ANTENNA SYSTEM FOR COASTAL SURVEILLANCE RADAR

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Abstract:
This paper describes the design of antenna for coastal surveillance radar (CSR) developed as part of an integrated coastal surveillance system (ICSS) along the Indian coast line. The antenna systems consists of back to back X-band horizontally polarized and S-band circularly polarized travelling waveguide slotted array antenna enclosed in metallic baffles.
Key words: CSR Antenna, travelling waveguide, slotted array

I INTRODUCTION

India has a very long coast line with large fishing industry utilizing the coast. As past incidents have shown, effective surveillance and monitoring of the coast is imperative to keep the nation secure and economically strong. The ICSS programme is taken up to have an indigenous solution which covers the whole coastal line and to provide integrated coastal surveillance using the in-house sensors/communication technologies available with DRDO for better maritime domain awareness and decision making. A round-the-clock coverage along the coast for all seasons necessitates the introduction of a number of different kinds of surveillance sensors. One of the sensors which are commonly employed for surveillance application is CSR. The targets of interest are predominantly small boats of sub 20-meter size and detecting any subversive activities taking place through these small boats. The main goal is to develop a prototype CSR and demonstrate its capabilities, which in the near future can be further developed as part of ICSS and utilized to serve the above mentioned purpose.

The CSR is the primary sensor for detection and tracking of sea surface targets for the ICSS. CSR should be able to detect and resolve sub 20m length boats whose Radar Cross Section (RCS) is about $1m^2$ to $4m^2$ in the presence of huge cargo ships and container carriers, the RCS of such cargo ships is of the order of $1000m^2$. The radar should be operational 24x7 under various sea states. The functional requirements of CSR are that it should support for dual frequency band operation for Clear and Inclement Weather conditions with ability to resolve closely moving boats.

Since the radar has to resolve closely spaced boats of 20m length, X-band operation is chosen which gives good azimuth resolution. Horizontal polarization is chosen for X-band operation, which gives low clutter reflectivity at lower grazing angle. For normal weather operation X band works satisfactorily, but during inclement weather such as rain etc. the attenuation due to rain is high in X-band. Since the radar has to work in all weather conditions, S-band operation is also incorporated which will be invoked by the operator, during inclement weather such as rain. Circular polarization is chosen for S-band operation, which gives better performance in rain clutter.

Hence, the antenna configuration chosen is X- and S-band antenna mounted back to back. Figure 1 depicts the antenna system configuration for CSR application.

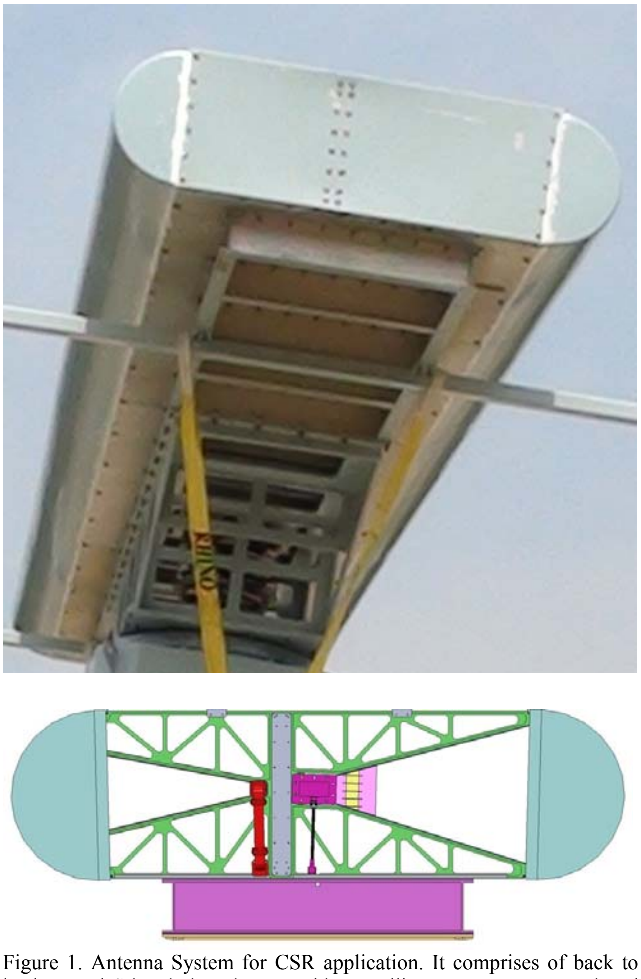

Figure 1. Antenna System for CSR application. It comprises of back to back X-and S-band slotted waveguide travelling wave antenna enclosed in metallic baffles covered with radome.

The objective of this paper is to explain in detail the design and development of antenna system CSR. The functional requirements of antenna are derived from the radar requirements. The various design options with merits and demerits along with the chosen option and reasons for selection are discussed in the following section.

II DESIGN DETAILS

To meet the CSR functional and technical requirements, there are various types of antenna configurations available such as active aperture array antennas as well as passive arrays/antennas. Each type of antenna has its own advantages and limitations. The type of antenna is decided based on factors such as frequency of operation, polarization, bandwidth, efficiency, side lobe levels, weight, size and mounting aspects. Travelling wave slotted waveguide array is popular because of its size, weight and high power handling capability. Hence it is chosen to develop travelling wave slotted waveguide array antenna for CSR application. The major design specifications for X-band antenna are: azimuth -3dB beam width≤0.5° with overall gain ≥38dB and horizontal polarization. The major design specifications for S-band antenna are: azimuth -3dB beam width≤2.0° with overall gain ≥30dB and circular polarization (axial ratio≤3.0dB).

2.1 X-band Antenna Design:

The X-band antenna system for CSR application consists of a linear travelling wave slotted waveguide array with approximately 256 slots cut in narrow wall of the waveguide to produce horizontal polarization and enclosed in metallic flares to produce the required the beam width in elevation plane. X-band antenna configuration for CSR application is shown in figure below.

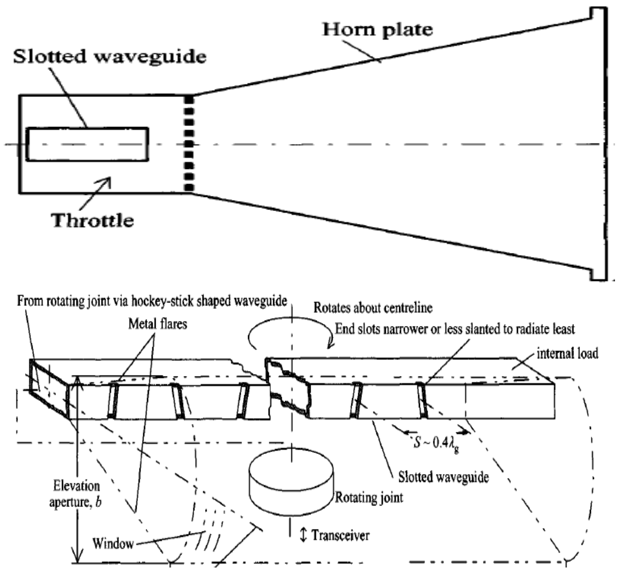

Figure 2. X-band Antenna Configuration for CSR application.

Traveling-wave arrays are used in applications where the direction of the main beam is pointed at angles that are not broadside to the waveguide wall or where frequency scanning is desired. Inter-element spacing does not have to be the same between the elements, and $\lambda_g/2$ spacing is particularly avoided. The initial design of slotted waveguide traveling wave array is implemented using the design equations given in [1, 2]. If the reflections between elements are negligible, a constant phase difference between elements results in a progressive phase shift along the array aperture. The resulting phase front points the peak of the beam to an angle other than bore sight. However for a given fixed inter-element spacing, the beam scans toward the load end of the waveguide as the frequency is increased. This inherent property of beam scanning as a function of frequency makes the traveling wave antenna gives it the advantage in CSR application.

Once an array excitation is obtained that includes compensation for edge effects, then the element coupling can be readjusted. Since the elements have been moved, a last performance prediction is made to verify that performance is as desired through simulation in HFSS 3D electromagnetic software. A linear array of length 6400mm with 256-radiating elements is designed and simulated in HFSS.

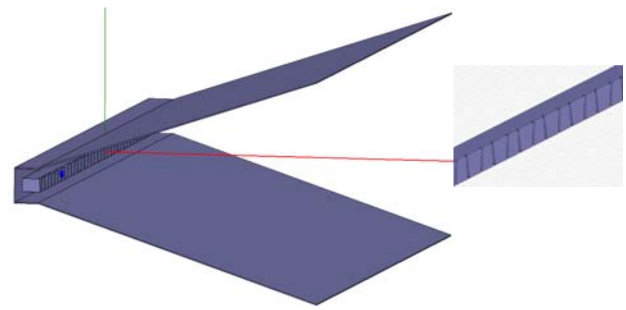

Figure 3. Simulation Model of X-band Antenna.

2.2 S-band Antenna Design:

The S-band antenna system for CSR application consists of circularly polarized travelling wave type non resonant slotted waveguide antenna in which slots are cut on the narrow wall of the waveguide which will operate in S-Band. This linear array radiates linearly polarized wave which is then converted into circularly polarized wave using quarter wave plate polarizer. The polarizer consists of quarter wave length metallic plates having 1mm thickness and kept at 45 degree with respect to azimuth plane and having equal spacing between them. These plates are held in place using rohacell material, which has the dielectric constant equivalent to that of air. The rohacell is kept on the top of the waveguide and polarizer plates are kept in between these rohacell spacers having same depth as that of quarter wave polarizer plates. S-band linear array of length 6400mm with 120-radiating elements with quarter wave polarizer enclosed in metallic baffles is designed and simulated in HFSS.

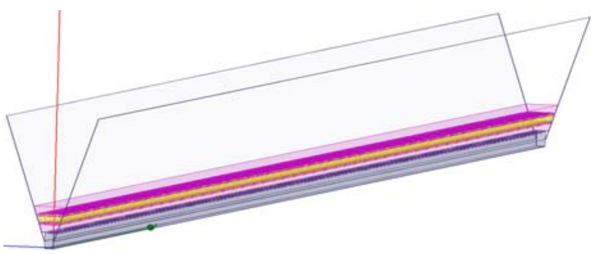

Figure 3. Simulation Model of S-band Antenna.

III MECHANICAL CONSTRUCTION

The development of CSR antenna mainly consists of the following main sub-assemblies:

- S-Band slotted waveguide assembly with polarizer
- X-Band slotted waveguide assembly
- Vertical Stiffeners
- Antenna base frame
- RF plumbing
- Antenna Interface Structure

S-band and X-band slotted wave guide assemblies are placed back to back. The waveguide assembly basically consists of wave guide and diverging metallic flares. Radiating slots are cut on the narrow side wall of both X-band WR 90 wave guide and S-band WR 284 wave guide. Metallic baffles / flares are mounted on top and bottom faces of both the slotted wave guides. Both the wave guide assemblies are supported at regular intervals throughout its length by using vertical stiffeners. These vertical stiffeners are riveted on to antenna base frame. Since Antenna base frame imparts stiffness to the antenna and it forms the load bearing member. It is manufactured from extruded ‘I’ section with weight reducing slots cut on its web.

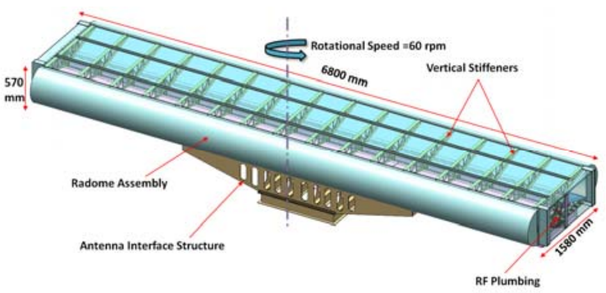

Figure 4. Sub-assemblies / components of CSR Antenna System.

Rigid wave guides are used for X-band and low loss coaxial cables are used for S-band RF plumbing. These are properly anchored and routed through the slots provided on stiffeners. The radiating faces of the antenna are covered by radome and are fixed to stiffeners and cross member by screws. Top face and bottom faces of antenna are protected by covers which are riveted to stiffeners and end caps are used to cover sides of the antenna. Similarly bottom face of antenna base frame is closed using cover plates. The antenna is handled using handling members as shown below. Handling members are fixed to base of antenna frame and are removed once assembly / dis-assembly is complete.

IV RESULTS AND DISCUSSIONS

The first prototype antenna array has been designed and developed in LRDE. The proto type array has been subjected to electrical parameters tests, such as return loss and radiation pattern using vector network analyzer and planar near field test range at LRDE. The measured return loss of X- and S-band antennas are ≤ -20dB throughout the operating frequencies. The return loss plots of X- and S-band antennas are shown in figure 5 and 6 respectively.

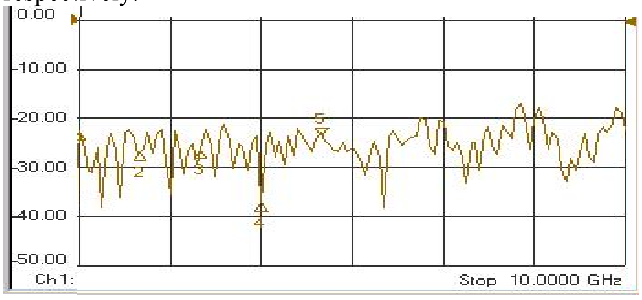

Figure 5. Measured return loss of X-band antenna.

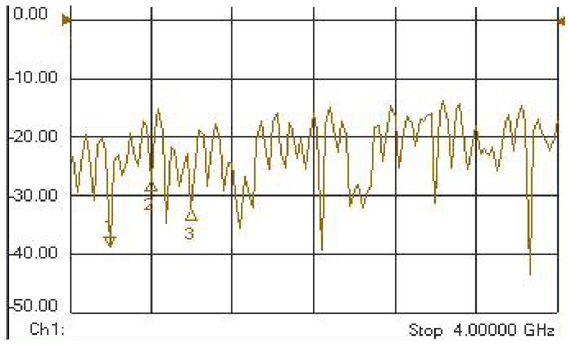

Figure 6. Measured return loss of S-band antenna.

The traveling wave array achieves its large impedance bandwidth by virtue of the phase differences between the reflections from the various slots. The phase differences, which arise from non-resonant spacing, cause the resultant sum of all the reflected waves to be quite small. The measured radiation patterns of X- band horizontally polarized antenna in azimuth and elevation plane with and without radome are shown in figure 7.

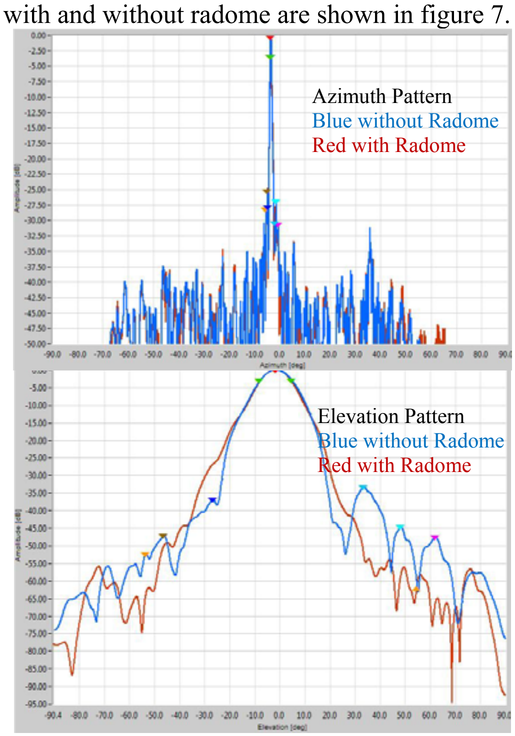

Figure 7. Measured radiation pattern of X-band antenna.

The major design specification goals of -3dB beam width of ≤0.5° in azimuth, with overall gain ≥38dB are achieved throughout the operating frequency band width of 0.5 GHz. In elevation plane, -3dB beam width of ≤12° is achieved. Peak side lobe level (SLL) of the order of -25dB in both azimuth and elevation planes are achieved.

The measured radiation patterns of S- band circularly polarized antenna in azimuth and elevation plane with and without radome are shown in figure 8. The major design specification goals of -3dB beam width of ≤2.0° in azimuth, with overall gain ≥30dB and axial ratio ≤3.0dB are achieved throughout the operating frequency band width of 0.3 GHz. In elevation plane, -3dB beam width of ≤20° is achieved. Peak side lobe level (SLL) of the order of -22dB in both azimuth and elevation planes are achieved.

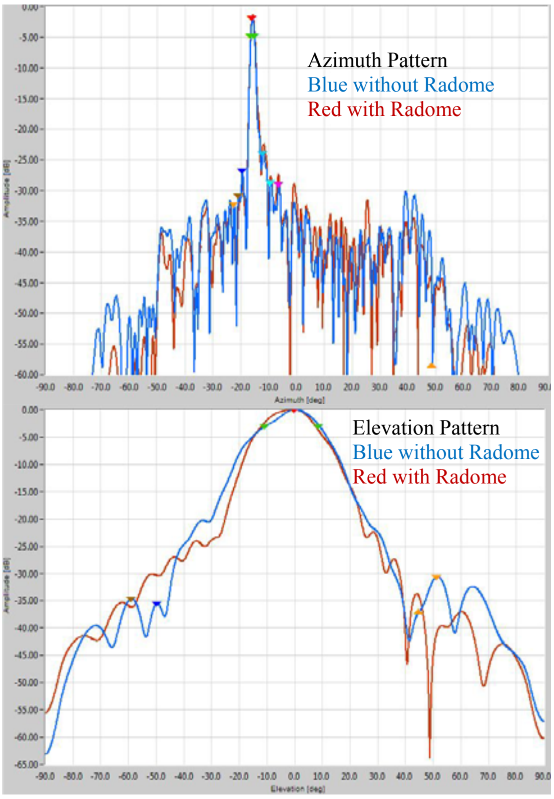

Figure 8. Measured radiation pattern of S-band antenna.

V CONCLUSIONS

First prototype CSR antenna system meeting all design specifications is designed and developed in LRDE. Three engineered antenna systems are also realized by industry (M/s BEL, Ghaziabad). The engineered antenna systems are integrated with other radar subsystems and the complete operational CSR systems are installed at three different locations near Cochin.

ACKNOWLEDGEMENTS

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Dr. Iqbal Ahmed Khan obtained his Ph.D. in 2004 in Applied Electronics from Gulbarga University, Gulbarga, (INDIA). He joined Electronics and Radar Development Establishment (LRDE), Bangalore in June 2004 and presently involved in design and development of microwave antennas for radar applications. He is a member of IETE.

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Dr. A K Singh obtained his Ph.D. in 1991 in electronics engineering from IT-BHU (now IIT-BHU), Varanasi, India. He joined Electronics & Radar Development Establishment (LRDE), Bangalore in November 1991. Presently he is Outstanding Scientist / Scientist H, Divisional Head of Radar Antenna & Microwave Division and Associate Director of LRDE. He is involved in the design & development of Antenna, RF & Microwave systems for various AESA Radars under development at LRDE/DRDO. Earlier as a Project Director of 3D Low Level Light weight Radar ASLESHA for Indian Air Force , he steered the successful development, user acceptance and production of the radar most suitable for high altitude snow bound mountainous terrains. As a Project Director of AESA Radar for fighters, he has steered the development of Transmit-Receive modules and established necessary design and manufacturing infrastructure in the country to produce large nos. of T/R modules required for different Active Phased array radars. He has established design and manufacturing technology for Multi Beam Antennas required in large numbers for various military radars like Rohini for Air Force, Revathi for Navy, 3D-TCR for Army & 3D-CAR for Akash Weapon System for Airforce & Army. More that 100s of these systems are deployed all over the country to provide required air surveillance. He has also established core antenna technologies for Slotted waveguide Array Antennas for LCA & ALH, Microstrip Array Antennas for UAVs & Missiles, Active Array Antennas and digital arrays for medium range surveillance radars by systematically developing necessary EM design and analysis CAD software packages.

He has served as Chairman, Technical Programme Committee of International radar Symposium (IRSI) in 2007, Chairman IEEE International Symposium on Microwaves in 2009, Chairman IETE conference on RF & wireless in 2010 & 2012, International Correspondent for IEEE Radar Symposium (Germany) in 2008 & 2014. He has authored more than 140 research papers in different international / national journals and symposiums. He has 6 copyrights and 10 patents to his credit. For his significant contributions, he has been awarded NRDC (National Research Development Corporation) meritorious invention award in 1997, DRDO National Science Day commendation in 2005, DRDO Technology Group Award in 2006, DRDO performance excellence award in 2008, IETE-IRSI award in 2009, DRDO AGNI Award of excellence in self reliance in 2010, IEEE International Microwave Symposium Best Paper Award in 2011, best paper award in 2012 & 2013 and IETE-CDIL award in 2014. He is member of academic/research council of IIT Roorkee, IIT BHU & NAL. Dr Singh is editorial board member / reviewer of many peer reviewed journals and Ph.D. examiner in many institutes like IISc, IITs & other institutes. He is a Fellow of IETE, Senior Member of IEEE and Member of Society of Electronics Engineers.

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