Ka-band Feed Horn with Monopulse Comparator

S R Tamilarasan, Mohan Kumar, Dr. Iqbal Ahmed Khan, Dr. Anil Kumar Singh
Electronics and Radar Development Establishment
Defence Research and Development Organization
C V Raman Nagar, Bangalore, India
Email- srtamilarasan08@gmail.com

Abstract:
This paper describes the design and development of Ka-band feed horn with monopulse comparator for tracking radar. The feed horn consists of metallic baffles in one plane and flaring inward in other plane to broaden the beams for efficient illumination of existing reflector antenna as well as support higher order modes to generate sum and difference channels in Azimuth and Elevation planes using monopulse comparator.
Key words: Feed Horn, monopulse comparator, tracking radar

I INTRODUCTION

Ground based air defence radars are usually deployed for surveillance, acquisition and tracking of aerial targets such as Fighter Aircrafts, Helicopters & UAVs. Such systems are configured using multi sensors like 3D search radar, a dedicated single target tracking radar, electro-optical (EO) sensors, etc. The target tracking data is available from all sensors. In fire control radars, addition to tracking by search radar, a dedicated 3D tracking radar is also provided for accurate 3D target tracking data (even for low flying targets) to facilitate successful engagement using air defence guns.

DRDO is developing air defence fire control radar system in which the tracking radar is a servo driven parabolic reflector based coherent mono-pulse radar operating in Ka-band capable of tracking a single target very accurately even at low heights. One of the main elements of this radar is antenna assembly.

Generally, antenna in the tracking radar of air defence fire control radar system is reflector based and is steered by a servo mechanism. Antenna assembly consists of the circular aperture parabolic reflector with mono-pulse feed horn and radome covering reflector & feed assembly. In the transmit mode antenna forms narrow pencil beam and in receive mode simultaneous beams of sum, azimuth difference and elevation difference patterns are formed using multimode feed and mono-pulse comparator.

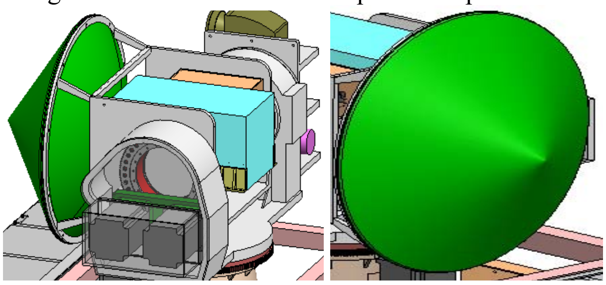

Figure 1. Tracking Radar Antenna Assembly.

The objective of this paper is to explain in detail the design and development of Ka-band feed horn for tracking radar reflector antenna. The functional requirements of reflector antenna are derived from the requirements of the tracking radar system. 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

The commonly used antenna system for tracking radar applications at Ka-band is pencil beam parabolic reflector fed by a point source feed horn. Reflector antennas have high gain and directivity making them well suited for tracking radar applications. The simplest reflector design can be a parabolic dish antenna with the feed horn at the focus. The only disadvantage is reflector antenna systems requiring mechanical control and closed loop tracking, such as conical scanning when the platform is mobile. The components needed with this technology take up a significant amount of space (volume). However, reflector antennas are wideband, the beam width is limited by feed band width.

The prime focus parabolic reflector antenna was first studied and analyzed to meet the functional requirements of Ka-band tracking radar system. The antenna subsystem for tracking radar consists of the main primary parabolic reflector antenna fed by a multimode feed horn to generate sum and difference beams in both planes. Since prime focus parabolic reflector antennas are one of the most popular reflector antenna configurations, the radiation characteristics of prime focus fed parabolic reflector antennas illuminated by a single-feed horn (fixed-phase center) is designed.

The major design specifications for Ka-band reflector antenna are: both (azimuth, elevation) plane sum channel -3dB beam width ≤0.6°, overall gain ≥48dB, side lobe level of ≤-25dB, null depth ≤-25dB and horizontal polarization.

Since, the existing reflector antenna with the dimensions of diameter 1000mm is used in this case; only feed horn is required to be designed. With the antenna aperture size being fixed at 1000mm diameter and the antenna being intended for tracking radar application, the ***f/D*** ratio is the key design parameter. The ***f/D*** ratio determines

(a) Reflector shape
(b) Volumetric space
(c) Feed location and Feed type

(d) Aperture illumination

Based on these factors and available volumetric space for accommodating the antenna smaller ***f/D*** ratio may not be suitable for mono pulse feed. So for tracking radar antennas with mono pulse comparator, ***f/D*** of 0.7 is considered.

Since D = 1000 mm, f =0.7*1000 mm = 700 mm.

2.1 Calculation of subtended angles for f/D of 0.7:

Consider a symmetric parabola in the azimuth and elevation plane with 1000mm diameter $\tan(\psi_0/2) = D/4f$ where ψ_0 is half subtended angle as shown in figure 1.

$\tan(\psi_0/2) = D/4f$ = (1000)/(4*700) =10/28 = 0.3571

$$\therefore \psi_0 / 2 = \tan^{-1}(0.3571) = 19.65^\circ;$$

Hence

$$\psi_0 = 2*19.65 = 39.3^\circ;$$

The total subtended angle is 2*$\psi_0 = 2*39.3 = 78.61^\circ$.

The feed horn positioned at the focus should give these beam-widths in E- and H-planes corresponding to –10dB point.

2.2 Feed design for f/D of 0.7:

In order to have the first side lobe level of the order of –25dB it is required that the edge illumination of the reflector should be –10dB below that at the center. We assume a feed illumination function, which is of the form $\cos^2\psi$ .The feed horn design is based on WR – 28 waveguide with internal dimensions of broader wall ***a*** = 7.11mm and narrow wall ***b*** = 3.56mm. A rectangular aperture horn meeting this criterion is used as a feed for prime focus parabolic reflector antenna.

Monopulse in azimuth and elevation plane are achieved through higher order modes in the feed horn.

As an initial choice, a wave-guide horn is considered for the feed. The subtended angle at the focus by the reflector in the azimuth and elevation plane is 78.61°. This corresponds to the -10 dB taper selected for the design. The -3 dB beam width can be calculated from the -10 dB beam width by using the empirical formula

$$\frac{\theta_{3dB}}{\theta_{10dB}} = \sqrt{\frac{3}{10}}$$

$$\theta_{3dB}(az) = 0.547*78.61 = \underline{42.99}^\circ$$

The size in the E-plane can be calculated from the equation

$$\theta_{3dB} = \frac{70L}{\lambda}$$

$$\therefore L_B = \frac{70\lambda}{\theta_{3dB}(E)} = \frac{70*8.57}{42.9} = \underline{13.98mm}$$

The size in H-plane can be calculated from the equation

$$\theta_{3dB} = \frac{60L}{\lambda}$$

$$\therefore L_A = \frac{60\lambda}{\theta_{3dB}(H)} = \frac{60*8.57}{42.9} = \underline{11.98mm}$$

The standard Ka-band wave-guide (WR28) size is:
a = 7.11 mm,
b = 3.56 mm.

To achieve monopulse in azimuth and elevation plane through higher order modes in feed horn, the requirement of L_A is 2*a = 2*7.11 mm = 14.22 mm and L_B is 2*b = 2*3.56mm = 7.11 mm. With these dimensions of L_A= 14.22 mm and L_B = 7.11 mm, the required taper cannot be achieved. Due to the minimum dimension of the monopulse feed with higher order modes the requirement of horn aperture (≈ 14.22 mm + Flare ≈ 25 mm), the ***f/D*** of 0.4 or 0.7 will not be sufficient.

In order to achieve the required taper for the feed horn, beam broadening techniques as discussed in [1] are used in both E and H planes. In one plane, metallic baffles are used and in other plane inward taper is used. The 3D model of such a feed horn is shown in figure 2. To verify the performance prediction, the design is simulated in HFSS 3D electromagnetic software. The simulation results are shown in figure 3.

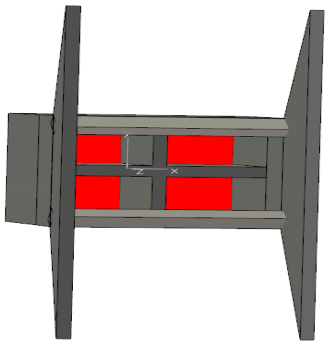

Figure 2. Simulation Model of Ka-band Feed Horn.

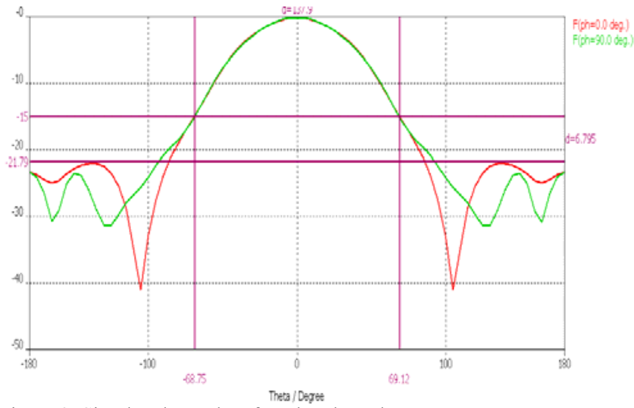

Figure 3. Simulated Results of Ka-band Feed Horn.

III MECHANICAL CONSTRUCTION

The development of Ka-band feed horn mainly through CNC machining and extruding a solid metallic block. Figure 4 shows the mechanically realized Ka-band feed horn.

Figure 4. Mechanically Realized Ka-band feed horn.

IV RESULTS AND DISCUSSIONS

The first prototype Ka-band feed horn has been designed and developed in LRDE. The proto type feed integrated with Ka-band waveguide monopulse comparator has been subjected to electrical parameters tests, such as return loss and radiation pattern using vector network analyzer and far field test setup of Spherical Near Field Measurement (SNFM) facility at LRDE. The measured return loss of sum, azimuth and elevation difference ports are shown in figure 5.

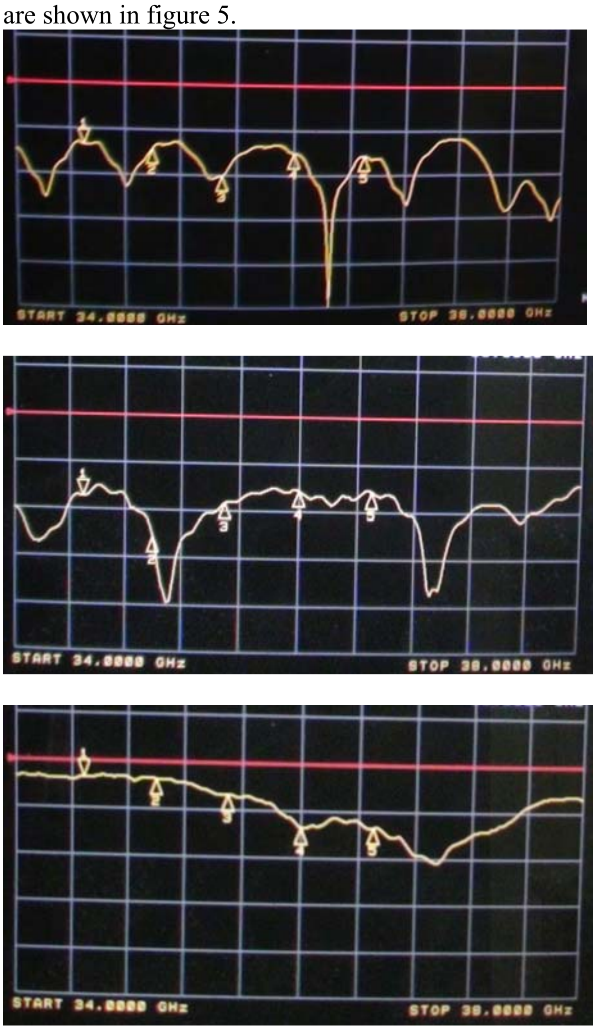

Figure 5. Measured return loss of sum, azimuth and elevation difference ports of Ka-band feed horn integrated with monopulse comparator.

The measured radiation patterns of Ka- band feed horn (integrated with monopulse comparator) in azimuth and elevation plane are shown in figure 6.

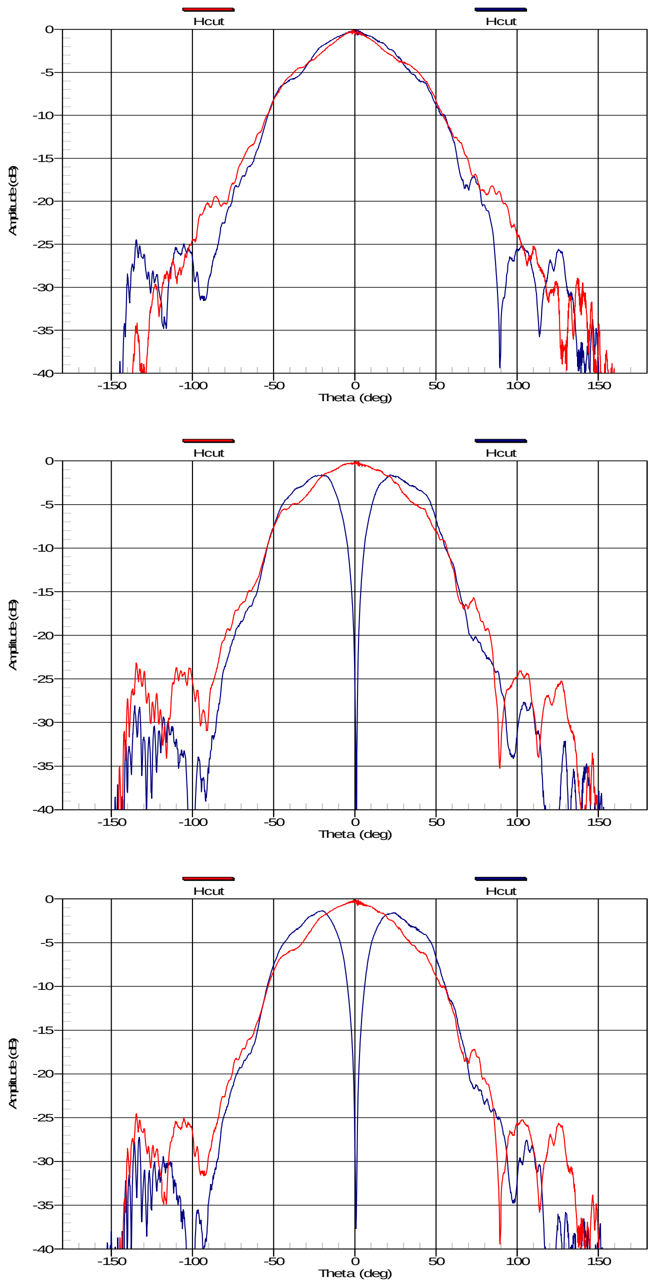

Figure 6. Measured radiation pattern of Ka-band feed horn intergrated with monopulse comparator.

The major design specification goals of -10dB beam width of 78° in azimuth and elevation are achieved over a frequency bandwidth of 1GHz.

V CONCLUSIONS

First prototype Ka-band feed horn with monopulse comparator meeting all design specifications is designed and developed in LRDE. The monopulse comparator feed horn assembly integrated with existing reflector antenna is being tested at far field test range of M/s BEL, Ghaziabad.

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BIODATA OF AUTHOR(S)

S R Tamilarasan received his Master of Engineering degree in Communication Systems from Anna University Chennai in 2012. He joined Electronic and Radar Development Establishment as Junior Research Fellow in July 2012. He obtained his Bachelor degree in Electronics and Communication Engineering from Visvesvaraya Technological University, Belgaum in 2010. He is active member in IEEE for the past three months and also having membership in IEEE Antenna and Propagation Society (IEEE-APS). His field of interest includes Antenna design and Radar System design.

Mohan Kumar K obtained his B.E. degree in Electronics & Communication engineering from the Bangalore University in 2006. In 1998 he joined Electronics and Radar Development Establishment (LRDE) Bangalore, and became scientist in the year 2010. He has got 15 years in the measurement of active and passive antenna array. He is responsible for the Maintenance, Establishments and Up-gradation of Spherical near field measurement (SNFM) facility at LRDE. He has evaluated various antennas in SNFM facility. He is currently involved in design, development, evaluation and calibration of active and digital antenna systems for various kind of Radar. His field of interests includes antenna measurement techniques, RCS measurements, antenna arrays, DBF.

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.

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.