Modeling and Simulation of Phased Array Antenna for Long Range Tracking and Surveillance Radar

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Abstract:- Radar systems transmit high power to survey long distances, which needs a costly component to handle such a power. Array and phased array antenna can accomplish this purpose with low power component, but with more complexity in design and control. Also tracking radars require antennas with sophisticated beam shape with specific characteristics such as narrow beam width and ability to scan the coverage with high data rate. These requirements lay a great burden on radar system's designer to satisfy the characteristics of surveillance and tracking with one beam. Carefully designed phased array antenna may solve the problem of surveillance and tracking simultaneously, realizing the well-known Track – while- Scan technique (TWS). This paper focused on the issues related to the model, design, and simulation of phased array of dipoles antenna in CST Microwave software. A pencil beam that has 2.1^o half beam power width HBPW that can be electronically steered to scan in elevation plane has been developed and tested against the design requirements. Array antenna gain of more than 34dB and array antenna efficiency more than 98% are achieved from the current design at desired frequency of 1.3GHz.

Keywords:- *Radar Systems, Radar Design, Radar Phased Array Antenna, Tracking Radar.*

I. INTRODUCTION

In radar systems, the antenna has the function to transmit the electromagnetic energy through the medium and collect the reflected energy form a distant target. In order to do the described process in an efficient way, the device should have an appropriate impedance matching, high gain, low sidelobes level, and guarantee a precise angular resolution enough for the application. For that reason, it's almost mandatory to use large aperture antennas, commonly reflectors or large arrays to achieve the mentioned specifications. Array antennas have the capability to steer their beams electronically, avoiding the mechanical wear and making possible the dynamic and efficient beam control, which is one of the fundamental characteristics of modern radar systems.

II. DESIGN PARAMETERS

Phased array antenna design for land based surveillance radar application in L-band (1.3 GHz center) is presented. The choice of L band for long range surveillance radar is due to the facts found by experimentally tests, that it has significant performance advantages in clutter over S-band, also lower frequency makes radars less susceptible to different forms of clutter. Figure1 shows that L- band coverage and detection in 4mm/hour rain almost 3.5 times greater than S-band [1]. Center frequency of 1.3 GHz chosen in the design for the benefit of clutter resistance and good detection range in rainy environment, it's just above the range of Secondary Surveillance Radar (SSR)

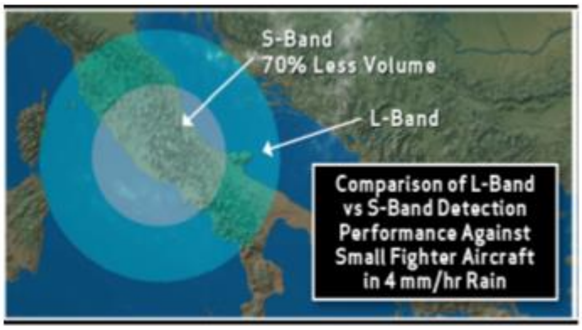


Fig.1:- (L & S) band detection in 4 mm/hour rain operating frequency band. The design specifications are listed in Table 1.

No.	Parameter	Value
1	Operation band	L- band (1.3GHz)
2	Elevation coverage	50^O
3	Azimuth coverage	360^O
4	Radiation Pattern	Pencil
5	Elevation scanning	Electronic
6	Θ_{3dB} (Azimuth & Elevation)	$\leq 3^O$
7	Polarization	Linear horizontal
8	Array dimensions	≤ (8m length, 6m width)
9	Radiation efficiency	At least 0.8
10	Side -lobe levels	≤ -40 dB
11	Gain	> 35dB

Table 1:- Design Parameters.

III. DESIGN PROCEDURE

The single element is selected to be a dipole. Due to the fact that it is simple to design, construct, and well-suited for wireless communication applications. Though they are omni-directions and have poor gain, but when used as array element it has a good behavior regarding surface currents mutual coupling and peak power handling. The gain will be boosted by the array factor and using Yagi- Uda configuration can set an end fire pattern [2]. A dipole with 0.478 λ length, which is the half wave resonant length when operated in free space [3], and a 0.5 λ length reflector 0.25 λ beyond the dipole.

The array antenna design equations used to apply the proposed parameters are:

- The array factor can be given as:

$$\sum_{m=0}^{M-1} e^{-jm(k_0 d_x \cos\theta\cos\emptyset-\emptyset_x)} \sum_{n=0}^{N-1} e^{-jn(k_0 d_y \cos\theta\cos\emptyset-\emptyset_y)}$$

- Number of elements chosen is:

$$M_x X N_y = \frac{1000}{\theta_x X \theta_y}$$

- The gain for the array is given as

$$\text{gain} = \pi.\,N\cos\theta$$

Beside a consideration of other criterion such as beam broaden, scan blindness and mutual coupling. Using Matlab array sensor analyzer, a rectangular array of 52 rows with 24 elements per row are simulated to specify the maximum spacing between rows without the occurrence of grating lobes during the scanning of the main beam. Applying Taylor window with 40 dB sidelobes attenuation for amplitude tapering in both columns and rows. Final acceptable results are listed in Table 2 and Figs.(2a,2b, 3a,and 3b) below. The spacing between elements in rows are chosen to be 0.608λ and spacing between adjacent two rows is 0.606λ.

No.	Parameter	Value
1	Array span	7.16m×3.22m
2	Elements No.	1248
3	Gain boresight	35.41dB
4	Gain scanning	34.79dB

Table 2:- Array Parameters

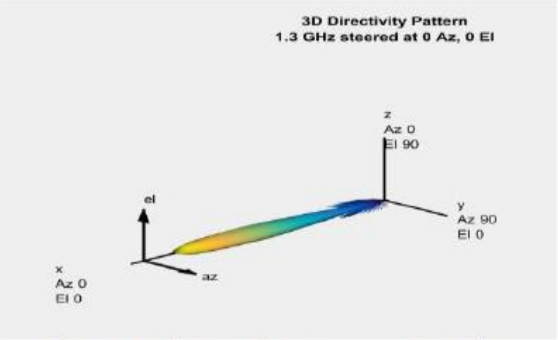
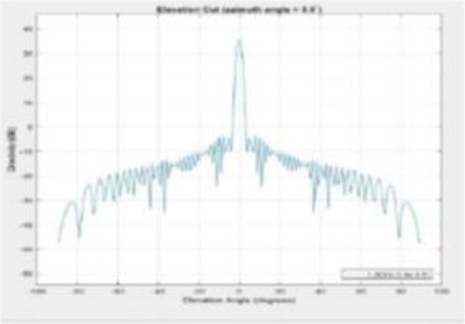


Fig.2.a: Optimum polar pattern non-scanning.



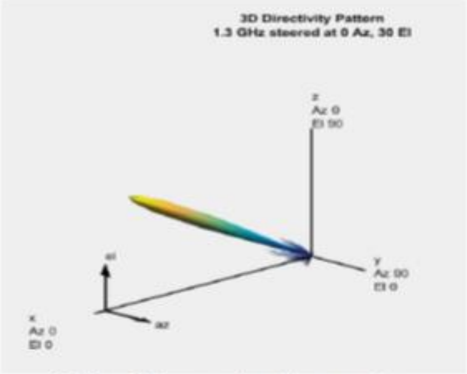


Fig.3.a: Optimum polar pattern scanning.

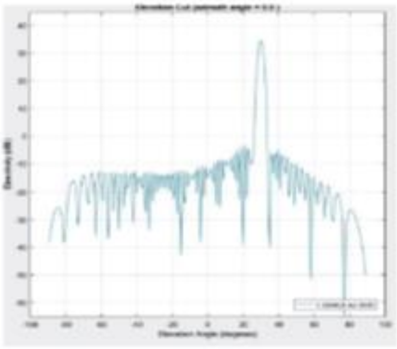


Fig.3.a: Optimum rectangular pattern scanning.

The desired array will be mounted with a 200 angle shifted from a vertical, so with a 200 scanning below the boresight and 300 above it, the desired scanning range can be achieved. Fig. 4 below shows the proposed antenna configuration with mechanical scanning in azimuth direction.

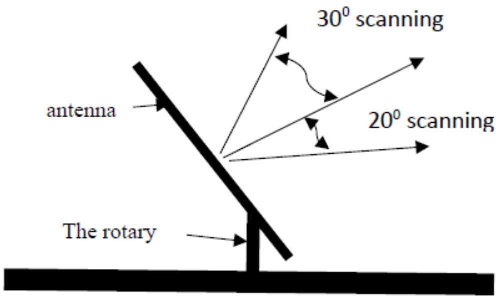


Fig.4: Proposed Design configuration.

ISSN No:-2456-2165

A. Single Element Simulation

To realize the design the thin dipole model considered. The simulated dipole will have a radius of 5mm. This choice of dipole length gives rise to some issues. First, the resonant length of the dipole will decrease as a result of the capacitance effect of the non-zero radius. Secondly, enlarging the radius enhances the dipole bandwidth from 3% up to 30% for the ratio L/D = 200 [4]. The reflector has the same radius as the dipole and with the aid of optimized length of parasitic elements for Yagi antenna [2] its length is set as 0.472λ, positioned 0.2λ beyond the dipole for best front to back ratio. Single element configuration is shown in Fig. 5. Table 3 shows the design parameters of single radiating element of dipole type.

No.	Parameter	Value
1	Reflector length	0.472 λ
2	Reflector position	0.2 λ
3	Feeding gap L/200	≈ 0.5mm
4	Rod radius	5mm

Table 3:- single element CST parameter.

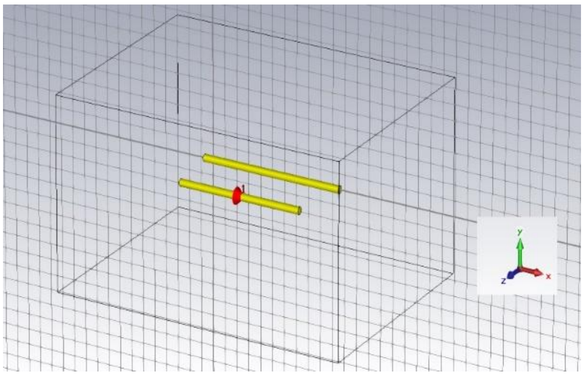


Fig. 5:- Single element configuration.

The excitation signal is a pulse of 0.5 watt shown in Fig. 6. The simulation results and outputs for single element are shown in Table 4 and (figures 7, 8, 9, 10, 11, 12, 13, and 14) below.

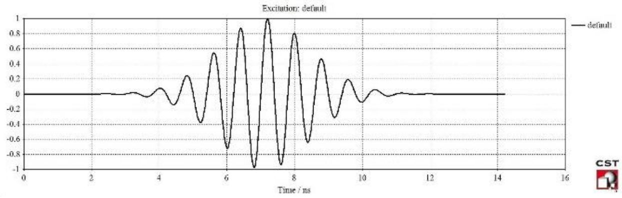


Fig 6:- Excitation signal.

No.	Parameter	Value
1	S-parameter Balance	0.0906
2	S_{11}	-20.8541dB
3	Radiated Power	0.49545 watt
4	Radiation Efficiency	-0.00386dB, 0.9991
5	Total Efficiency	-0.03968dB, 0.99
6	VSWR	1.199

Table 4:- Single element CST simulation Results

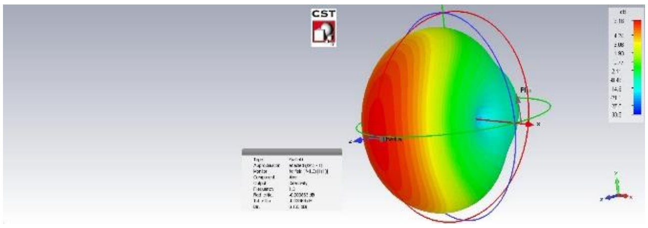


Fig 7:- Single Element 3D Radiation Pattern.

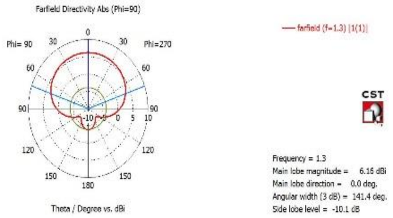


Fig. 8:- Single Element Polar Radiation Pattern.

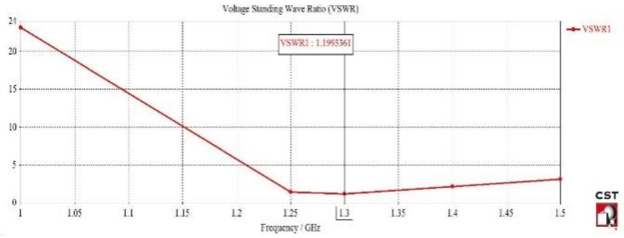


Fig. 9:- Single Element VSWR.

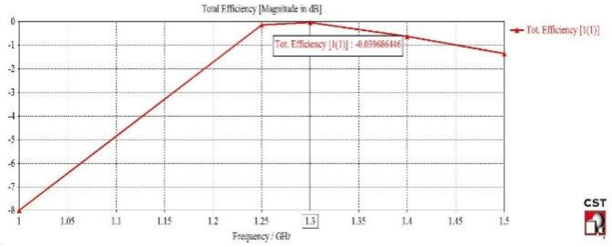


Fig. 10:- Single Element Total Efficiency.

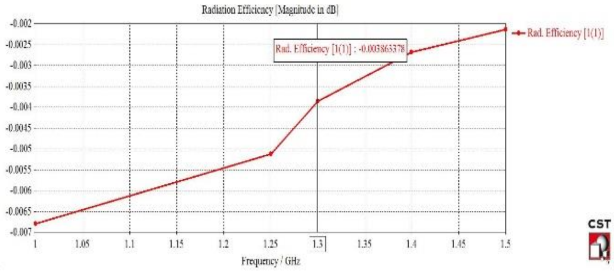


Fig. 11:- Single Element Radiation Efficiency.

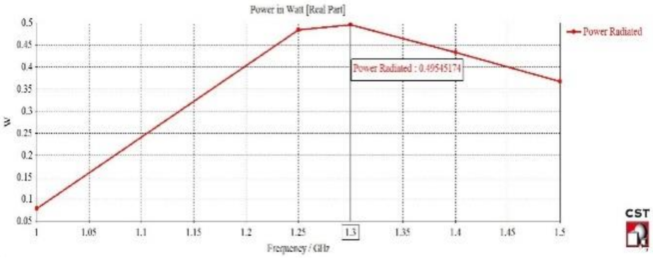


Fig. 12:- Single Element Radiated Power.

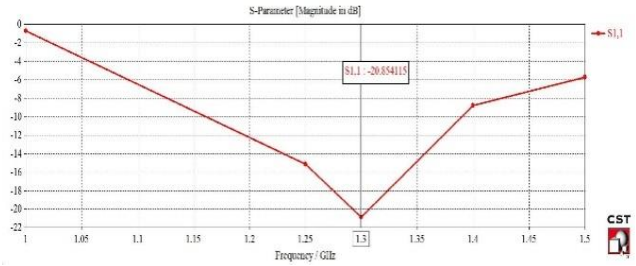


Fig. 13:- Single Element S-Parameter.

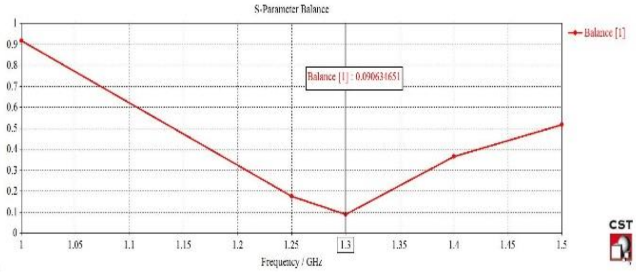


Fig. 14:- Single Element S-Parameter Balance.

The results shows that the element has a gain of 6.16dB, 141.4^{0} HPBW, and -10.1dB sidelobes which is a high value that must be taken into account in array simulation. The approximate bandwidth of this antenna by setting an acceptable VSWR of 1.99, makes the antenna working range from 1.2438GHz up to 1.3919GHz or a bandwidth of 148.07MHz. The total efficiency decreases behind 1.3 GHz. and the radiation efficiency which is shown in Fig. 12 rises as it is computed as a ratio from the antenna accepted power. In the other hand the single element s-parameter (s_{11}) of Fig. 14 and the balanced parameter of Fig. 15 both rises beyond 1.3 GHz.

B. Array Simulation

The full array has been constructed in CST Microwave Studio based on the single element simulated in Section 3.1. The array parameters taken from array antenna design equations and implemented in the software. The design parameters are shown in Table 5.

No.	Parameter	Value
1	No. of rows	52
2	No. of columns	24
3	Grid angle	90 degrees
4	Rows spacing	140mm
5	Columns spacing	140.5mm
6	Dipole length	97.7mm

Table 5:- CST Array Design Parameter

After the simulation dipole length modified to 97.7 to best fit the frequency of operation as the length simulated in single element section gives high values of s-parameters and poor efficiencies. Tayler amplitude tapering has been applied across the array aperture. The same excitation signal used and the time domain transmission line solver (TML) applied. The simulation results are shown in Table 6.

No.	Parameter	Value
1	S- parameters balance	0.2188
2	Radiation Efficiency	-0.02408514dB, 0.994
3	Total Efficiency	-0.23901731dB, 0.946
4	Array Gain	35.95dB
5	Side lobe level	-34.5dB
6	HPBW	2.1degrees

Table 6:- CST Array simulation Results

The results and outputs are shown in Figs. (15, 16, 17, 18, 19, 20,21, 22 and 23) below

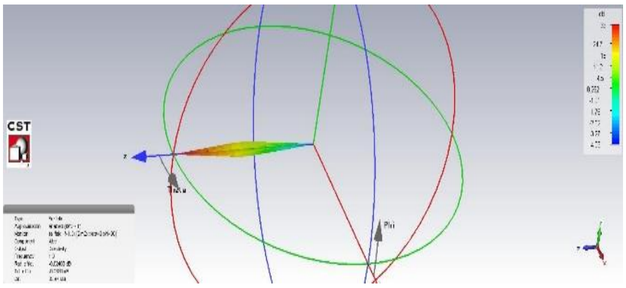


Fig. 15:- 3D array radiation pattern.

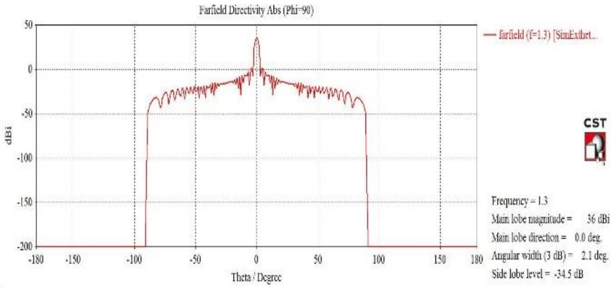


Fig. 16:- Array Cartesian radiation pattern.

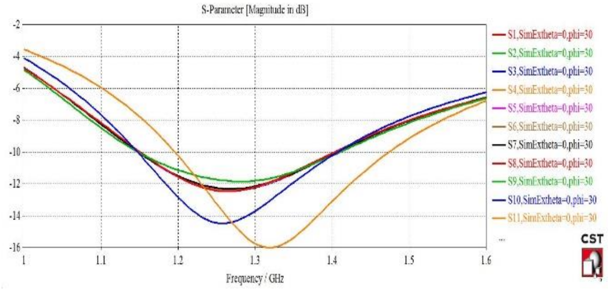


Fig. 17:- Array S-Parameters for all ports.

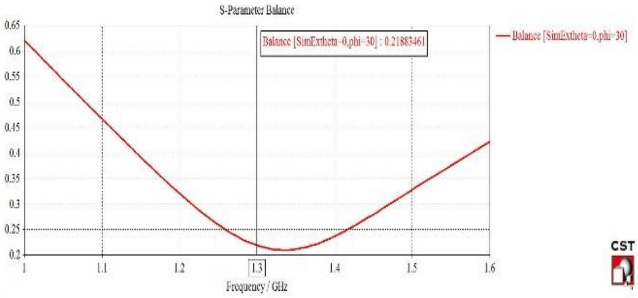


Fig. 18:- Array S-Parameters Balance.

Fig. 19:- Array metallic loss.

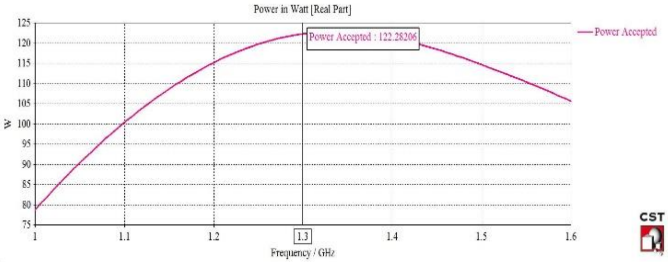


Fig. 20:- Array accepted power.

Fig. 21:- Array Radiated power.

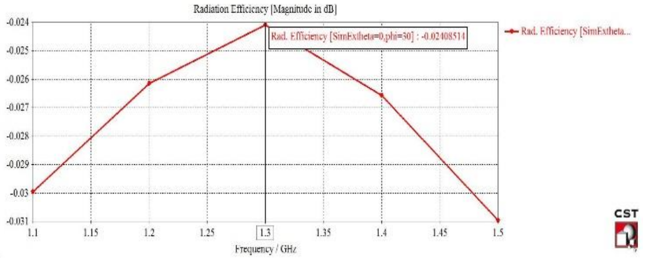


Fig. 22:- Array Radiation Efficiency.

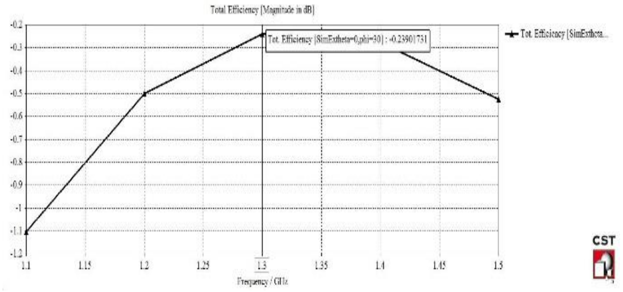


Fig. 23:- Array Total Efficiency.

The gain in CST enhanced due to the use of amplitude taper, the modified formula ($\frac{\sin \pi u}{\pi u}$) of Taylor distribution taper used in the simulation and the array accepted power differ from the expected value of the summation of all ports power due to the Same reason.

As shown in Fig. 19 of array metallic loss the values rise after 1.3 GHz, which is different from single element simulation results due to the mutual coupling between array elements, that results in decreasing of the array radiated power of Fig. 21, the array radiation efficiency of Fig. 22, and the array total efficiency of Fig. 23.

IV. CONCLUSION

All the simulation results show that the dipole phased array performs better than single dipole element. The simulation leads to the conclusion that the number of elements in an array is directly proportional to the efficiency, directivity, and gain of the antenna. If we increase the number of elements in the array, the radiation pattern will improve further.

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