Comparison of Vertical Coverage Diagram for Multi Beams Radar for Different Frequencies and RCS

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Abstract-The primary surveillance radars and secondary surveillance radars in airport applications are generally located in complex environments. Most of the times the airports are located near the mountain regions. These complex environments will have a greater impact on the vertical coverage area. The transmitting frequency, atmospheric attenuation, surface roughness and radar cross section area are the important parameters that alter the radiation pattern characteristics.

The objective of the project is to design and compare simultaneous Multi - beams under complex environments. The objective is accomplished by using a planar array to implement different beam patterns (Pencil beam, Fan beam and Intermediate beam) to have a required coverage area. The variations in the vertical coverage area as a function of transmitting frequency, attenuation, surface roughness, variation in reflection coefficient of the earth surface and radar cross section is also analyzed in this project. The objective of this project is achieved making use of MATLAB software.

Keywords-*component; beam-forming; Radar coverage; smart processor*

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1. INTRODUCTION

Antenna Fundamentals:

Field orientation:

Practically any antenna cannot radiate energy with same strength uniformly in all directions. The radiation from the antenna in any direction is measured in terms of field strength .at a point located at a particular distance from the antenna. The field strength can be calculated by measuring the voltages at two points on the electric line of force and dividing the distance between the two points .units of radiation is volt/meter.

Arrays:

It can be defined as a system of similar antennas directed to get required high directivity is called antenna array. Each radiator is denoted as an element. The elements forming an array could be dipoles, slots in a wave guide, or any other type of radiator . The small radiators acting together with some over all area to produce the effect of an antenna having over all area . The mechanical problems associated with a single large antenna are traded for the electrical problems of feeding several small antennas.

Array Antenna (Planar Type):

It is an antenna in which all the elements are in one plane and it provides a large aperture and it used for changing the relative phase of each element

$$E_x(\theta,\varphi) = \sum_{n=1}^{N} e^{j(n-1)kd_x sin\theta cos\varphi} \qquad (1)$$

Radar Cross Section:. The amount of incident power interrupted by the target and reradiated in the direction of radar is known as radar cross section.

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \left|\frac{E_r}{E_i}\right|^2 \qquad (2)$$

Radar Beam: The movable beam of radio frequency energy produced by a transmitting antenna.

Pencil Beam: A beam of radiant energy concentrated in an approximately cylindrical portion of space of relatively small diameter.

Fan Beam: It is a directional antenna producing a main beam having a narrow Bandwidth in one direction and wider beam width in other dimension.

Intermediate Beam: It is a compromise between fan beam and pencil beam.

Albershiem Equation of Radar Systems:

$$\mathrm{A} = \log\left(\frac{0.62}{\mathrm{P_{FA}}}\right) \qquad \mathrm{B} = \log\left(\frac{\mathrm{P_D}}{1-\mathrm{P_D}}\right) \qquad (4)$$

$$\chi_{1,\mathrm{N}} = -5\log_{10}\mathrm{N} + \left(6.2 + \left(\frac{4.54}{\sqrt{\mathrm{N}+0.44}}\right)\right)\log_{10}(\mathrm{A} + 0.12\mathrm{AB}+1.7\mathrm{BDB} \qquad (5)$$

Vertical Reflection Coefficient: The amount of energy reflected back vertically is called vertical reflection Coefficient.

$$\Gamma_V = \frac{\varepsilon \sin\varphi_g - \sqrt{\epsilon - \left(\cos\varphi_g\right)^2}}{\epsilon \sin\varphi_g + \sqrt{\epsilon - \left(\cos\varphi_g\right)^2}} \qquad (6)$$

Atmospheric Attenuation:

Electromagnetic waves travel in free space without suffering any energy loss. Alternatively, due to gases and water vapor in the atmosphere radar energy suffers a loss. This loss is known as the atmospheric attenuation. The two-way atmospheric attenuation over a range R can be expressed as

$$L_{atmosphere} = e^{-2\propto R} \qquad (7)$$

Radar Range Equation:

The radar equation shows the inverse proportionally of the square root of transmitting frequency with the maximum range that follows

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 B F_n (SNR)_{0min} K T_e}\right)^{1/4} \qquad (8)$$

Where: Pt: transmitted power(watts), G:antenna gain, λ:wavelength, $\boldsymbol{\sigma}$:radar cross section(RCS), S_{min}=minimum detectable signal(watts), K=kelvins boltzmann's constant, $T_{e=}$effective Noise temperature. $F_{n=}$Noise figure B=Bandwidth of the Intermediate frequency amplifier

The maximum range is proportional to the 4th root of the RCS σ . If we assume that allother parameters are constant are constant and is given by ; $R_{max} \propto^{1/4} \sqrt{\sigma}$
(9)

Also the relation between the maximum range and the transmitting frequency if we assume all other parameters are constant is given by ;

$$R_{max} \propto {}^{1}\!/\!_{\sqrt{F}} \qquad (10)$$

Which means that by increasing the transmitting frequency , the maximum range is decreased accordingly. The increasing f transmitting frequency will increase the atmospheric attenuation due to this equation :

$$\alpha_{db} = K_1 . P \qquad (11)$$

Where P is the perception rate mm/h and K1 is a function of the wave length from which it may be expressed analytically as :

$$K_1 = 0.00274\,\lambda 2 - 0.042408\,\lambda + 0.149679 \ (12)$$

2. NON- COHERENT &COHERENT INTEGRATION GAIN

2.1 Coherence:

A signal is said to coherent when it is having constant phase difference and same frequency and it also describes the properties of correlation between physical quantities of a single wave.

2.2 coherent integration gain:

It is the effect obtained by increasing the length of a time during which a coherent signal is observed and it is known as coherent integration gain.

2.3 Non coherent integration gain:

It is the effect obtained by averaging together signal estimates taken during successive time slices, each having the same, fixed length is known as non coherent integration gain.

3. PHASED ARRAY ANTENNAS

3.1 DIRECTIVITY, POWER GAIN, AND EFFECTIVE APERTURE

Radar antennas can be characterized by the directive gain G_D , power gain G , and effective aperture A_e . Antenna gain is a term used to describe the ability of an antenna to concentrate the transmitted energy in a certain direction. The directivity of a transmitting antenna can be defined by

$$G = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} \qquad (22)$$

The radiation intensity is the power per unit solid angle in the direction (θ, φ) and denoted by $P(\theta, \varphi)$. The average radiation intensity over 4πradians (solid angle) is the total power divided by 4π . Hence, above equation can be written

$$G_D = \frac{4\Pi(\text{maximum radiatedpower}/\text{ unit solid angle})}{\text{total radiated power}} \qquad (23)$$

$$G_D = 4\pi \frac{P(\theta,\phi)max}{\int_0^{2\pi}\int_0^{\pi} P(\theta,\phi)d\theta d\phi} \qquad (24)$$

3.2 NEAR AND FAR FIELDS

The electric field intensity generated from the energy emitted by an antenna is a function of the antenna physical aperture shape and the electric current amplitude and phase distribution across the aperture.

Consider a radiating source at point O that emits spherical waves. A receiving antenna of length d is at distance r away from the source. The phase difference between a spherical wave and a locally plane wave at the receiving antenna can be expressed in terms of the distance δr . The distance δ r is given by

$$\delta r = \overline{AO} - \overline{OB} = \sqrt{r^2 + \left(\frac{d}{2}\right)^2} - r \qquad (25)$$

and since in the far field $d \ll r$, Eq. (4) is approximated via binomial expansion by

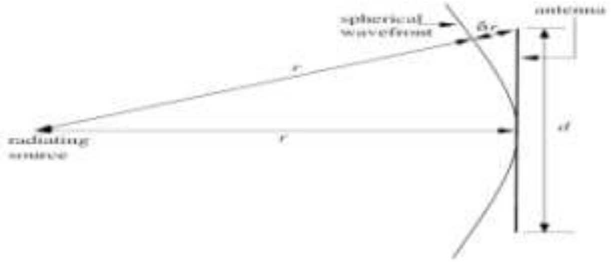


Figure 3.1 Construction for far field criterion.

$$\delta r = r\left(\sqrt{1+\left(\frac{d}{2r}\right)^2}-1\right) \approx \frac{d^2}{8r} \tag{26}$$

It is customary to assume far field when the distance δr corresponds to less than 1/16 of a wavelength (i.e.,22.5^0). More precisely, if

$$\delta r = d^2/8r \leq \lambda/16 \tag{27}$$

then a useful expression for far field is

$$r \geq 2d^2/\lambda$$

(28)

Note that far field is a function of both the antenna size and the operating wavelength.

4. SIMULATION OF RADAR COVERAGE

A. Simulation of radar coverage

The software package which is used in the present work is C++ and Matlab programming languages and modified to construct the simultaneous Multi-Beams radar coverage. Also the new radar performance is tested and examined for different RCS and different transmitting frequencies. The probability of detection (P_d) is taken to be 80% and the probability of false alarm (P_{fa}) is taken to be 10^-6 for both conditions.

5. RESULTS OF BEAM SHAPING TECHNIQUES

The simulation package is used to create 3 different coverage of the 2D search radar as Explained before, which are: Intermediate, fan and pencil beams. For this study, the outputs of beam Forming network for this radar are examined for different radar cross sections and different Transmitting frequencies.

A. Results of beam shaping techniques

The same package is modified in order to study the RCS effects in different beam coverage in addition to changing the transmitting frequency from 900 MHz to 1300MHz for the same RCS of 2 s.q.m . Two RCS parameters are used 2 s.q.m and 5 s.q.m.

B. Radar Cross Section and TRANSMITTING FREQUENCY

1 $2\ m^2$ RCS:

By considering this case, the radar cross section is taken and is simulated for small size of target which is $2m^2$.The frequency transmitted is 900MHz, the P_d id 80% and the P^{fa} is 10^-6. Figure (1,2,3) shows the intermediate, pencil and fan beam respectively when the RCS-2s.q.m. Also fig.[13] shows the results of 3 coverage obtained in this work, Fan, pencil and intermediate beam . The coverage area of pencilbeam gives 162.27 km, with maximum height of 56.83 km. While the fan coverage has a maximum range of 85.17km, and the maximum height is 88.87 km . For the intermediate coverage, the maximum range 129.57 km and the maximum height is 59.81km. It is obvious that the maximum range of the Pencil coverage is greater than of the fan and the intermediate coverage . But the fan coverage has maximum height of 88.87 km which is greater than that of the pencil and intermediate coverage.

TRANSMITTING FREQUENCY=900MHz

By considering this case the three coverage are obtained where the transmitting frequency is 900MHz and the radar cross section is 2sq.m, the P_d=80% and the P_{fa}=10^-6. The results obtained for this case are shown in fig (13) . the maximum range for the case of pencil coverage is 162.27 km, while the maximum range for the case of fan coverage is 85.17 km, and it is increased to 129.57 km for the intermediate coverage case.

Case(i) vertical coverage diagram for pencbeam at900MHZ;RCS=2Sq.m

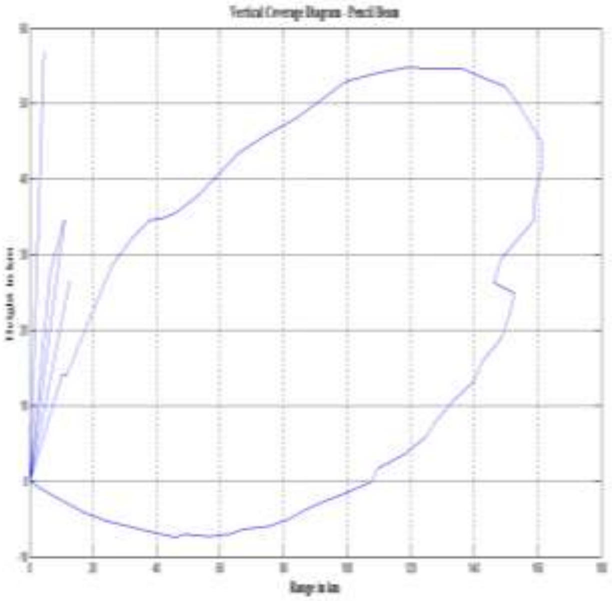


Fig.1

Case (ii) Vertical Coverage Diagram for Fan Beam at900MHz; RCS = 2Sq.m

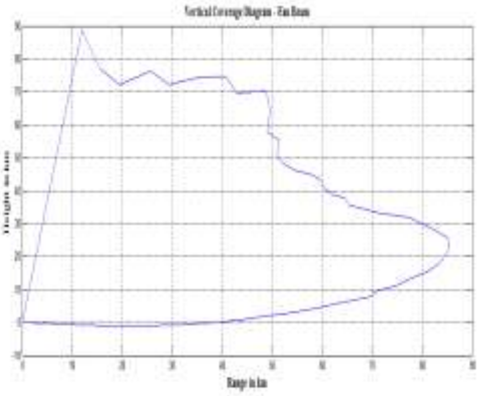


Fig .2

Case (iii) Vertical Coverage Diagram for Intermediate Beam at 900MHz; RCS = 2Sq.m

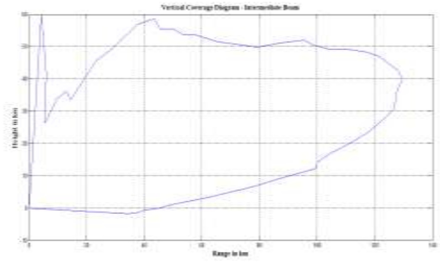


Fig.3

2. <u>**5m^2 RCS:**</u> By considering this case, the radar cross section is taken to be simulated for theIntermediate target which is equal to 5sq.m. The radar parameters are the same as in that of 2sq.m where the transmitting frequency is 900MHz, P_d=80% and P_{fa}=10^-6. The results for this case are shown in figures 4, 5 and 6 of the different beams, intermediate beam coverage, pencil beam coverage and fan beam coverage respectively, and it gives different maximum ranges and heights for different coverage. For the pencil coverage, the maximum range is increased to 207.75 km and the maximum height is 78.56 km which is greater than that obtained when the radar cross section is 2sq.m.

Also for the fan beam coverage, the maximum range is 111.59 km, and the maximum height is 102.44 km, but in the case of the intermediate coverage the maximum range is measured to be equal 165.42 km and the maximum height is 79.56 km. It is that the intermediate coverage has intermediate maximum range which is equal to 165.42 km which is less than the 267.75 km maximum range for the pencil beam coverage case greater than the 111.59 km maximum range which is obtained for the intermediate coverage is intermediate between the pencil and fan beam coverage, the maximum height in the intermediate coverage is 79.56 km which is greater than that obtained for the pencil coverage which is 78.56 km and smaller than that obtained in the fan coverage which equals to 162.44 km.

Case(i) Vertical Coverage Diagram for Pencil beam at 900MHZ;RCS=5Sq.m

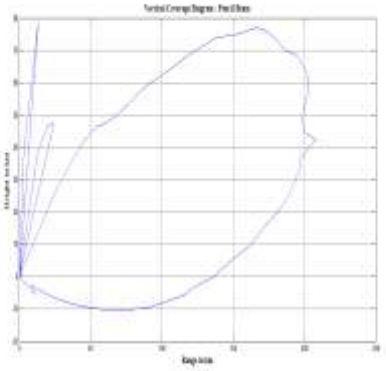


Fig.4

Case (ii) Vertical Coverage Diagram for Fan Beam at 900MHz; RCS = 5Sq.m

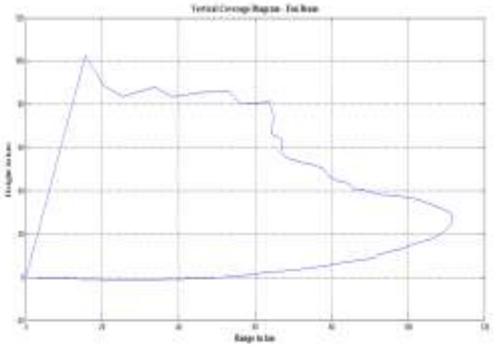


Fig.5

Case (iii) Vertical Coverage Diagram for Intermediate Beam at 900MHz; RCS = 5Sq.m

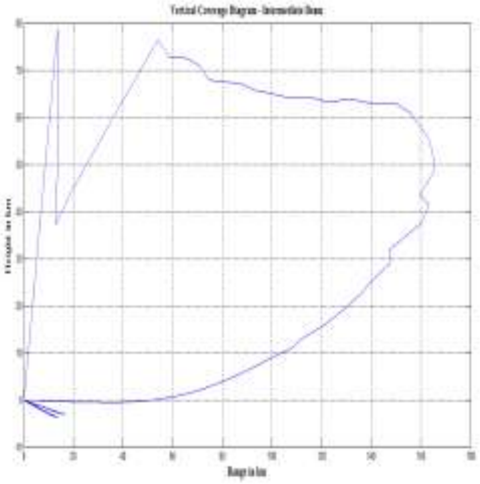


Fig.6

TRANSMITTING FREQUENCY=1300MHz

By considering this case the transmitting frequency is changed to be equal to 1300MHz, and the three beams together are shown in fig 16. The radar parameter are the same as that mentioned for the frequency 900MHz, i.e., the radar cross section is 2sq.m, the P_d=80% and P_{FA}=10^-6. The maximum range for the pencil coverage is 136.51km which is smaller than 162.27 km when the frequency is 900MHz, also the maximum height in the pencil coverage is 45.46km which is also less than 56.83 km when the frequency is 900MHz. for the fan coverage case, the maximum range is 70.22 km which is also smaller than the 85.71km for the case when 900 MHz was used. The maximum height is reduced in this case to 75.01km , because it was 88.87km when the frequency was 900MHz. also, the maximum range in the case of the intermediate coverage is reduced to 110.02km instead of 129.57km using frequency of 900MHz. The maximum height becomes 48.96km when the frequency is 1300MHz and it is smaller than 59.81km when the frequency is 900MHz . for this case of transmitting frequency =1300MHz, different beams are obtained as shown in fig 15 for RCS=2sq.m, and fig 16 for RCS=5sq.m.

SL NO	BEAM	TRANSMITTING FREQUENCY	RCS	HEIGHT (km)	RANGE (km)
1	PENCIL	900MHZ	2Sq.m	162.27	56.83
2	PENCIL	900MHZ	5Sq.m	207.75	78.56
3	PENCIL	1300MHZ	2Sq.m	136.51	45.40
4	PENCIL	1300MHZ	5Sq.m	170.86	60.5
5	FAN	900MHZ	2Sq.m	85.17	88.87
6	FAN	900MHZ	5Sq.m	111.59	102.44
7	FAN	1300MHZ	2Sq.m	70.22	75.01
8	FAN	1300MHZ	5Sq.m	89.35	93.76
9	INTERMEDIATE	900MHZ	2Sq.m	129.57	59.81
10	INTERMEDIATE	900MHZ	5Sq.m	165.42	78.65
11	INTERMEDIATE	1300MHZ	2Sq.m	110.02	48.96
12	INTERMEDIATE	1300MHZ	5Sq.m	139.13	72.06

Case(i) Vertical Coverage Diagram for Pencil Beam at 1300MHz; RCS = 2Sq.m

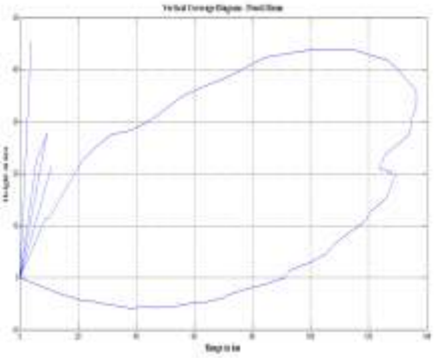


Fig.7

Case (ii) Vertical Coverage Diagram for Fan Beam at 1300MHz; RCS = 2Sq.m

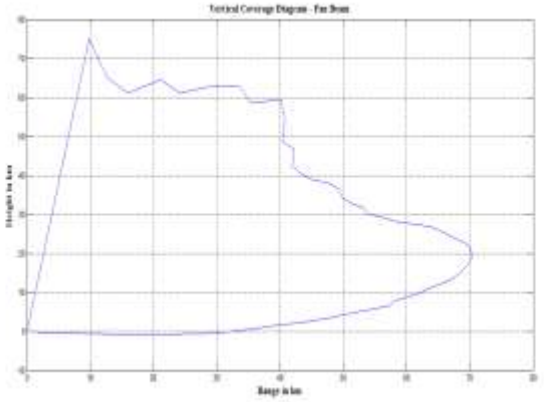


Fig.8

Case (iii) Vertical Coverage Diagram for Intermediate Beam at 1300MHz; RCS = 2

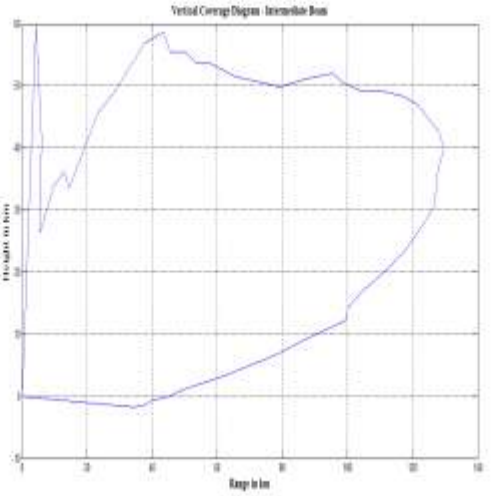


Fig.9

Case(i) Vertical Coverage Diagram for Pencil Beam at 1300MHz; RCS = 5Sq.m

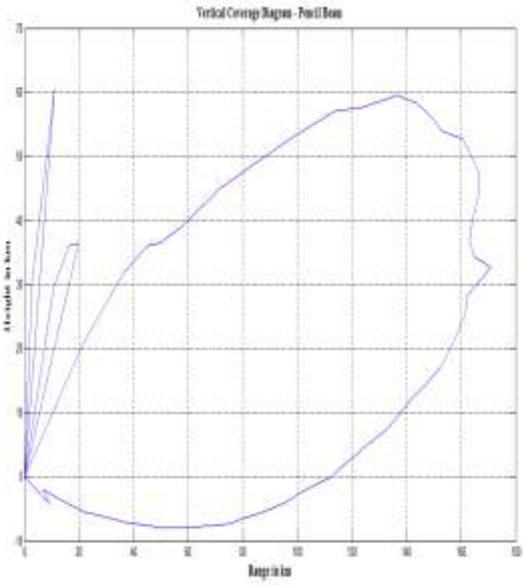


Fig.10

Case (ii) Vertical Coverage Diagram for Fan Beam at 1300MHz; RCS = 5Sq.m

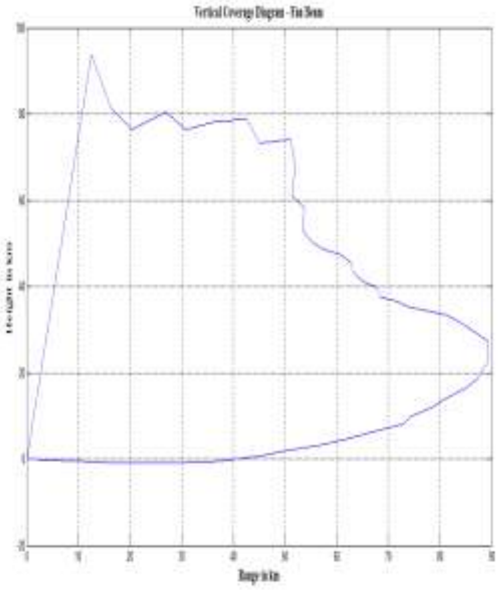


Fig.11

Case (iii) Vertical Coverage Diagram for Intermediate Beam at 1300MHz; RCS = 5Sq.m

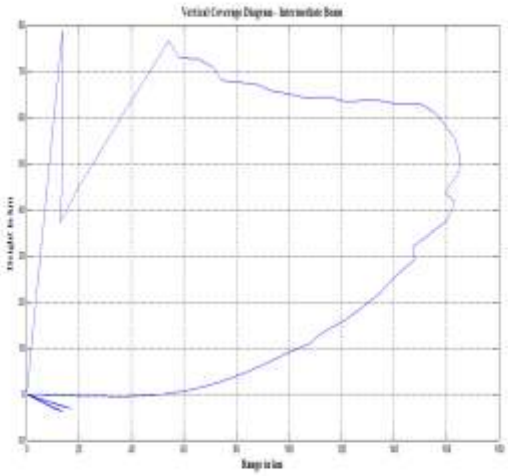
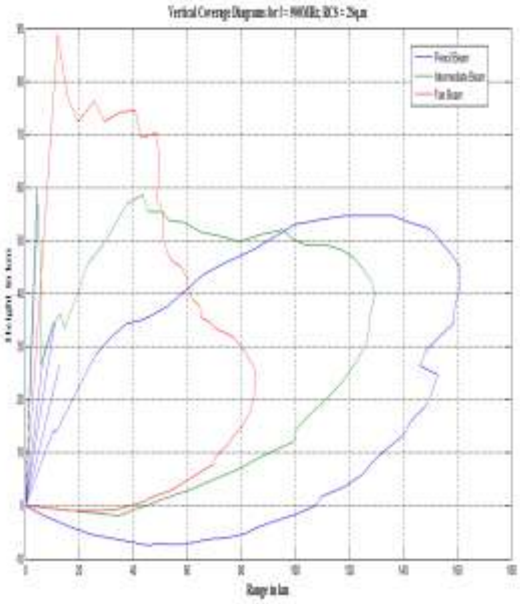


Fig.12

Comparison plots

Case (i) Vertical Coverage Diagrams for 900MHz; RCS = 2Sq.m



Case(ii)Vertical Coverage Diagrams for 900MHz;RCS= 5Sq.m

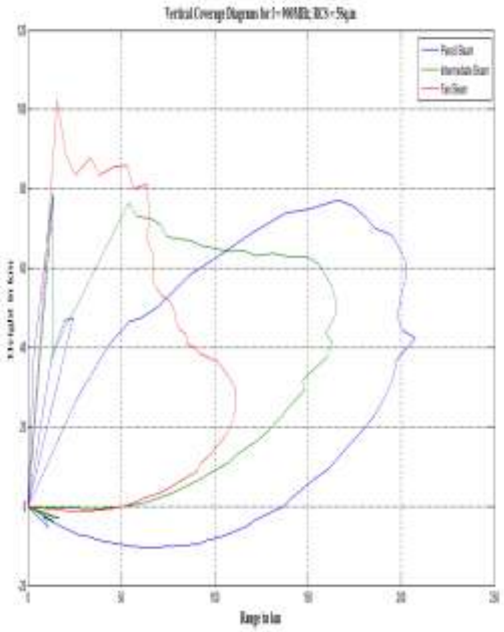


Fig.14

Case (iii) Vertical Coverage Diagrams for 1300MHz; RCS = 5Sq.m

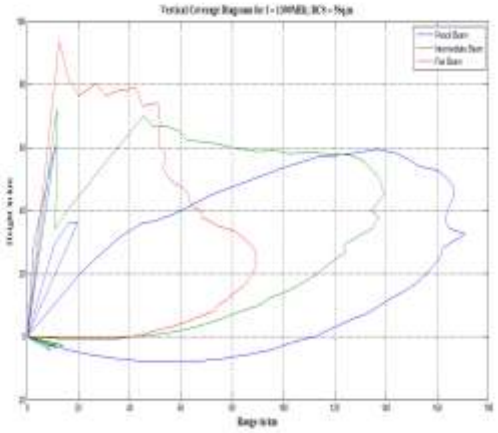


Fig.15

Case (iv) Vertical Coverage Diagrams for 1300MHz RCS = 2Sq.m

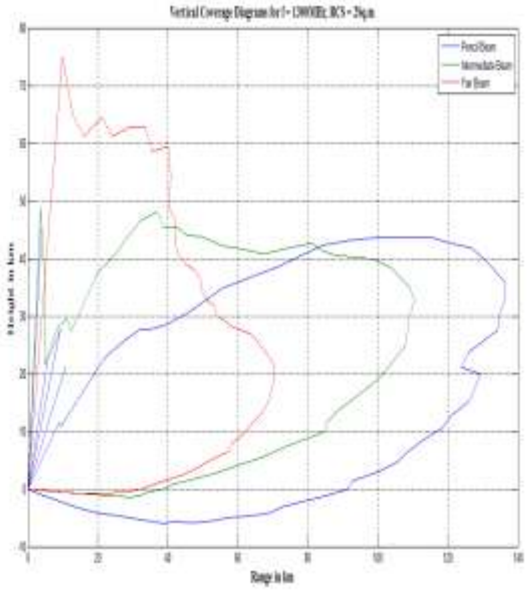


fig.16

6. Conclusion And Future Work

In this using planar arrays different types of radar beams Pencil beam, Fan beam, Intermediate beam are designed. These beams are scanned to cover a specific area using phase control. Here linear phase is added to have scanning characteristics.

Simulation results showing all the three beams (Pencil, Fan and Transmitting) with their Vertical coverage areas at f = 900MHz and RCS = 2Sq.m. Results concludes that the fan provides good detection characteristics at higher ranges and its corresponding altitudes. The fan beam provides good detection characteristics at higher altitudes at low ranges. The intermediate beam covers the higher altitudes of medium ranges. By varying operating frequency and RCS characteristics the vertical coverage areas are observed. From the results it is observed that as the RCS increases the area of vertical coverage increases. It is also observed that with increase in the operation frequency the area of vertical coverage decreases.

The features for this study are used in designing the primary surveillance radar and the secondary surveillance radar of the civilian airports especially in complex terrain and environment like mountains

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