Grid Selection and Validation for Wide Angle Scanning in Active Phased Array Antenna

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***Abstract* – In this paper graphical design technique is used for designing the geometry of planar phased array antenna to optimise scan loss and minimising the total number of elements.Graphical technique makes it possible to effectively use the space inside the grating lobe boundary by matching the grating lobe boundary and radar scan boundary as closely as possible even for unusual scan requirements. A detailed analysis on grid selection and grid validation for wide angle scanning in active phased array antenna is discussed. By implementing An experimental array with more than 1000 radiating elements for radar applications has been designed, realized and evaluated.Its radiation performance with permissible side lobes is demonstrated by near field test range measurements.**

Keywords: Triangular grid, Phased array, NFTR.

I. INTRODUCTION

Active phased-array antennas for radar applications are currently being designed to provide electronic beam scanning throughout wide angular sectors. In phased array beamforming is the combination of radio signals from a set of small non-directional antennas to simulate a large directional antenna. In active phased array radar each of the radiating elements shall be capable of changing its amplitude/phase and shall able to steer the antenna beam in the desired spatial region. In the design of antenna array, the most important design parameters are usually the number of elements, scan requirements, excitation (amplitude and phase), half power beamwidth, directivity, and sidelobe level [3].In a large aperture electronic scanning antenna array with unusual scan requirements the number of elements; type of grid with proper spacing has to be judiciously chosen for acceptable cost and complexity with useful performance.

II. ACTIVE PHASED ARRAY DESIGN

Electronically scanned phased array radar technology comprising several thousand RF T/R modules and associated RF beamforming is employed in the present generation of high performance military radars. In this paper an active phased array antenna having approximately 1000 elements with scan angle requirements of ± 60^0 in azimuth and 0^0 to 50^0 in elevation is considered. Anactive phased array antenna in S-band using conventional analog Transmit receive (T/R) modules is considered. The analog S-band transmit receive modules are developed based on MMIC (Monolithic Microwave Integrated Circuit) and RF power transistor technology with RF power amplification andLow noise amplification in receive mode. These modules are having MMIC phase shifter for beam formation in transmit and receive mode.

The number of antenna elements, phase shifters, and associated components are extremely large which has direct impact on cost and complexity of the system. If the number of antenna elements can be reduced by spacing them farther apart or in suitable grid configuration, the number of phase shifters and associated components can also be reduced resulting in a sizable decrease in cost and complexity of scanning array.

A. Element Grid Calculation

In active phased array element grid selection depends upon scanning requirements and antenna tilt for optimum operational requirement. Inter element spacing can be further increase or decrease for given scan requirement based on antenna tilt. The selection of the tilt angle for a particular electronic scanning array application involves consideration of following factors; (i) Angular coverage equalization, (ii) Maximum array gain, (iii) Beamwidth management and (iv)Maximize coverage. As per the technical requirements, the antenna is envisioned to achieve scan angle of ± 60^0 in azimuth and 0^0 to 50^0 in elevation. Scan loss equalisation for the requires azimuth scanning requirement is made equal for minimum and maximum elevation angle and array tilt is calculated by equation (1).

$$\theta = cos^{-1}[cosEl\ sin\ Az\ sin\ N_t\ cosT + sinEl\ sinT + cosEl\ cos\ Az\ cos\ N_t\ cosT] \quad \dots\dots (1)$$

Where;

Az, is azimuth scan angle, El, is elevation scan angle, N_t, is angle between true north from antenna bore sight, T is antenna tilt angle between antenna plane and normal [4].

A graphical design technique is used for designing the geometry of planar phased array antenna to minimising the total number of element considering antenna tilt as per equation (1). Graphical technique makes it possible to effectively use the space inside the grating lobe boundary by matching the grating lobe boundary and radar scan boundary as closely as possible even for unusual scan requirements. An additional advantage of the method is that all of the information required determining to optimum tilt angle, element geometry, grating lobe position, element area, and scan losses are contained on single plot [3].

$$k_x = cosEl \sin Az \quad \ldots\ldots(2)$$
$$k_y = sinEl\, cos\, \mathrm{T} - \mathrm{cosEl\ cosAz\ sin\ T} \ldots(3)$$
$$k_x = sinEl\, sin\, \mathrm{T} + \mathrm{cosEl\ cosAz\ cos\ T} \ldots(4)$$

The antenna is required to scan ± 60^0 in azimuth and -5^0 to $+50^0$ in elevation. These angles are in the earth's coordinates with the antenna located at the origin of the coordinate system.Figure 2 shows the same scan limits in the antenna centred sine space coordinate system when the array face is tilted back with tilt angle 'T', to minimise the required off axis scanning. The goals of the design technique are to choose the optimum tilt angle and element geometry to minimise the total number of array elements [4].

The spacing between elements is limited by the formation of spurious beams in the array pattern. To prevent spurious beams from formation, the element spacing must be less than a certain maximum. This maximum element spacing can be determined by examining the array pattern and finding the element spacing at which a spurious beam just begins to form. When the array elements are arranged in a triangular pattern we find that the maximum elements spacing is larger than when the array elements are arranged in a rectangular pattern; and thus fewer elements are needed to complete an antenna aperture when the elements are arranged in triangular pattern [5].

In figure 1 triangularly packed radiating elements for the designed active phased array is shown.

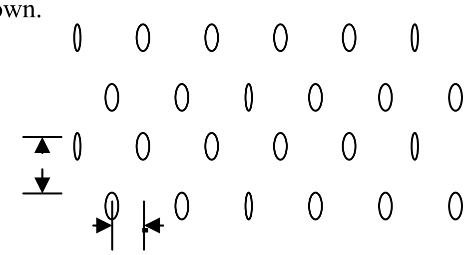

Figure 1Triangularly packed radiating elements in active phased array

The reduction in the number of elements resulting from the use of the triangular array depends upon the region through which the main beam is positioned. If the main beam is positioned within the interior of a cone whose axis is the array normal, the number of array elements can be reduced by 13.4 % by arranging then in a pattern of equilateral triangles instead of square. If the main beam is positioned throughout the interior of a square pyramid whose axis is the array normal, the reduction in the number of elements may vary from 13.4% to 5.7%, depending upon the maximum main beam angular position from the array normal [5].

For triangularly packed array, grating lobes occurs in sine space at

$$k_{xg} = k_{x0} + \frac{p}{2\Delta x}, \quad p = 0, \pm 1, \pm 2 \ldots.(5a)$$
$$k_{yg} = k_{y0} + \frac{q}{2\Delta y}, \quad q = 0, \pm 1, \pm 2 \ldots.(5b)$$

Where p+q is even, the boundary at which these grating lobes form in real space is the unit circle

$$k_{xg}{}^2 + k_{yg}{}^2 = 1 \ldots\ldots(6)$$

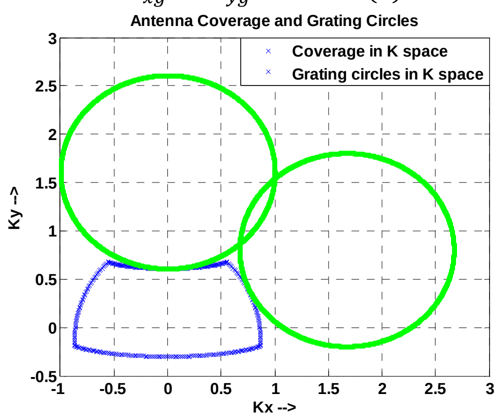

Figure 2 Grating lobe circle passing tangent to radar scan boundary for required scan of active phased array

The green unit circles in above figure 2 are the grating circles next to the real spectrum. The centre of circles will move as the separation between elements changes. The shape shown in blue is required coverage with antenna tilted by 12.5^0. The green circles need to be tangential to the blue coverage so that the grating lobes do not enter the real space when beam is steered to any of the extreme coverage position.

Inter element spacing has been calculated using graphical method for given tilt angle to satisfy required electronic scanning volume.

$$\Delta x = \frac{1}{k_{xg}} \ldots\ldots(6a)$$

$$\Delta y = \frac{1}{k_{yg}} \ldots\ldots (6b)$$

B. Validation of Grid

The region over which the main beam can be positioned without the formation of spurious beam can be determined for triangular elements arrangements using equation (5) and (6). As the main beam positioned away from the normal an angle is reached at which a spurious beam just begins to form in the plane of array. Therefore in order to find the region over which the main beam can be positioned for given element spacing's, one set $sin\varphi = \pm 1$ using appropriate values of p and q. If the centre of the beam is positioned on the boundary of the region, a spurious beam forms completely in the plane of the array. To keep the spurious form forming the peak of the main beam must be kept just inside the boundary by approximately one half the null beamwidth [5].

In figure3 radar scan coverage boundary is shown as rectangle in 2D azimuth and elevation co-ordinates for azimuth scanning ± 60^0 and elevation scanning 0^0 to 50^0 for highest frequency of operation. Figure 3 validates grid selection and shows safe operation of scanned array without spurious beams at extreme scan angles.

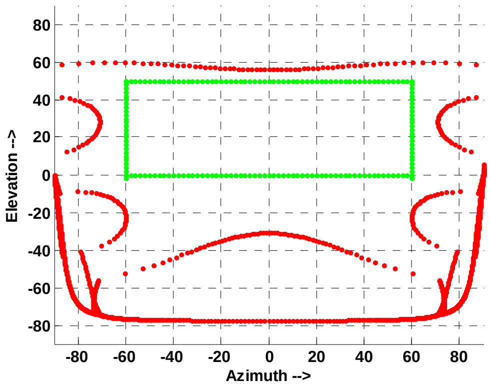

Figure 3 Demonstration of radar scan boundary without spurious beam at the highest frequency of operation

An experimental proto array has been configured with triangular element arrangement which is having more than 1000 radiating elements. Inter element spacing in x is 0.5787λmin and in y is 0.5927λmin as per triangular arrangements of antenna elements without formation of spurious beam in radar scan boundary.In figure 4 a quasi elliptical antenna aperture with triangular element grid arrangement is shown. To validate element grid design for the required electronic scanning various radiation patterns have been simulated for maximum azimuth and maximum elevation electronic scanning. Planar array radiation pattern is simulated by equation (7).

$$AF = AF + amp(m,n) * \exp\left(-jphs(mn) * \exp\left(jk * colspacing.\cos(theta)\sin(phi) * \exp(rowspacing) * \sin(theta) * \sin(phi)\right.\right. - (8)$$

where:

$\boldsymbol{m}$ is no of rows in antenna array, $\boldsymbol{n}$ is no of columns in antenna array, $\boldsymbol{amp}$is amplitude excitation for radiating element, $\boldsymbol{phs}$is steering angle for antenna array, $\mathbf{k = 2\pi / \lambda}$, and $\boldsymbol{\lambda}$ is the wavelength of the RF signal [3].

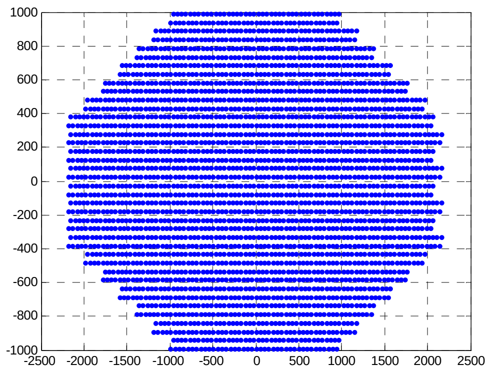

Figure 4 quasi elliptical antenna aperture with triangularly packed radiating

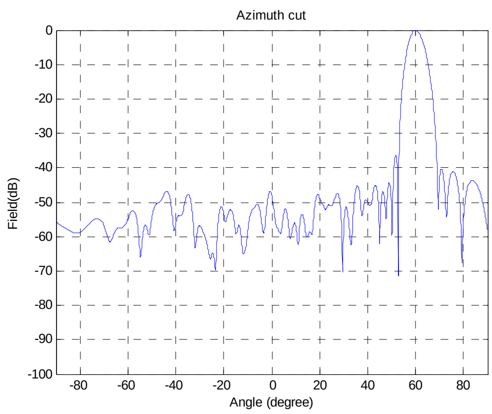

Figure 5 (a) Extreme azimuth electronic scanning at 60^0 to validate element grid

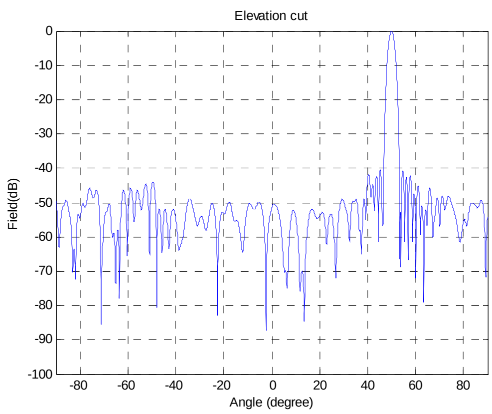

Figure 5 (b) Extreme elevation electronic scanning at 50^0 to validate element grid

Figure 5 (a) and (b) shows simulated extreme electronic scanning for azimuth and elevation radar scanning. These simulated results shows that selected element grid is complying radar scanning requirement without generating spurious beam in the visible region. Since radar operational scenario is with the antenna tilt of 12.5^0, which may not impose extreme elevation angle scan requirement.

III. Wide Angle Scanning Validation in NFTR

Realized active array has been evaluated in near field test range (NFTR) for its performance in terms of beamwidth, directivity, sidelobe level, beam steering and beam pointing error, etc. Near field characterization typically requires measurement of both the amplitude and phase response of the AUT.

Active array measurement has been performed in near field in a rectangular scan area with a sampling interval of less than $\lambda/2$ at 81 points in Y and 121 measurement point in X. Near field measurement is performed by moving NFTR probe at a distance of 5λ from the surface of antenna aperture. During near field measurement NFTR probe is moving at constant speed within scan area, and at each measurement point probe motion controller generated trigger which is utilized for synchronisation of all subsystem of active array.

Near field to far field transformation is performed on measured near field data by analysis tool to calculate measured radiation performance of DBF array. Analysis tool utilizes FFT based algorithm as transformation technique for near field to far filed pattern computation [9].

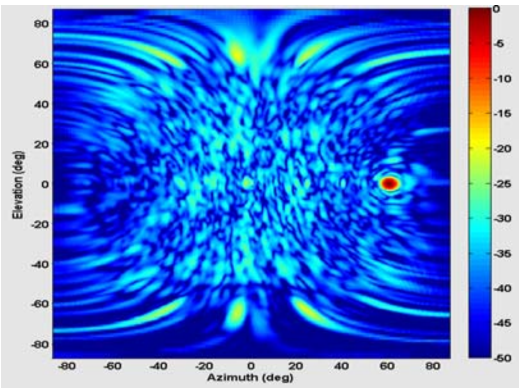

Figure 6 (a) Measured extreme azimuth electronic scanning at 60^0 to validate element grid

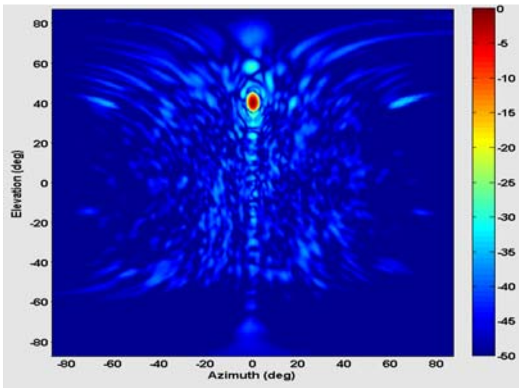

Figure 6 (b) Measuredextreme elevation electronic scanning at 50^0 to validate element grid

In figure 6 (a) shows measured extreme azimuth scanning at + 60^0,and figure 6 (b) shows maximum elevation scanning within near filed test facility constraints. Measured results have been compared with the simulated results for side lobes, beam with, beam pointing error and antenna array directivity.

IV. Conclusion

An active phased array with triangular element grid has been realised and tested in near field test facility for wide electronic scanning in azimuth and elevation. Simulated results are in close agreement with the measured results for the non existence of spurious beam in visible region. Extreme elevation scanning ($+50^0$) could not be measured /validated due to measurement limitation of near filed test range (NFTR). Maximum radar coverage requirement in extreme elevation angle can be met with antenna tilt (for optimised for tilt angle of 12.5^0). Hence optimised antenna tilt and selected antenna element grid can meet wide electronic scanning of ± 60^0 in azimuth and 0^0 to $+50^0$ in elevation for radar system.

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Virendra Kumar, received B.E. in EC in 2003 from K.E.C., Dwarahat, Almora, Nanital University, M.Tech in EC in 2006, from H.B.T.I, Kanpur. He joined LRDE in 2007 as scientist-'B', his current responsibilities include active array aperture and architecture design, development, integration, and calibration of phased array antenna subsystems, primarily in near-field test facilities. He is having seven publication in national and international conferences and symposium, and ten technical reports in his credit. He applied for two software copyrights and two patents.He is recipient of three Technology Group Awards in 2008, 2010, 2012 and 2014 in the field of Active Phased array calibration. He received best paper award in 2009 in ICMARS, Jodhpur, Rajsthan.

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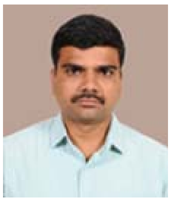

Lenin Naraganiobtained his Master of Engineering degree in 2004 from Osmania University, Hyderabad, India. Since then he has worked for several organizations in the development of various types of Antennas for wide varieties of applications including Defense, space, public safety, personal communication, and telecommunications. Currently he is working as Scientist in LRDE-DRDO, Bangalore involved in development of active phased array antennas. He has co-authored 13 research papers in different international journals and conferences/symposiums.

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.