Innovative approach for co-mounted IFF System with Active Phased Array Radar

Subhasis Marndi[1], Rose Abraham[2], Neha Agarwal[3], Sweetlin P[4], Radha M[5], LGM Prakasam[6]
[1, 2, 3, 4, 5, 6] Electronics and Radar Development Establishment, DRDO, C V Raman Nagar, Bangalore
marndi.subha@gmail.com, rosejesmon@gmail.com, nehanith699@gmail.com, prsweetlin@gmail.com
radha.nayak@yahoo.co.in, lgmprakasam@gmail.com

Abstract - The main purpose of the IFF system is to identify the targets detected by the primary radar. Existing active phased array radars the co-mounted IFF system with the primary radar operates only in rotational mode. The staring mode of operation of primary active phased array radar forces the radar designer to operate the IFF system in same mode. IFF in staring modes can achieve variable targets update rates like primary radar. It is a challenging task to realize the integrated IFF system to work in staring mode than rotation mode. This is the first time an IFF system with staring mode is implemented and tested with indigenously developed active phased array radar. This paper describes the design, implementation of various IFF subsystems, then integrated with the primary radar and checked the performance in rotation and staring mode. The IFF system is realized using an indigenously developed Mk XII IFF interrogator and phased array antenna. This paper also describes various test methods used to verify the beam steering after integrating with primary radar. Transition between rotation to staring and vice versa are also checked successfully with primary radar. All the modes of IFF interrogator are successfully verified. The Indian secure mode of IFF is also successfully checked using a cryptographic computer.

Key Words: Active Phased Array Radar, mono pulse comparator, Interrogator, scheduler, IFF, NFTR, Staring Mode, Rotation Mode, ARP, ACP

I. INTRODUCTION

IFF system in surveillance radar is used to identify the target as a Friend or Foe. In traditional passive radar, IFF system will be co-mounted with radar and operates in same rotation mode. In current generation of active phased array radar, the co-mounted IFF system has to operate both in rotation and staring mode. Rotational operation is same as earlier but it is a great challenge for the radar designer to make the co-mounted IFF system to work in staring mode synchronously with primary radar. The electronically-scanned IFF technology matches the primary E-scan radar performance in terms of agility of operation and enhanced angular coverage. Electronic beam steering technology allows the IFF interrogation beam to be steered independently like main radar. The primary radar data processor associates the IFF data with the primary data and sends to radar display with a master ID. The necessary design requirements for an IFF system are briefly explained below:

II. DESIGN CONSIDERATION

The design block diagram of an integrated IFF system with an active phased array radar is shown below (*figure1*). The major systems are Phased Array Antenna, IFF Scheduler, Beam Steering Unit, Interrogator and Radar Data Processor. The major design concerned is the integration and synchronous operational of all the subsystems. The data communication between IFF scheduler, IFF interrogator, Radar Data Processor and Radar display are established through high speed LAN. All control signals interfaces between scheduler, interrogator and antenna are through RS-422 lines. The functional details of each subsystems are explained subsequently.

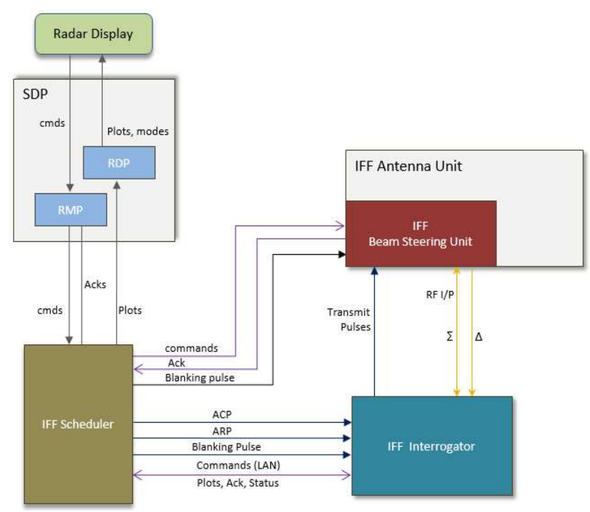

Figure 1: Interface diagram for IFF system in radar.

i. Antenna

The IFF antenna operates in L-band frequency. To operate the IFF in staring mode, it is required to have an active phased array antenna like primary to steer the beam in different azimuth angle. In secondary antenna high power RF digital phase shifters are used to cater the maximum power to get the desire max range. The antenna used in IFF system is a linear phased array antenna to steer the beam only in azimuth. Different IFF antenna parameters gain, azimuth and elevation beam width, directivity, first side lobe level are measured in Near Field Test Range (NFTR). Antenna has a monopulse comparator gives sum and delta outputs and used to compute the monopulse curve. The monopulse curve at bore sight is measured and stored to carry out the azimuth extraction dynamically for every look angle. The dimension of the antenna is kept as small as possible to mount above the primary antenna.

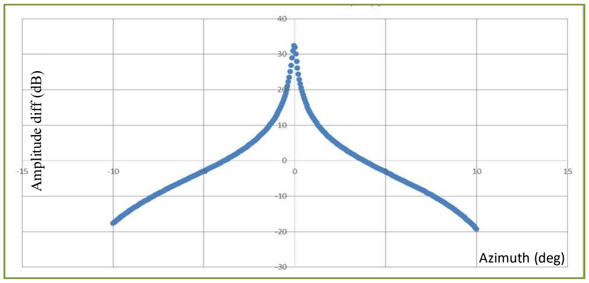

Figure2: Amplitude difference between Sum (∑) and Delta (Δ) outputs.

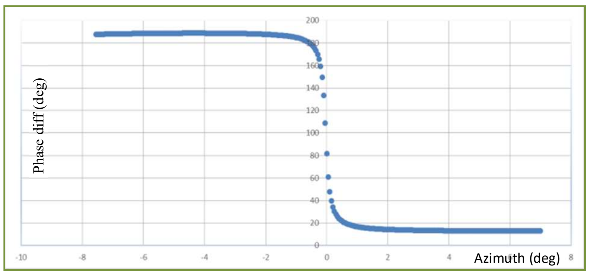

Figure3: Phase difference between Sum (∑) and Delta (Δ) outputs.

Because of beam broadening the monopulse curve is different for each interrogation position. A monopulse correction has to be applied on the current beam position to obtain the required azimuth accuracy for targets and can be performed either at the IFF interrogator or scheduler. A back fill antenna also has been incorporated with main antenna to reduce the effect of back lobe in steering mode. The actual Azimuth position of targets in staring mode is calculated using the below equation:

$$A_{zcorr} = \sin^{-1}(\sin(A_z) + \sin(\Delta A_{zref}))$$

A_{zcorr}: Corrected azimuth in staring mode of operation

A_z: Steering angle of the beam

ΔA_{zref}: Reference angle w.r.t to bore sight

IFF antenna receives the transmit control pulses through the RS-422 lines and RF signals through low loss RF cables from IFF interrogator. The mono pulse comparator inside the antenna generates the sum (∑) and delta (Δ) outputs for every reception and send to the interrogator to extract the information of the targets. Phase matched cables are used for proper monopulse extraction n interrogator. The antenna is placed on a motorized mechanical platform to fold/unfold the antenna and also to change the elevation beam.

ii. IFF Scheduler

The IFF scheduler is designed to be capable of carrying out surveillance function as well as designated mode of operation. In every frame time of primary radar, scheduler ensures the volumetric coverage of air space. It holds the list of search positions and which will be updated in sequential manner. In addition to that user designated targets will be relooked with a defined update time. Feedback from the tracker is used to get the current azimuth of a designated target. Synchronous working of subsystems such as IFF antenna and IFF interrogator is achieved by the IFF scheduler. In addition to that special coverage and designations are ensured by the scheduler. The computation of staring angle for the antenna, as well as the azimuth computation of target also carried out by the scheduler. Phase values for the linear array for a particular staring angle are computed by the scheduler.

$$\Phi = \frac{360 \times dl \times \sin\theta}{\lambda}$$

Φ = phase shift between two successive elements in degree
dl = distance between two radiating elements
ϴ = beam steering angle in degree
λ = wavelength

All the scheduling algorithm are implemented on a power PC board using Vx Works platform and a FPGA board for generation of various control signals.

iii. IFF Interrogator

An indigenous compact liquid cooled IFF Mk XII interrogator with maximum power consumption of 500watt is used for IFF system. IFF interrogator comprises of solid state transmitter with inbuilt modulator, monopulse log receiver with phase detector and G4DSP power PC board for real time computing. The ADCs in digital board receives the sum and delta outputs and converts to digital format. Based on selected mode, control signals and acknowledgement from scheduler, Interrogator generates the RF signal to antenna. For every interrogation, interrogator generates the plots for the targets. The major functionality of the processor are code extraction in different modes, range detection, azimuth and bearing computation, plots centroiding, report generation in interlacing modes and secure mode evaluation. The IFF interrogator is ICAO compatible with mode-S and Indian secure mode 4 and 5. High speed LAN is used between IFF interrogator and scheduler for communication and RS-422 lines to receive various control signals.

iv. Beam Steering Unit

The Beam Steering Unit is a part of IFF antenna system and the beam steering logic is implemented inside the phased array antenna using a FPGA. In rotation mode by default beam is formed in bore sight, hence not required to load phase values to the phase shifters. But in staring mode, it is required to steer the beam and can be accomplished by loading different phase values to the phase shifters. For every position FPGA receives the phase value to be loaded to phase shifters located at the input of each radiating elements for main and backfill antenna. The phase shifters used in design are 6-bit phase shifters. FPGA serially receives the phase values and loads to the phase shifters. After receiving the acknowledgement command from the beam steering logic, scheduler removes the blanking signal and commands the IFF interrogator to start generating the transmitting pulses and RF signals for interrogation. The timing details for rotation and staring mode are shown in *figure 4* and *figure 5*.

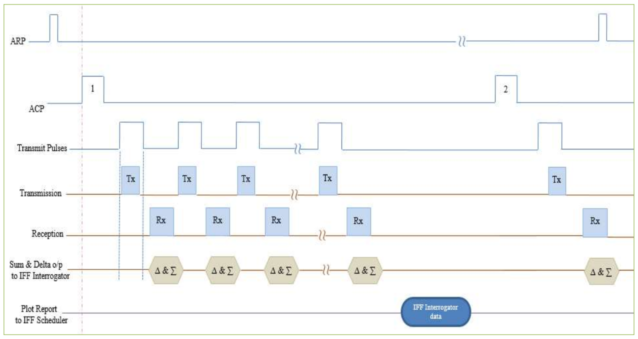

Figure 4: Timing diagram for rotational mode of operation.

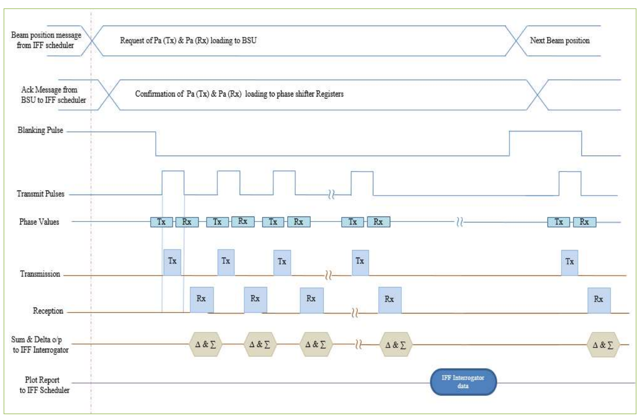

Figure 5: Timing diagram for staring mode of operation.

v. IFF tracking and association with Primary track

The primary Radar Data Processor (RDP) performs the secondary tracking and association with primary tracks in both rotational and starring mode. Secondary tracking are maintained in separate track database with track ID, track status with different mode codes. In rotational mode 360^0 data is maintained with multiple sectors and every sector data is processed with two sector lag. In staring mode data is mapped with corresponding sector of rotation mode and the data is processed immediately after reception. Secondary tracking is based on code match, if there is no code match then association of plot with track is based on distance. Secondary track updating is based on antenna rotation rate. In the beginning secondary track is associated with primary based on distance, then on successive scan primary and secondary is associated with respect to code match. If there is no code match then association is done with distance. Master track ID is assigned based on primary and secondary track life. If the track life of secondary is more, then same master track ID is assigned to primary and vice versa.

III. TESTING AND RESULTS

The testing and integration of IFF system followed a hybrid approach. The functionality of IFF scheduler, Beam steering unit and IFF interrogator are tested separately in lab setup. An IFF Beacon is used generating simulated targets for different modes of operation. The beam steering algorithm was checked with antenna using an IFF Beacon. Integrated testing of co-mounted IFF system along with an active phased array radar is the major challenge. All the subsystems are integrated on radar and command, control and timing flow are tested on the radar with OWS and RDP. The IFF system required to follows the primary radar mode of operation. During the initialization the GPS timing of the radar is send to IFF interrogator and the primary and secondary radars are time synchronized. The associated primary and secondary tracking checked with real time targets for both rotation and staring mode. When the primary radar is switching to staring or rotation mode of antenna the secondary radar system also switches automatically to the same mode. The antenna mode is sensed based on the rotation speed of the radar and IFF will reconfigure by itself to align with the primary radar mode of operation. Once the antenna mode is sensed IFF scheduler will issue required commands to antenna and interrogator, which make the IFF radar to work in synch with primary radar. All the modes of IFF interrogator i.e. Mode1, Mode2, 3/A, Mode C and Mode S are successfully verified in staring mode and rotation mode with live opportunity targets and as well as with dedicated sorties. The Indian secure mode of IFF/Mode 4 is successfully checked using a cryptographic computer. Operation in staring to rotation and rotation to staring are successfully checked with continuous tracking of real time targets. The Continuous Built in Test (CBIT) is implemented in standby and normal modes for the identification of any hardware fault and software error.

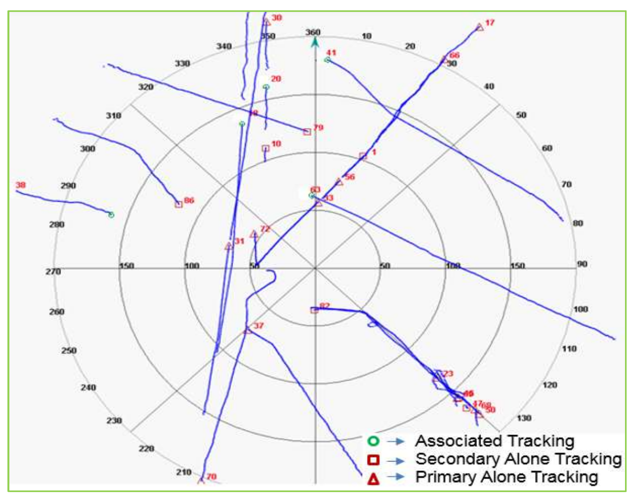

Figure 5: Primary and Secondary associated tracking in rotation mode

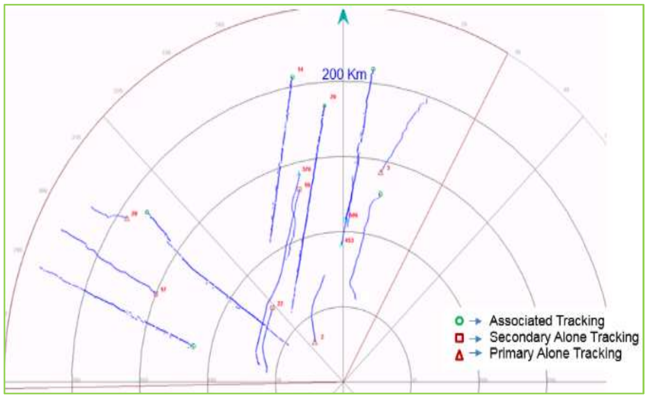

Figure 6: Primary and Secondary associated tracking in staring mode

IV. CONCLUSION

The co-mounted IFF system for an active phased radar is successfully tested and satisfied all the design aspects. The feature of IFF in staring mode operation has increased the capability of surveillance radars. This work also demonstrates the realization of an advanced indigenous IFF system.

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AUTHORS

Subhasis Marndi is working as Scientist in Electronics & Radar Development Establishment (LRDE), Defence R&D Organization (DRDO) Bangalore since Aug 2005. He has completed his BE degree from VSSUT, Sambalpur, Odisha. His work contributions are design and development of various FPGA based digital systems for Active Phased Array Radars. He has also worked in High Speed Printed Circuit Board designing and fabrication and recognized as Advanced Certified Interconnect Designer (CID+) from IPC designer council, USA in 2013. He has received DRDO Technology Group Award in 2009 and 2013.

Rose Abraham completed her B.Tech (E&C) form Calicut University and M. Tech (C&S) from Cochin University of Science and Technology. She received DRDO cash award in the year 2005, "laboratory scientist of the year" award in 2009 and "DRDO award for performance excellence" in 2010 for her contribution for 3D Surveillance Radars. Currently working in the field of Signal and Data Processing systems for active phased array multifunction Radars.

Neha Agarwal has joined Electronics & Radar Development Establishment (LRDE) as a Scientist in 2009. She has completed MTech from NIT, Hamirpur with Gold Medal. Her area of interest is design and development of FPGA based boards for radar systems. She has implemented various interface logic, timing and waveform generation logic, beam steering logic using VHDL for active phased array radar.

Sweetlin P completed her BE degree from Madras University in 2004 with distinction and joined Electronics and Radar Development (LRDE), DRDO as a Scientist in 2008. Her contributions are design and development of Radar data processor for active phased array radar. She has also developed tools for analysis of logged real time data.

Radha M is working as Technical Officer in Electronics & Radar Development Establishment (LRDE), Defence R&D Organization (DRDO) Bangalore since Jan 2003. Her work contributions are design and development of IFF scheduler for Active Phased Array Radars and have designed and developed Graphical User Interface using Visual C++ for configuration and Testing of IFF Interrogator.

LGM Prakasam obtained his M.Tech in ICs & Systems from IIT Madras in 1986 and MBA in Finance Management in 1996 from Annamalai University. He joined Electronics & Radar Development Establishment (LRDE), Bangalore as a Scientist in Dec 1987. Before that he worked as Aero Engineer in HAL for two years. Currently he is leading a team at LRDE for the design and development of an active phased array radar with Digital Beam Forming Technology. He is the recipient of DRDO Scientist of the year award in 2016 and DRDO Agni Award for Excellence in self-Reliance in 2015. He has authored more than 30 research papers in different international / national journals and symposiums.