# A Novel Method of Distributed Computational Approach for Electronic Beam Steering in Multi Object Tracking Radar

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***Abstract:* MOTR (Multi Object Tracking Radar) is an electronically beam steering Active phased array Radar system, operating in L-band, capable of tracking a minimum of 10 targets simultaneously by switching the beam and allocating the defined dwell period among targets. A phased array radar calls for computation of specific phase shift command and simultaneous phase shifter control for each radiating element. This paper aims to bring out the details on the realised digital interface for active array control and the distributed computational approach implemented for achieving electronic beam steering. Distributed approach has been selected to distribute the computational load among multiple computing elements and ensure that the phase shift commands are computed for all radiating elements within the stipulated time period in each measurement cycle.**

***Key Words:* MOTR, Active Phased Array, T/R Module, T/R Unit, Singe Board Computer, Electronic Beam Steering.**

## INTRODUCTION

MOTR has been realised to track multiple targets simultaneously with Radar Cross Section (RCS) of 0.25sq.m up to a slant range of 1000km at 10dN SNR in skin mode of operation. This enables the simultaneous tracking of forwarding moving target and the spent out stages in any launch vehicle mission. MOTR operates in the frequency band of 1.3GHz to 1.4GHz with 860kW peak power with steering capabilities of ±60deg in azimuth axis and ±45deg in elevation axis.

MOTR employs a planar array antenna having 4608 capacitive coupled micro-strip patch antenna elements. Each multi-layer patch antenna is connected to an independent TRM which generates 200W RF power during transmission. Each TRM is, in turn, connected to the RF feeder network which distributes the required RF input power to all TRMs. Linear Frequency Modulated (LFM) Chirp signal is transmitted in to the space at the start of each measurement cycle. A portion of the transmitted signal is scattered back to the antenna from targets, if any. During reception, the reflected signal is picked up by patch antenna and amplified by the low noise amplifier (LNA) inside TRM. The feeder network combines the received power output from each TRM and delivers the combined RF signal to the mono-pulse comparator which generates the sum and difference signals (in both azimuth and elevation channels) for target tracking. After RF-IF down conversion, this signal is further processed in digital receiver, from which signal strength, range and angle errors are estimated. This information is sent to radar data processing system for real time processing involving track initiation and track update.

MOTR carries out tracking of multiple targets simultaneously using a single beam on time sharing basis. The beam is switched among the targets under track using electronic beam-steering technique. This paper explains the details on the realised digital interface for controlling the active array and the distributed computational approach implemented for computing the phase shift commands for all 4608 radiating elements in each measurement cycle (minimum 100µs) in order to realise electronic beam steering in MOTR.

Section-I of this paper explains the active array interface & control configuration for MOTR project. Section-II explains the hierarchy of distributed computations implemented for achieving electronic beam-steering. The hierarchy includes computations in Radar controller, TRU controller and TRM controller. Section-III describes the achieved results and measurements for verification of electronic beam-steering. The conclusion is given in Section-IV.

## I. ARRAY CONTROL INTERFACE

PowerPC processor (MPC8641D) based Single Board Computer (SBC) housed in a VPX chassis is used as the main controlling element (Radar controller) for active array data interface and beam steering computations. The

SBC generates and writes the required commands to XMC FPGA daughter card. XMC FPGA frames the commands in the required formats and transmits them to the active array following a customised serial synchronous protocol at 10Mbps data rate. As per the realised protocol, the control commands are transmitted in the form of gated Clock, serial Data and SOB (Start of Burst) cover Pulse from XMC FPGA to TRUCs and TRMCs. The FO buffer card converts the command data and the control signals in to fibre optic (FO) signals and transmits them to the active array. FO mode of signal transmission is selected because FO signals are immune to electromagnetic interference. 24 numbers of Tile Interface Cards (TIC) are used across the active array for receiving and converting the FO signals in to electrical signals. The control hierarchy is shown in figure.1.

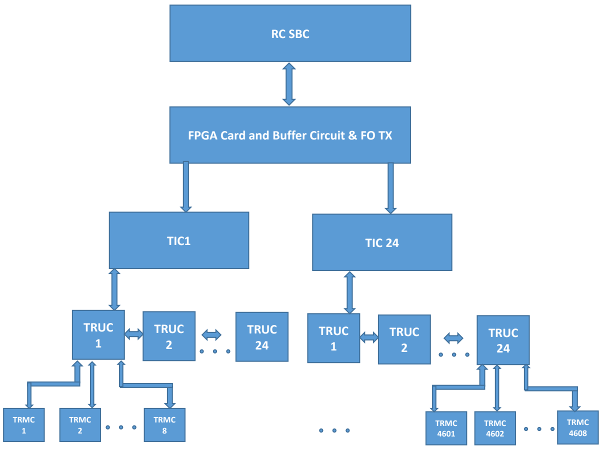


*Figure 1. Active Array control interface*

TIC drives the command and control signals to a group of 24 TRU controllers (TRUC), which are connected in a daisy chain, by following Low Voltage Differential Signalling standard (LVDS) in a multi-drop LVDS configuration. LVDS based signalling standard is selected because the tightly coupled transmission wires reduces the susceptibility to electromagnetic noise interference and common mode noise [3]. LVDS receiver senses the differential voltage between the lines which is not affected by common mode voltage changes.

Each TRUC controls 8 TR modules accommodated in it, based on the received command data & control signals. TRUC transmits the control commands to all 8 TRM controllers (TRMC) or any one of the addressed TRMC based on the addressing mode in the received commands. The control commands are transmitted to TRMC at 10Mbps data rate following LVDS electrical standard. TRMC executes the operations according to the control commands received from TRUC.

## II. DISTRIBUTED COMPUTATIONAL APPROACH

A distributed computational approach, to compute phase shift command of each radiating element, has been implemented involving computations in Radar Controller SBC, TRUC and TRMC for achieving electronic beam steering using the active array. The phase gradients in X and Y directions for a given beam coordinates are computed by the Radar Controller (RC) and broadcasted to the active array. The computation of phase shift commands for 4608 radiating elements is distributed across 576 TRUCs.

Each TRUC computes and transmits phase shift commands to 8 TRMs under its control. TRMC receives phase shift command and carries out the required phase compensation for both transmit and receive operations due to their insertion phase.

### *A. Computation in Radar Controller*

The RC receives the beam coordinates corresponding to next scheduled measurement cycle from the Radar Scheduler and it computes the required phase gradients in X and Y direction in the current measurement cycle. The phase gradients are computed using the following equations [1] where $\lambda$ is the operating wavelength, $d_x$, $d_y$ are the inter-element spacing in X and Y directions and $(\theta,\varphi)$ are the beam coordinates.

$$\psi_x = (2\Pi/\lambda)*d_x*\sin(\theta)*\cos(\varphi) \quad \text{……….(1)}$$

$$\psi_y = (2\Pi/\lambda)*d_y*\sin(\theta)*\sin(\varphi) \quad \text{……….(2)}$$

RC applies a required weighing factor to both X and Y phase gradient values and represents them in required frame format. In each PRT, RC generates beam steering command consisting of phase gradients in X and Y direction and trigger command consisting of PRF, PW and range gate position corresponding to the next measurement cycle.

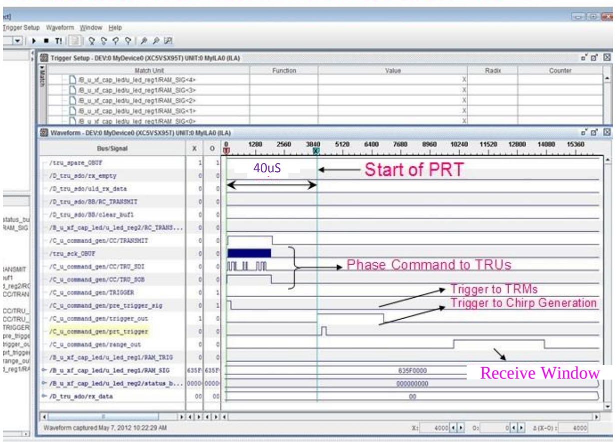


*Figure.2 Transmission of phase gradients to TRUs w.r.t Pre-trigger and Tx trigger*

RC writes the command to XMC FPGA through via 133MHz PCI-X across the PMC connectors. RC creates a device handle for FPGA board and a map which can be used for accessing the resource of block of registers in FPGA. Using the created map, RC performs required number of 32-bit wide write/read operations to/from identified register locations for writing commands/reading status data. XMC FGPA, in turn broadcasts the phase gradient values in X and Y directions corresponding to the next scheduled measurement cycle to the active array.

As shown in figure.2, the phase gradient commands are transmitted to the active array (all TRUCs) with reference to Pre-Trigger which is the starting reference of each PRT. Tx/Rx trigger, which is used for controlling RF transmission and reception in TRM is generated after 40µS from Pre-Trigger. The phase shift commands for all 4608 elements need to be computed and made ready loading in to the phase shifter well ahead of the rising edge of Tx/Rx trigger [4].

***B. Computations in TRU Controller***

A group of 8 TRMs are accommodated in a single unit, known as TR unit (TRU). TRU has a SPARTAN-6 FPGA on-board taking care of computation of phase shift commands and transmission of the control commands to 8 TRMs. TRUC also caters for acquisition of status data and health parameters from TRMCs and transmits to RC SBC based on TRU/TRM specific queries.

Each TRUC is identified with its location in the planar array in terms of its row and column numbers. TRUC has been provided with two 8-way DIP switches which are used for configuring the row and column numbers at which the TRUC is to be positioned. TRUC receives the command frame containing the X and Y phase gradient values and computes 7-bit phase shift command for a TRM at (m,n) location using the following the equation [1].

$$\phi_{(m,\,n)} = m.\psi_x + n.\psi_y \quad \ldots\ldots\ldots(3)$$

TRUC computes the phase shift value and performs modulo-360 operation on the obtained value and represents the resultant value in 7-bit format (in the range of 0 to 127) for each TRM. TRUC performs the above mentioned operations for all 8 TRMs sequentially. After carrying out the computations, TRUC transmits 7-bit phase shift values simultaneously to 8 TRMs at 10Mbps data rate.

***C. Phase Compensation in TRM controller***

TRM has got SPARTAN-6 FPGA on-board, 6-bit digital phase shifter and 6-bit digital attenuator. The TRMC caters for control operations like phase shifter control and transmit/receive path operations. It also monitors the status information like availability of supply voltage, Tx/Rx trigger, power amplifier output status and the temperature inside TRM.

TRMC receives 7-bit phase shift command and performs phase corrections by applying 7-bit phase compensation values stored on-board FLASH memory for both transmit and receive paths respectively. These corrections are performed to compensate the additional phase offsets introduced by the RF feeder network cables, TRM to radiating antenna patch feeding cables and TRM's transmit and receive paths separately.

The compensation values for transmit and receive operations are measured through phase calibration process and they are stored permanently as 7-bit values in the FLASH memory of each TRM. After phase correction, TRMC ignores the LSB in compensated phase shift commands for transmit and receive paths and loads them into the 6-bit phase shifter with respect to Tx/Rx control trigger. The following table summarises the break-up of activities involved in realising electronic beam steering and their distribution among the control elements.

| S.No | Control Element | List of Functionalities |
|---|---|---|
| 1 | RC | ➢ Scheduling of a measurement task in each scheduling cycle and computation of phase gradients for the scheduled beam angles.<br>➢ Transmission of Phase gradients command to the active array (TRUCs). |
| 2 | TRUC | ➢ Computation of TRM specific phase shift commands for 8 TRMs.<br>➢ Parallel Transmission of phase shift commands from TRUC to 8 TRMCs. |
| 3 | TRMC | ➢ Phase compensation to the received phase command using the phase offset values stored on-board FLASH memory. |

**Table 1 List of activities and their distribution among control elements**

## III. RESULTS

The above mentioned computations have been implemented successfully at different levels of the control hierarchy namely, RC, TRUC and TRMC. The phase computations performed in TRUCs are verified by acquiring the phase shift values computed by TRUC (from all TRUs) and comparing the same with the expected phase shift values (computed in RC SBC). Similarly, the arithmetic operations performed in TRMCs as part of TRM phase compensation (both transmit and receive paths) are verified by acquiring and comparing the compensated phase shift commands from TRMCs with similar computations in RC SBC. For a given beam position, the above mentioned verification has been carried out and found that the compensated phase shift commands are matching with that of expected values by half LSB resolution.

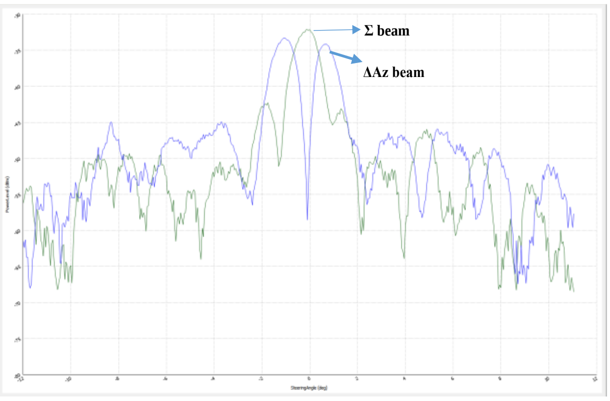


*Figure 3 Measured Antenna Pattern in Receive path through Electronic Beam Steering*

The antenna pattern (receive path) in azimuth axis has been measured by steering the antenna beam electronically in azimuth axis around the broadside by ±12deg. The measured sum and delta azimuth patterns are given in Figure.3 as a function of the offset angle w.r.t broadside. The 3-dB beam-width, sum-delta beams cross over points and the null depth in delta beam are verified and found to be 1.06deg, 1.4deg and 26dB respectively.

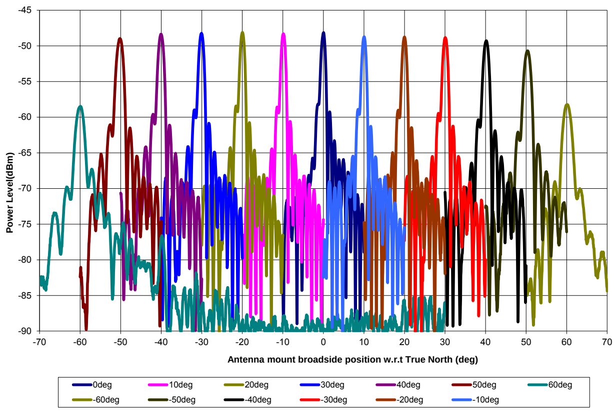


***Figure.4 Measured Antenna Patterns (Azimuth axis) at different positions of Antenna mount broadside***

Similarly, beam steering has been verified by positioning the antenna mount at different azimuth angles and measuring the antenna pattern using a fixed RF signal source. The antenna mount azimuth was positioned from -60deg to +60deg in steps of 10deg w.r.t the fixed RF source and the antenna pattern was measured at each position. The measured antenna pattern profiles are given in figure.4. It is clearly understood from figure.4 that the beam steering is effective and antenna mount offset w.r.t the RF source is reflected in terms of the main beam getting shifted w.r.t the broadside angle (0deg).

The time taken for transmission of command from RC to TRMC through TRUC and computations at RC, TRUC and TRMC and the availability of phase shift commands across all TRMs have also been measured with reference to the start of each measurement cycle. The cumulative time taken is measured to be within 12 microseconds. By means of the above mentioned distributed computational approach, a faster response time has been obtained in computing the phase shift commands for all 4608 radiating elements.

## IV. CONCLUSION

The digital interface for commanding and controlling the active array has been implemented in MOTR active array. The computation of phase shift command and its availability to the TRMC before the start of next measurement cycle has been verified across the active array. With respect to the starting reference in each measurement cycle, the phase shift command is readily available for loading in to the phase shifter within 12μs. This indicates that a lot of time margin (28μs ) is available from the readiness of transmit/receive phase shift commands at each TRM to the instant at which the phase shift command is to be loaded to the phase shifter in a given measurement cycle. The distributed computational approach for electronic beam steering purpose have been implemented successfully and electronic beam steering has been realised in MOTR active array.

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