot was found to be the ideal element for the purpose. In addition, the bandwidth and the power handling capacity are controlled through the slot width. The element and its pattern are shown in Fig.16.

An antenna panel contains 8x16 elements and it has been subjected to environmental qualification tests as per MIL-STD-810E as seen in Fig.17. Since the AEW&C system has secondary surveillance radar (SSR), or, IFF, the antenna has 'L'- band C-slots also to achieve the required inter element spacing to get the required scan angle. Another C-slot in 'S'-band as shown in Fig. 18 is for real time calibration.

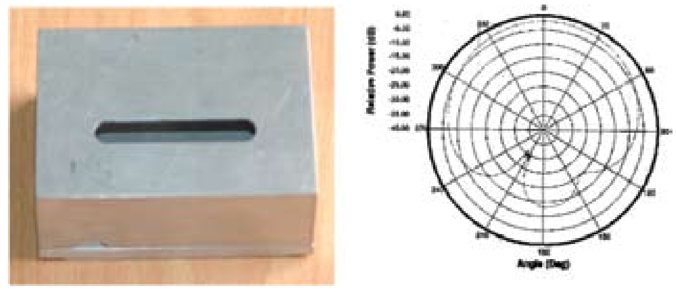

Figure 16. The element and its pattern.

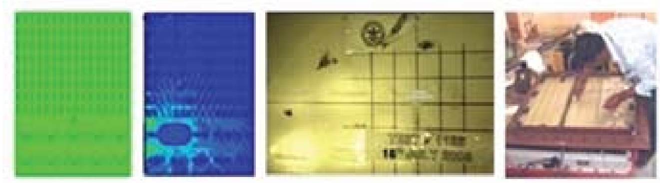

Figure 17. Analysis and test for bird strike.

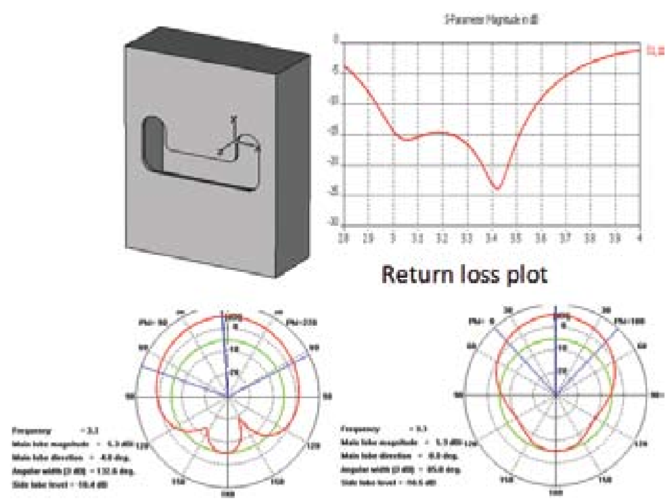

Figure 18. C-slot in S-band.

12. STRUCTURAL REQUIREMENT OF AAAU

Being external to the fuselage, the cross section of the AAAU perpendicular to the aircraft flight path should be minimal to have low additional drag. Hence, a low drag design was done by suitably designing the antenna panels as integral structural parts of the AAAU and eliminating the need for an additional protective radome. This has not only reduced the drag but also the total weight of the AAAU. After analysis, four antenna panels, as shown in Fig.19, were joined to form a lager single panel to enhance torsional rigidity. FEM analysis was carried out on the structure as shown in Fig. 20 and found to be meeting the FAR-25 requirements. The results of the analysis were cross checked with experimental measurements.

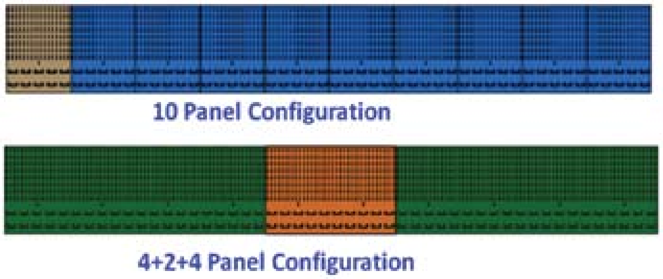

Figure 19. Combining panels for rigidity.

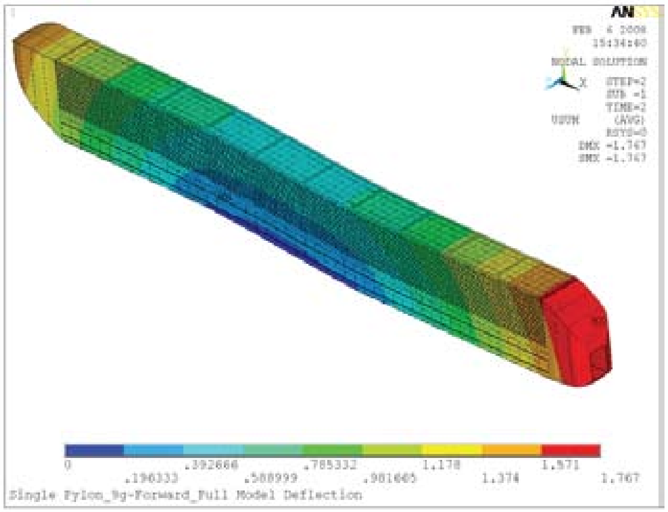

Figure 20. FEM Analysis for inertial loads on AAAU.

13. AAAU TECHNOLOGIES

As seen from the above, the AAAU design is not a purely electromagnetic one, but it is inter-disciplinary and has to satisfy several requirements simultaneously. Some of the technologies involved are shown in Fig. 21. As shown, technologies relating to electronic/electromagnetic, aerodynamic, mechanical, environmental, electrical, and material fields are involved for proper design of the AAAU.

14. TRANSMIT-RECEIVE MULTI-MODULE

The most critical technology element for the radar is the Transmit-receive multi-module (TRMM). Design of the TRMM was carried out in the microwave lab and evaluated in detail. The most difficult part of the design was thermal management of the components in the TRMM without giving rise to hot spots by usage of ram-air-cooling. The inside of the TRMM and the thermal analysis are shown in Figs. 22 and 23 respectively.

15. AAAU PATTERN MEASUREMENT

The AAAU should have the required radiation pattern to match its functional requirements. Unlike the passive antenna, the active array antenna has transmit- and receive- patterns, as it is non-reciprocal. For collimation of the antenna, the best measurement system to be used is the planar near field measurement facility. The pattern measurements made of the AAAU are shown in Fig. 24.

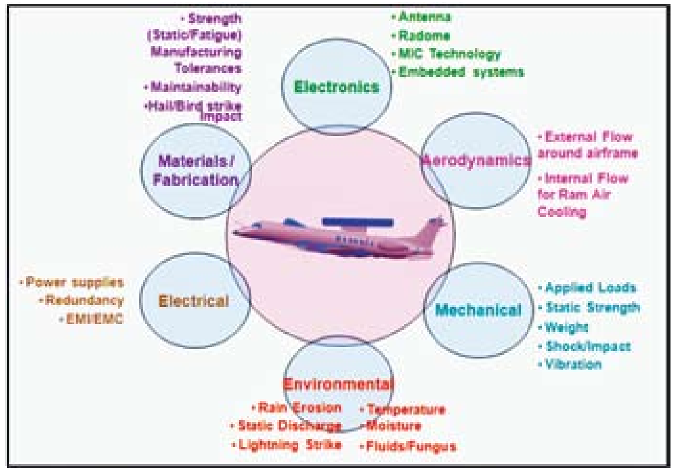

Figure 21. AAAU technologies.

Figure 22. The TRMM.

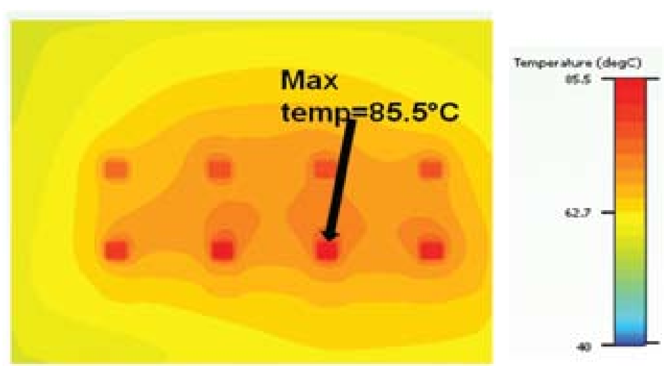

Figure 23. TRMM has safe thermal management.

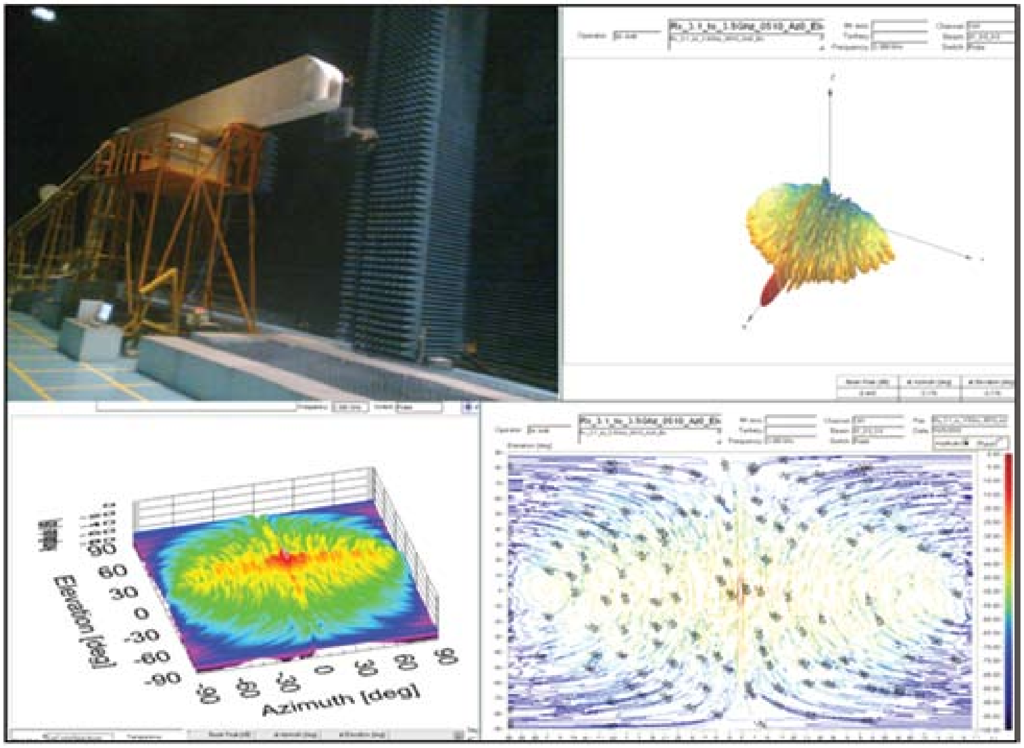

Figure 24. AAAU Radiation Pattern measurement in PNFM facility.

16. CONCLUSION

Use of microwaves for airborne surveillance is common. AEW&C system, in particular, uses almost the complete spectrum of microwaves. It is also seen that the antennae required for the AEW&C application have to satisfy several requirements. Microwave antennae lend themselves adequately for the requisite stringent conditions of operation.

Contributor

Dr S. Christopher obtained his BE (Hons) in (Electr. Comm. Eng.) from University of Madras, and MTech from IIT Kharagpur. He received his PhD in Engineering from IIT Madras. He joined DRDO in 1988. He developed the slotted array technology, systematically from basics- a technology which only a few countries in the world have. He also served as the Project Manager of ASP and Project Director of LCA-MMR, MBA, ALH Radar, and various resource generation projects.