ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 4, Issue 9, September 2015

Beam Steering of Antenna Array of Radar using Progressive Frequency Shift in Excitation

Mr. Vikas Kumar Sahu, Prof. Ravi Mohan, Prof. Rahul Koshta

Abstract— **Beam Steering is one of the most important sections in efficient working of any radar. Electronic beam steering has been the most successful scheme so far in radar. Electronic scanning can be implemented in three ways: phase scanning, time delay scanning and frequency scanning. Phase shifters play a vital role in establishing beam steering using electronic scanning. However phase shifters like ferrites, TWT, delay line etc are narrowband systems. Thus we propose to provide steering of beam without the use of phase shifters, hence eliminating the problems associated with it. The new scheme investigated in this thesis is based on pattern control of antenna array by controlling the excitations of each element with any use of phase shifters. This concept of controlling the beam using excitations of elements has been first derived in the form of equations and then the same is simulated using MATLAB. Conceptually, time, range and angle dependent electronic scanning is achieved by introducing progressing small frequency shifts among the antenna elements. The simulation results for the same are obtained and verified.**

Index Terms— **Antenna Array, Beam Steering, Electronic Scanning.**

I. INTRODUCTION

Radar is one of the most important technologies that we have in our hands because of its wide range applications in military as well as civil areas. Researchers have been working continuously to improve its performance and upgrade its various sub-sections. Beam-steering is a very significant parameter of radar which determines the performance of the Radar. In this thesis, a new method based on changing the frequency; has been introduced and successfully simulated.

Traditionally mechanical beam steering was used which was soon replaced by electronic scanning. Electronics scanning was a revolutionary change because of its obvious advantages like increased data rate, instantaneous positioning of the radar beam, and elimination of mechanical errors, beam agility, multi-mode operation and simultaneous multi-target tracking.

Phase shifters play a vital role in electronic scanning but at the same time put limitations on Radar. Thus the main focus in this work is to eliminate the phase shifters from beam steering part of Radar and researches the applications of frequency diverse arrays and explores its potential capabilities.

II. FREQUENCY SCANNING

The outstanding feature of frequency scanning is that it is a means for providing inertialess beam scanning, which in comparison with other inertialess scanning techniques is economical, relatively simple, and reliable. This is extremely desirable in modern radars that have as performance objectives the rapid detection and accurate position measurement of multiple targets at widely different positions, including cases where the targets have high velocities and acceleration and hence require rapid updating.

So far, the widest application for frequency scanning has been found in the fields of air surveillance and aircraft control. Radars for these applications have been advantageously designed and produced with, in most cases, antennas mechanically rotated in azimuth and frequency scanned in elevation to provide three-dimensional aircraft position data. Many other configurations have been conceived to cover a relatively broad spectrum of applications ranging from such diverse fields as airborne surveillance and mapping, mortar shell detection, and aircraft landing precision radars [12].

To establish the basic technique of frequency scanning, consider an electromagnetic wave of frequency f propagating through a transmission line of length l with a velocity of v. The electromagnetic wave experiences a phase shift as follows:

$$\phi = kl = \frac{2\pi}{\lambda} l = 2\pi \frac{f}{v} l \qquad (1)$$

Therefore, a change in the frequency of the electromagnetic wave propagating at constant velocity along the transmission line introduces a phase shift as seen in Equation (1). In this manner, it is possible to get an electronic phase shift (ψ) relatively easy compared to other methods. Frequency scanned arrays mostly use equal length series feed structures to very simply introduce linear phase across elements. Since no phase shifting devices are required, there is no insertion loss due to phase shifters. The series feed arrangement is illustrated in Figure 1

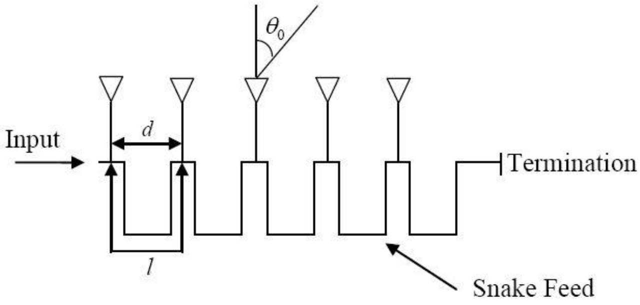

Fig.1 Series–fed, Frequency Scanned Linear Array

Manuscript received Sep 05, 2015.

Arvind Kumar Sahu, *Department of Electronics and Communication.*
Prof. Ravi Mohan, *Department of Electronics and Communication, Shriram Institute of Technology*
Prof Rahul Koshta, *Department of Electronics and Communication, Shriram Institute of Technology.*

If the beam is to point in a direction θ_o, the phase difference between elements should be $kd\sin\theta_o$. In frequency scanned arrays, usually an integral number of 2π radians is added. This permits a scan angle to be obtained with a smaller frequency change. Equating phase difference to phase shift obtained from a line of length l gives Equation (4).

$$\frac{2\pi}{\lambda} dSin\,\theta o + 2\pi m = \frac{2\pi}{\lambda} l \tag{2}$$

$$Sin\,\theta o = -\frac{m\lambda}{d} + \frac{l}{d} \tag{3}$$

When $\theta_o = 0^o$, which corresponds to the broadside beam direction, Equation (2) results in $m = l/\lambda_o$, where λ_o corresponds to the wavelength and f_o is the frequency at the broadside direction. Using this information, Equation (3) can be rewritten as:

$$Sin\,\theta o = \frac{l}{d}\left(1 - \frac{\lambda}{\lambda o}\right) = \frac{l}{d}\left(1 - \frac{fo}{f}\right) \tag{4}$$

If the beam is steered between $\pm\theta_1$, the wavelength excursion $\Delta\lambda$ turns out to be:

$$Sin\,\theta 1 = \frac{l}{2d}\frac{\Delta\lambda}{\lambda o} \tag{5}$$

An examination of Equation (4) shows that as the frequency is changed, one beam after another will appear and disappear, with each beam corresponding to a different value of m [3]. As the delay gets larger in the transmission line compared to the spacing of the elements, one can change the beam-pointing angle more rapidly as a function of wavelength. For this reason, in frequency scanned arrays usually tapped delay lines or slow wave structures are used, which may be folded, helically wound, or dielectrically loaded in form.

With antennas having such a delay line, the beam-pointing angle can be made to be an accurately controlled function of RF frequency. Volumetric aerial coverage can be obtained in radar systems using these antennas by radiating an orderly progression of sequentially generated transmitter signals, each at a different RF frequency [12]. This concept is illustrated in Figure 2. Beamwidths typically range from 0.5^o to 5^o in the frequency scanned plane. Angular coverage provided by frequency scan ranges from as low as 10^o to well over 90^o and is commonly achieved with frequency bands of between one and ten percent of the carrier frequency [12].

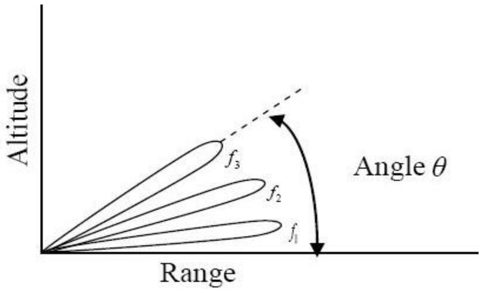

Fig.2 Frequency Scanning

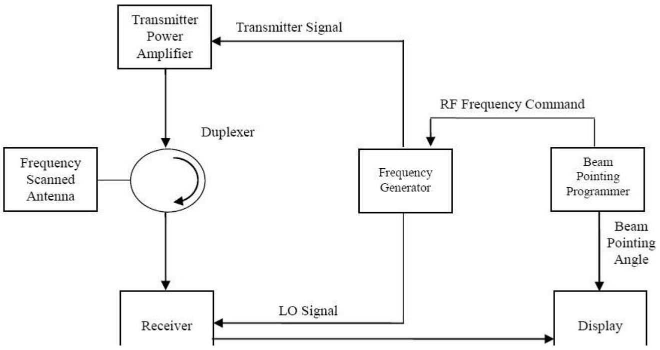

Fig.3 Block Diagram for Frequency Scanning

III. ANTENNA ARRAY CONFIGURATION FOR BEAM STEERING

A. *Concept*

This type of array configuration is different from the traditional arrays used for beam steering in radar. In this array, different type of waveforms can be given to the array elements. However to keep it simple we have given same type of waveform for each element. The most important difference of this type of array from a conventional array is the introduction of small amount of shift in frequency in contrast to the conventional use of phase shifters. With the introduction of this frequency shift, the electric field of the antenna array turns out to be function of range, time and angle. Range-dependent beam forming is of importance because one can get local maxima at different ranges, and this can be used for multiple target detection with the use of advanced signal processing techniques, although the range ambiguities might be a problem.

B. *Theory*

Assume that the waveform radiated from each antenna element is identical with a frequency increment of Δf Hz applied across the elements. In a conventional array (see Figure (4)), the phase shift due to the path length is defined by

$$\psi = \frac{2\pi}{\lambda} d\,Cos\theta \tag{6}$$

where angle θ defines the direction of the target from the axis of the array. The concept of a frequency shift in array excitation is illustrated in Figure 4.

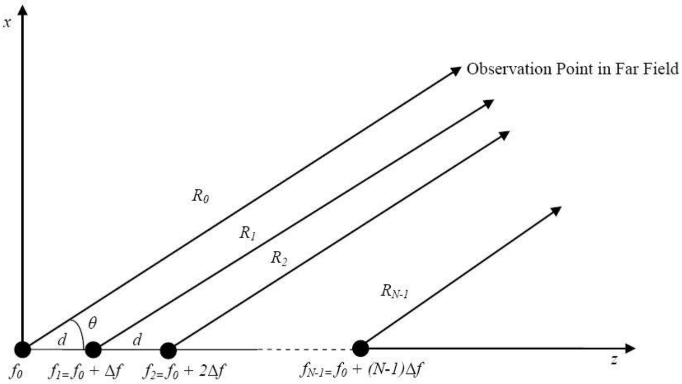

Fig.4 Array Configuration with shift in Frequency

The phase of the signal arriving at element zero, which is located at the origin of the coordinate system shown in figure 4 is

$$\psi = \frac{2\pi}{\lambda} R = \frac{2\pi f}{c} R \qquad (7)$$

where f is the frequency of the waveform radiated from element zero and R is the path length between the element and the far-field observation point. Similarly, the phase of the signal arriving at element one can be written as

$$\psi 1 = \frac{2\pi f1}{c} R1 = \frac{2\pi(f + \Delta f)}{c} (R - d\ Cos\ \theta) \qquad (8)$$

It is very clear from the above equation that excitation phase of the antenna array elements is now a function of frequency shift and the range. As the wave will change with time, the radiation pattern will also be a function of time.

C. Simulation Results

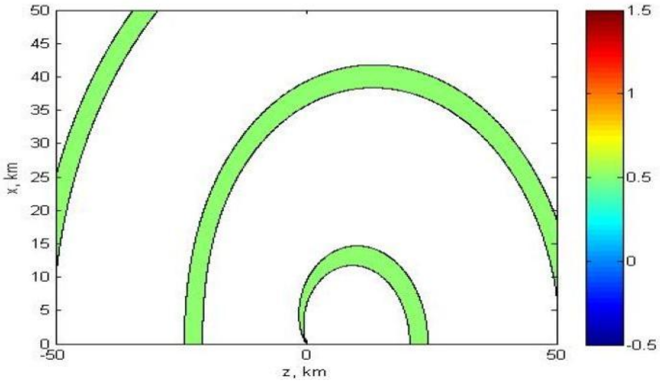

Fig.5 Normalized Radiation Pattern of the FDA for Time Instance t = 200 μsec

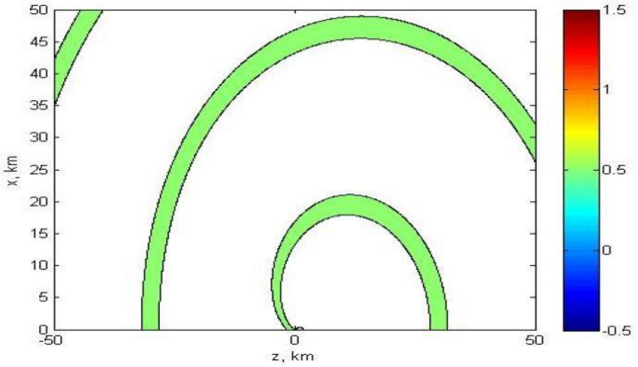

Fig.6 Normalized Radiation Pattern of the FDA for Time Instance t = 225 μsec

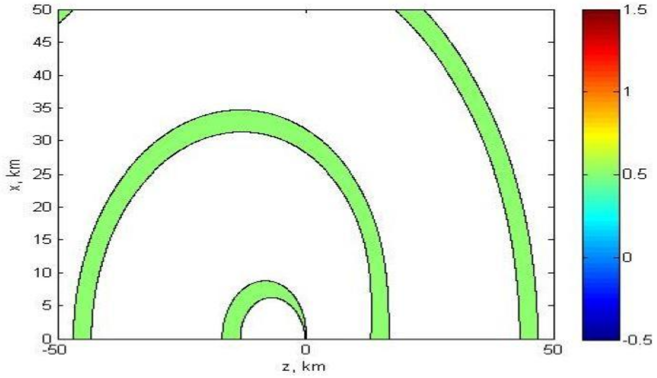

Fig.7 Normalized Radiation Pattern of the FDA for Time Instance t = 250 μsec

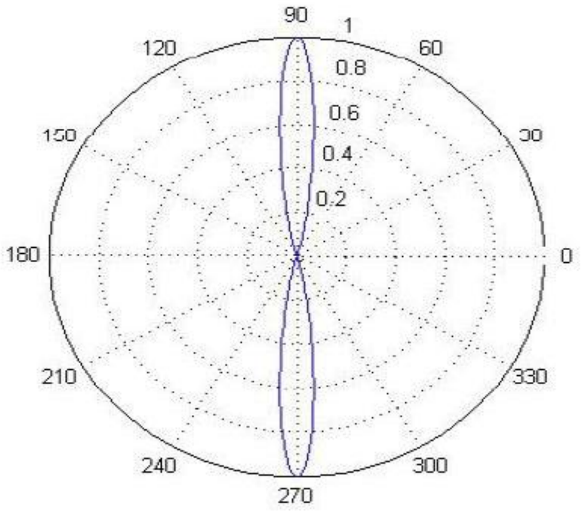

Fig.8 Polar Plot of the Normalized Radiation Pattern at Range R = 30 km and t = 200 μsec for Angle θ where φ = 0

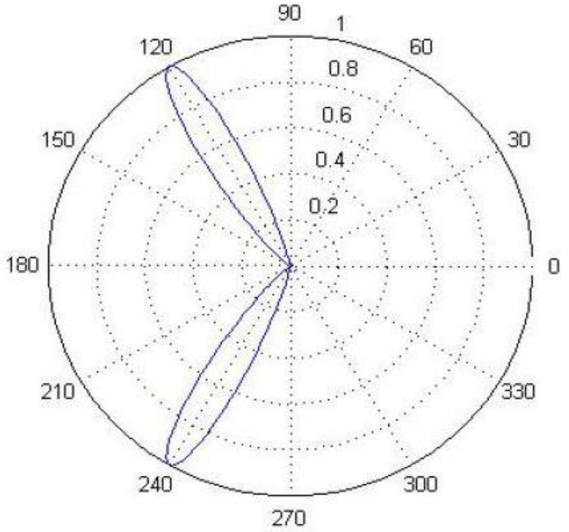

Fig.9 Polar Plot of the Normalized Radiation Pattern at Range R = 30 km and t = 225 μsec for Angle θ where φ = 0

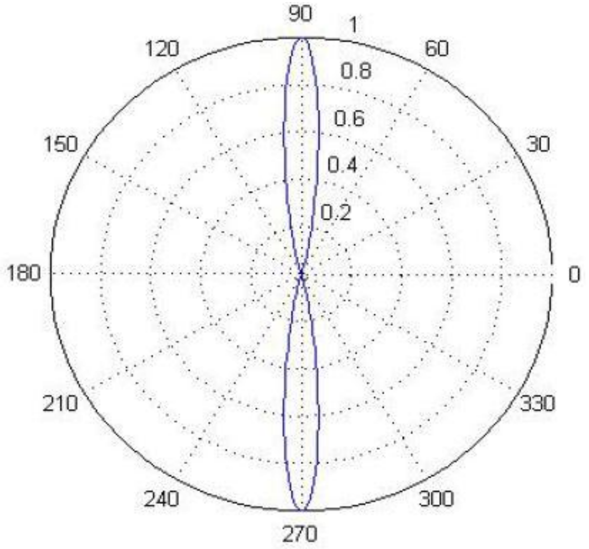

Fig.8 Polar Plot of the Normalized Radiation Pattern at Range R = 30 km and t = 200 μsec for Frequency Decrement where φ = 0

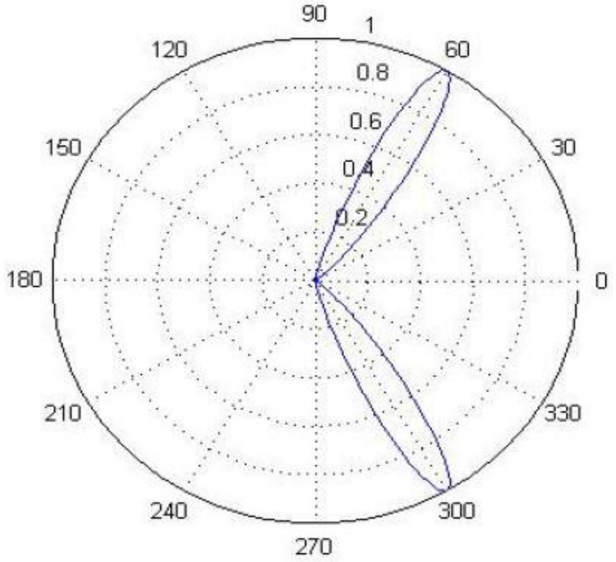

Fig.10 Polar Plot of the Normalized Radiation Pattern at Range R = 30 km and t = 225 μsec for Frequency Decrement where φ = 0

.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The focus of this thesis has been on the investigation of frequency diversity among the elements of a linear array which is in literature called frequency diverse array. This new and novel electronic scanning technique has been popular for the last 10 years and several papers were published concerning this promising electronic scanning technique.

First, the concept of frequency diverse array as a time modulated antenna was validated with the MATLAB simulations. It turns out that using a periodic travelling pulse waveform and exciting the antenna elements in an on-off-keying fashion generates simultaneous pencil beams in the desired directions where each beam is tagged with a different frequency. We should also note that the frequency tagging is a function of the modulation frequency, which depends on the period of the travelling pulse waveform. Several amplitude tapering functions were applied to the time modulated frequency diverse array and the results obtained from MATLAB simulation justified the given theoretical values.

Applying a continuous waveform and a small frequency increment compared to the carrier frequency generates a range, time and angle dependent array pattern. The most important feature of the frequency diverse array is that no phase shifters are needed. This unique feature can provide an inexpensive way of accomplishing electronic scanning. It can also be used in SAR and GMTI applications as explained in [7]. The periodic nature of the pattern in range, angle and time was validated with MATLAB simulations. The spiral plot obtained in Chapter IV shows the promising electronic scanning of the frequency diverse array where the main beam reaches its maximum value at all angles but in different ranges. Although this novel electronic scanning method has advantages over conventional arrays, having range dependent pattern may introduce range ambiguity problems.

The use of the frequency diverse arrays in radar applications can be considered in the time domain since time domain signals are used. In the last chapter of this thesis, the performance of the time domain receiver was discussed and radar range equation was presented. We clearly saw that the processing gain plays a key role in the time domain range equation. Therefore, the frequency diverse array receiver antenna can be considered as a time domain antenna and the time domain techniques can be applied.

B. Recommendations for Future Work

This thesis basically provides the theory of the frequency diverse array antenna. Throughout this thesis, theory was supported with MATLAB simulations. Therefore this thesis can be considered as an introductory thesis. Due to time limitations, hardware implementations could not be done. A future effort may focus on the simulation of the frequency diverse array in a computer-aided-design environment such as Microwave Studio, Agilent ADS or Labview. The results obtained from these simulations can be compared with the results provided in this thesis.

Other effort may include the implementation of the frequency diverse array with hardware. The FDA elements may be placed over a perfectly conducting electric ground plane and the results can be compared with the results given in this thesis.

One can also examine the use of frequency diverse array antenna in radar applications and try to derive a specific radar range equation for frequency diverse array radar. A further study may also include the definition of signal-to-noise ratio and examine how to avoid ambiguities due to the multiple maxima that occur in range and angle for FDA.

.

REFERENCES

[1] H. E. Shanks, “A new technique for electronic scanning,” IRE Trans. on Antennas and Propagation, vol. 9, pp.162-166, March 1961.

[2] M. A. Richards, Fundamentals of Radar Signal Processing: McGraw-Hill, 2005, pp. 1–22.

[3] M. I. Skolnik, Introduction to Radar Systems, 3rd ed. New York: McGraw-Hill,2001, pp. 1-16, 540–589.

[4] Radartutorial.eu, “Receivers bandwidth,” [Online]. Available: http://www.radartutorial.eu/09.receivers/rx10.en.html

[5] G. Li, S. Yang, Y. Chen, and Z. Nie, “A novel beam scanning technique in time modulated linear arrays,” in Antennas and Propagation Society International Symposium, 2013, pp. 1–4.

[6] P. Antonik, M. C. Wicks, H. D. Griffiths, and C. J. Baker, “Frequency diverse array radars,” in IEEE Conference on Radar, 2006.

[7] [7] P. Antonik, M. C. Wicks, H. D. Griffiths, and C. J. Baker, “Multi-mission multimode waveform diversity,” in IEEE Conference on Radar.

[8] M. Secmen, S. Demir, A. Hizal, and T. Eker, “Frequency diverse array antenna with periodic time modulated pattern in range and angle,” IEEE Conference on Radar, 2012, pp. 427–430.

[9] J. Huang, K. Tong, and C. J. Baker, “Frequency diverse array with beam scanning feature,” in Antennas and Propagation Society International Symposium, 2011, pp. 1–4.

[10] W. L. Stutzman and G. A. Thiele, Antenna Theory and Design, 2nd ed. New York: John Wiley & Sons, 1998, pp. 107–109.

[11] F. T. Ulaby, Fundamentals of Applied Electromagnetics, 5th ed. New Jersey: Pearson Prentice Hall, 2007, pp. 403–416.

[12] M. I. Skolnik, Radar Handbook, 2nd ed. New York: McGraw-Hill, 1990.

[13] D. C. Jenn, “Arrays with elements above a ground plane,” lecture notes for EC4610 (Microwave Devices and Radar), Naval Postgraduate School, Monterey,CA, 2003.

[14] H. E. Shanks and R. W. Bickmore, “Four Dimensional Radiators,” Canadian Journal of Physics, vol. 37, p. 263, 1959.
[15] D. C. Jenn, “Dipoles of arbitrary orientation,” lecture notes for EC4610 (Microwave Devices and Radar), Naval Postgraduate School, Monterey, CA, 2012
[16] J. H. McClellan, R. W. Schafer, and M. A. Yoder, Signal Processing First. New Jersey: Pearson Prentice Hall, 2003, pp. 47–50.
[17] P. Antonik, “An investigation of a frequency diverse array,” Ph.D. thesis, University College London, Bloomsbury, London, UK, 2009
[18] J. D. Taylor, Introduction to Ultra-Wideband Systems, Florida: CRC Press, 1995, pp. 609–644.
[19] Center for Computer Research in Music and Acoustics, ‘Transient and steady-state signals,” [Online]. Available: https://ccrma.stanford.edu/~jos/filters/Transient_Steady_State_Signals.html