Defence Science Journal, Vol. 60, No. 2, March 2010, pp. 184-188

REVIEW PAPER

State-of-the-Art in Active Electronically-Steered Array Surveillance Radar: Indian Value Addition

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ABSTRACT

The advent of active electronically steered arrays (AESA) marked the most important development in radar technology. With exceptional reliability, superior performance, and unprecedented beam-steering agility, this technology has drastically changed many aspects of airborne surveillance, and thereby the tactics of air warfare. The optimal configuration for the AESA antenna is still evolving towards exploitation of the radar's total potential in the airborne surveillance application. The paper briefly enumerates the efforts being made in this direction globally and elaborates the Indian line of approach for its current and future AEW&C systems.

Keywords: Air-to-air surveillance, air-to-surface surveillance, radar, EW, mechanically steered array, active electronically steered array, AEW, airborne early warning and control, AWACS, AEW&C

1. INTRODUCTION

1.1 Airborne Early Warning and Control Era

The significant inventions of the early 20^{th} Century, viz., the aircraft and the radar, led to the clever combination of the two technologies, giving birth to a distinctly identified airborne early warning and control (AEW&C) concept, that eventually rewrote the tactics for air warfare (Fig. 1).

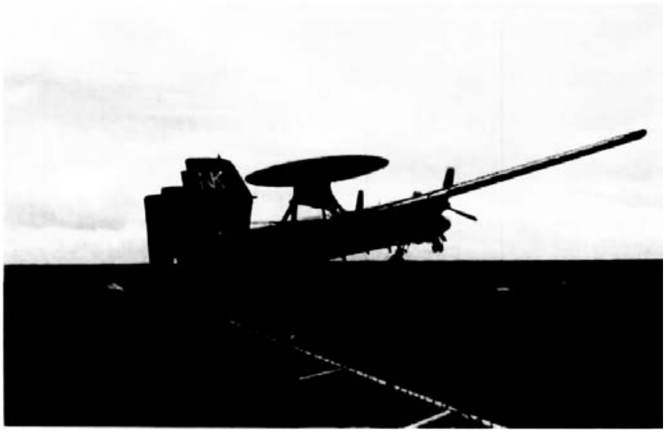

Figure 1. E-2C Hawkeye.

The roles that the two dominant AEW&C systems, viz., the E-2C Hawkeye and the E-3 AWACS played during the Gulf War (1991) amply illustrate the power of these systems. During operation 'Desert Shield' and 'Desert Storm,' the AEW&C aircraft helped overcome surveillance deficiencies and conducted successful air operations. These assisted the fighter fleet by providing early threat detection and building up situational awareness that led almost cent per cent of the air-to-air engagements being successful (Fig. 2).

Figure 2. E-3 AWACS.

The AEW&C system has quickly proved itself to be a dominant force multiplier with its abilities to execute multiple functions–surveillance, early warning, electronic intelligence, communication intelligence, command and control tasks, battle management, etc. all from a single airborne platform. The AEW&C systems effectively impacted the dynamics of air warfare and have irreversibly changed its nature.

2. EVOLUTION OF ACTIVE ELECTRONICALLY STEERED ARRAY RADAR

Both E-2C Hawkeye and E-3 AWACS aircraft carried mechanically-steered array (MSA) antenna in a rotating dome to scan the sky. In the early 1990s, a more versatile breed of AEW&C systems with electronically steered array (ESA) radar started making their appearance progressively.

The ESA is mounted in a fixed position on the aircraft structure and the beam is steered by individually controlling

Received 14 October 2009

electronically the phase of the radio waves transmitted and received by each of the multiple radiating elements in the antenna. Additionally, in the case of ESA, a low RF power generated in a single place is amplified at multiple places close to each of the radiating elements, thereby the array becomes active as against being passive. The major advantage is that the power generation is distributed, and consequently there is graceful degradation of the radar performance in the event of failure of a percentage of the transmitting elements. This is unlike in the conventional system, wherein the RF power is generated in a single place, and a failure, whatsoever in the system, can cause the mission to be aborted. In addition, about 3 dB (15%) of power, in general, is lost in the distribution network of the conventional system, whereas in the AESA system, there is no such loss.

The inherent advantages of the active electronically scanned array (AESA) radar are the obvious inertialess scanning and the minimal feeder loss as no lengthy feeder cables are involved. Unlike in the MSA radar, the AESA radar has the impudence to perform even with failure of some of its radiating elements. The AESA radar goes through a graceful degradation with cumulative failures in its battery of transmit-receive modules. The AESA radar helps build substantially compact radar systems resulting in low weight, minimal aerodynamic drag, and relatively smaller radar cross-section (RCS), all of which are of vital importance operationally for the platform aircraft. Besides, the AESA radar provides enhanced beam agility with higher reliability. The latest AESA sensor further helps track air- and sea-targets simultaneously as well as tracks continuously the high performance aircraft, while maintaining the routine scan over the operational area.

2.1 Saab-340 AEW&C

The world's first of the AEW&C systems to sport AESA radar was the Swedish Saab-340 AEW&C aircraft. The Saab-340 is a twin-engine turboprop aircraft. An AEW version with phased-array radar, Ericsson's Erieye, in a rectangular pod on top of the fuselage was delivered in 1994 (Fig. 3).

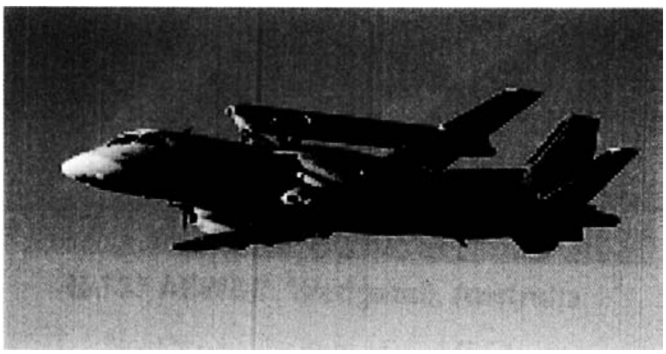

Figure 3. Saab-340 AEW&C, Sweden.

The Ericsson Erieye radar uses an active array with 200 solid-state modules. The antenna is housed in a 9 m long box radome mounted atop the fuselage. The look angle on each side of the radome is about 120° in azimuth. Since the surveillance is on the sides, azimuth coverage of 120° does not seem to be a limitation and the practice has been persisting for over a decade.

The electronically-scanned antenna can scan sectors of interest frequently while other sectors are monitored; and also a single sector can be scanned in different modes at the same time. The aircraft functions as an airborne radar integrated with the total air defence network.

2.2 EMB-145 AEW&C

Brazil saw the virtue of the Ericsson Erieye radar of the Saab-340 AEW&C and chose to mount the same on its bigger and fastert win-engine regional jet aircraft, EMB-145. The endurance of this system is about six hours (Fig. 4).

Figure 4. EMB-145 AEW&C, Brazil.

M/s Embraer of Brazil built the EMB-145 AEW&C aircraft for Air Forces of Brazil, Mexico, and Greece with the Erieye radar and other subsystems as opted by the user Air Forces.

2.3 G-550 CAEW

In 2009, M/s ELTA of Israel brought out a conformal airborne early warning (CAEW) aircraft based on the AESA on a Gulfstream G-550 platform (Fig. 5).

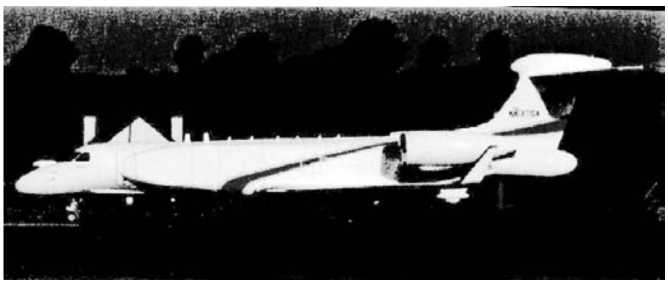

Figure 5. G-550 CAEW, Israel.

The ELTA radar conformally built on the sides of the fuselage works on the L-band and provides coverage on the LH and RH sides. In the forward and aft directions, independent radars mounted on the nose and tail of the aircraft work on the S-band and provide radar coverage of relatively reduced range.

2.4 B-737 AEW&C, Wedgetail

The Boeing Company is building for the Royal Australian Air Force (RAAF), an AEW&C system, designated B-737 AEW&C, Wedgetail. The Boeing AEW&C solution combines the new Being 737-700 aircraft with the Northrop Grumman multi-role electronically scanned array (MESA), which is basically an AESA-radar (Fig. 6).

Figure 6. B-737 AEW&C, Wedgetail, Australia.

Northrop Grumman's MESA radar is mounted on a rectangular T-structure atop the fuselage providing for 240^o full range coverage on the sides and for the rest of the azimuth angle partial range coverage in the fwd and aft directions through the top hat as end-fire array.

3. INDIAN AEW PROGRAMMES

3.1 IL-76 AWACS, India

Israel and Russia have jointly developed the first AEW&C system for India, christened IL-76 AWACS India, with true 360°-azimuth-coverage radar built into the Russian Briev IL-76 aircraft platform. This system is built around an AESA L-band radar (Fig. 7).

Figure 7. IL-76 AWACS India.

India's IL-76 AWACS uses a conventional circular radome mounted on top of its fuselage.The radome is however, fixed and not rotating. The ELTA radar, with a set of three phased-arrays fed from a single set of T/R modules housed in a triangular configuration inside the radome, will operate in L-band and scan 360° in the azimuth.

3.2 EMB-145 AEW&C, India

The Defence Research and Development Organisation (DRDO) have launched an indigenous AEW&C programme focussed on specific operational requirements of Indian Air Force. The Centre for Airborne Systems (CABS) of the DRDO is tasked with the development of the system and the Centre is pursuing the programme with participation of multiple workcentres from within DRDO as well as Indian industries in the public and private sectors (Fig. 8).

Figure 8. EMB-145 AEW&C, India.

The primary sensor for the AEW&C will be the indigenous AESA S-band radar with adequate detection range against targets of the fighter class of aircraft.

Two radiating planar arrays assembled back-to-back and mounted on top of the fuselage in an active antenna array unit (AAAU) will provide 240° coverage like Erieye (Fig. 9). The AAAU is configured to compactly house 10 x 2 antenna array panels, 160 transmit receive 10 x 2 antenna array panels, 160 transmit receive multi-modules (TRMMs) dividers, beam forming units, beam control units, power supply units and related electronic devices including cables and connectors. This has been achieved through an innovative and iterative process to arrive at the AAAU with minimal dimensions and optimum mass properties (Fig. 10).

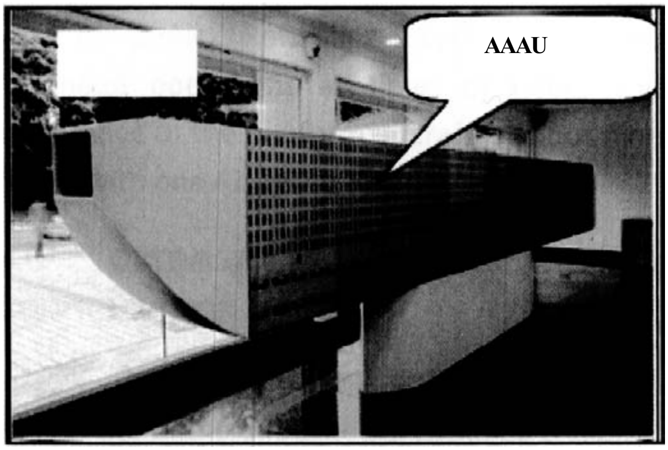

Figure 9. Active antenna array unit.

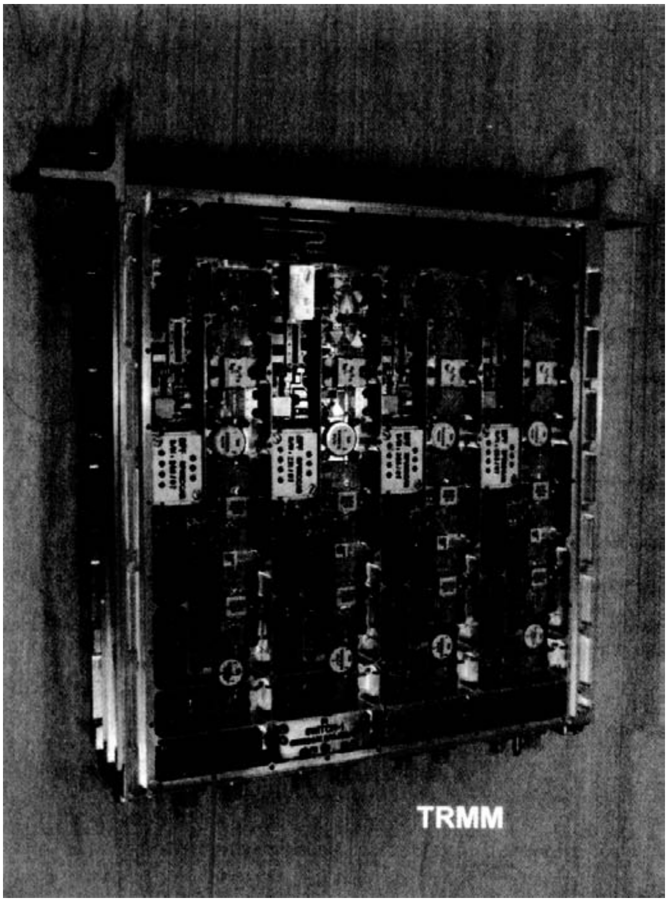

Figure 10. Transmit-receive multi-modules.

Development of the Transmit-receive multi-modules (TRMM) was a significant and high-value indigenous effort as the technology, hitherto available only to a handful of advanced nations, could be, for the first time, engineered successfully to fully meet the needs of the Indian AEW&C system. A unique feature of the indigenous TRMM design is that eight trans-receive modules are combined compactly to form a single TRMM, thus facilitating high density installation of 160 of them in the AAAU to power the surveillance radar. The important fact about the indigenous TRMM is that the quantity required for the Indian AEW&C programme could be produced through the industry in the private sector at a cost less than one-fourth of that of its imported equivalent. The realisation of the TRMM is a boost to self-reliance in development of indigenous defence systems.

Additionally, the aircraft has other mission capabilities like, Identification friend or foe (IFF), electronic and communication support measures, C-band line-of-sight and Ku-band SATCOM datalinks, etc., similar to those on the AWACS and CAEW systems.

The important modes of operation of the primary radar system are the surface surveillance and the air surveillance. The sensor has the abilities to search, track-while-scan, priority tracking, high performance tracking, etc. In priority tracking, the targets will be placed in full track mode even if these cross the primary surveillance area. In high performance tracking, additional measurements will be made to improve the tracking accuracy. Utilising active aperture technology, the radar provides a fast-beam agile system that can operate in several modes concurrently. lnteroperability with AWACS, other AEW&C aircraft, fighters and ground-exploitation stations is ensured using the datalinks with voice and data channels.

The aircraft cabin houses five operator work stations to adequately meet requirements of the operational mission tasks.

An air-to-air refuelling, system enables extended operations at times of need. The endurance of the platform aircraft is about nine hours with one air-to-air refuelling.

4. OPTIMISING AESA ANTENNA CONFIGURATION

The AESA radar has brought in many advantages in the airborne surveillance exercise. To exploit maximum gains of this new technology, quite a few antenna configurations have been evolved for intended deployment applications to suit the perceived defence scenario of concerned nations. Such evolution of antenna configurations had paid off in the form of optimal solutions for realising effective results at minimal overall costs.

The merits of the prevalent antenna configurations facilitated by contemporary technologies, viz., (i) dorsal-mounted rectangular twin antennae, (ii) conformally fuselage-mounted antennae, and (iii) three antennae triangularly arranged with in a circular radome, have been discussed.

4.1 Dorsal-mounted Rectangular Twin Antenna

The rectangular twin antenna, mounted back-to-back and installed in a dorsal unit on top of the fuselage, was the natural choice when the AESA radar was born. The early designers of AESA radar were keen to exploit its advantage over the MSA radar, for which the heavy and draggy rotodome was an inevitable penalty (Fig. 11).

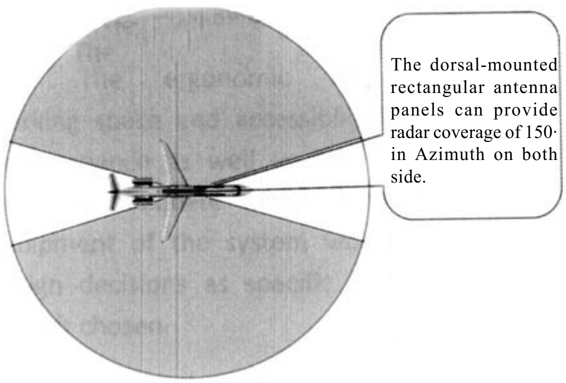

Figure 11. Dorsal-mounted rectangular twin antenna panels.

4.2 Conformal Fuselage-Mounted Antennae

The conformal side-mounted anten nae with nose and tail mounted additional antennae sought to overcome the gaps in the radar coverage in the fwd and aft directions. The solution, however, was more notional than practical as the limited detection range in the fwd and aft directions offered little help in terms of reaction time when the target aircraft were approaching head on. The reduced fwd and aft detection capability offered, however, marginal gain in respect of friendly aircraft in the region (Fig. 12).

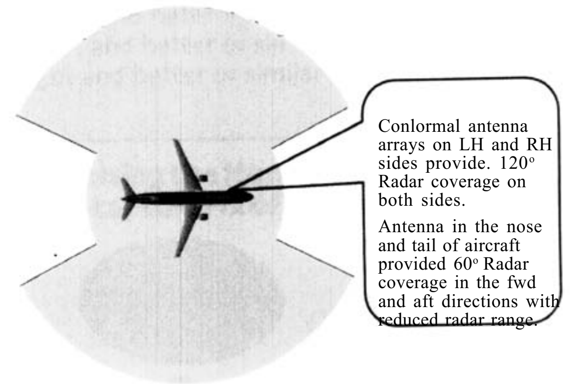

Figure 12. Conformal fuselage-mounted antenna.

4.3 Three Antenna Triangularly Arranged in a Circular Radome

The three antenna configuration arranged in a triangular fashion inside a circular radome was sure winner when the 360^0 coverage capability with equal range in all directions became mandatory. The only dissatisfaction was that the configuration did not exploit the advantages of AESA radar. The effects of the circular radome on the performance of the aircraft were just the same as for the MSA radar of the first generation AEW&Cs platform (Fig. 13).

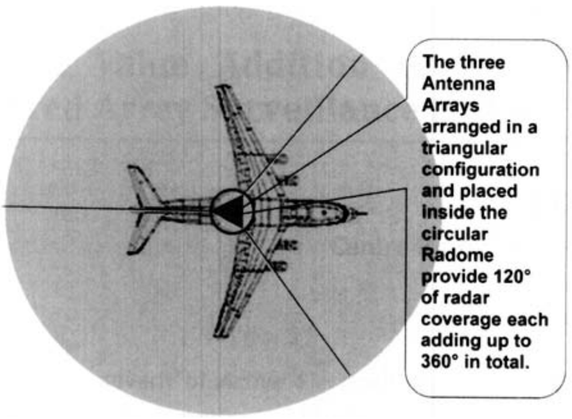

Figure 13. Triangular radome-mounted antennae.

4.4 Antenna Configuration as Specific to Application

The choice of the optimal configuration for the AESA antenna depends essentially on the type of role for which the system would be deployed majority of the times during its operational life. Besides meeting the radar performance requirements optimally, such a judicial choice of the antenna design should prove to be cost-effective from considerations of both procurement and operational costs of the system as a whole.

The ergonomic requirements of working space and accessibility for operation/maintenance as well as the convenience of providing adequate cooling for the electronic equipment of the system would also impact design decisions as specific to the platform aircraft chosen.

5. FUTURISTIC 360°-CAPABLE ANTENNA

Some preliminary studies have been carried out at CABS for a possible optimal design of a futurist ic antenna with the desirable 360°-vision for roles identified under various war situations.

A feasible configuration for the futuristic antenna is depicted in Fig. 14. The unique aerodynamically-shaped delta radome will blend with the aerodynamics of the platform-aircraft to provide the required radar performance together with better operational economy by virtue of its better aerodynamics, reduced weight, and better or similar electromagnetics.

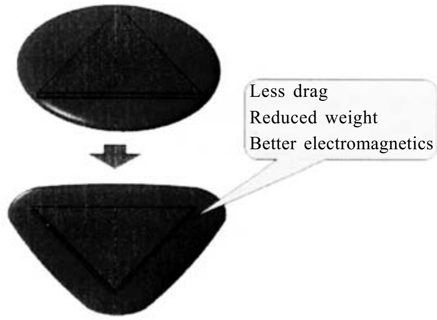

Figure 14. Optimising the non-rotating 360°-capable fixed radome.

6. CONCLUSIONS

The foregoing summarises the efforts made by DRDO towards development of the AESA radar for its current and future AEW&C applications as well as for realising essential allied technologies. The necessary core competence to evolve futuristic applications in AESA radar has thus been adequately established.

Contributors

Dr S. Christopher obtained his BE (Hons) in Electronics & Communication Engineering from University of Madras. He obtained his MTech from IIT Kharagpur. He joined IIT Madras as faculty member in 1980 and obtained PhD in Engineering from there. He then worked with M/s Bharat Electronics, Ghaziabad from 1985 to 1988. 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.