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Microstrip Array Antenna and Beamforming Algorithm for Phased Array Radar

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Abstract

Beamsteering antennas are the ideal solution for a variety of system applications, including traffic control and collision avoidance radar for WLAN and cellular communication. A microstrip antenna array is used since it is simple to design and fabricate. Small size, light weight, efficiency and high gain antenna array designed are important area of research in active phased array RADAR that can meet the subject requirement. This paper gives the review on different configuration of microstrip antenna array for Phased array radar and talks about beamforming algorithms. It also highlights the different beamforming algorithm. Simulation results are presented for conventional and LCMV beamformer.

Keywords

Microstrip Array , RADAR, Phased Array Radar, Beamforming algorithm, LCMV algorithm

I. Introduction

Focused of energy or organized efforts is inevitable for any breakthrough success. This outspoken feature when implemented for electromagnetic energy with the help of Phased Array Antennas results in well known and useful phenomenon of Beamforming [1]. Phased array antennas are useful in (active or passive phased array) radar application [2]. They are also worthy in wireless Satellite Communication [3]. Advanced weather, air traffic control and security applications also utilizes active Phased array antenna. A study regarding challenges in these areas has been carried out in [4].

In single element antenna, the radiation pattern is usually very broad and the directivity is relatively low. This problem can be overcomed by enlarging the size of the element thus increasing the directivity. Another way to enlarge the antenna without changing the size of the individual elements is to assemble the radiating elements in a geometrical configuration known as array. The individual elements forming the array are usually identical and they can be of any form [5].

Section 1 contains different types of Antenna arrays like linear array, Planar array and Scanned array. Section 2 highlights on Design Methodology of an antenna array , steps of designing microstrip antenna array and different types feeding techniques used to feed an antenna. Section 3 elaborates about Active Phased Array. In section 4 , we talked about Array Design Procedure like Coaxial feedline, Series fed taper antenna array design and corporate feed antenna array.

II. Array Antennas

Some antenna sources can be seen as isotropic elements, which mean that they radiate equally well in all directions [6]. Array antennas can be divided into two main groups, broadside and endfire array, depending on how their main beam is designed to radiate. End-fire array has its main beam in the direction along the array while the broadside array radiate to the arrays orientation.

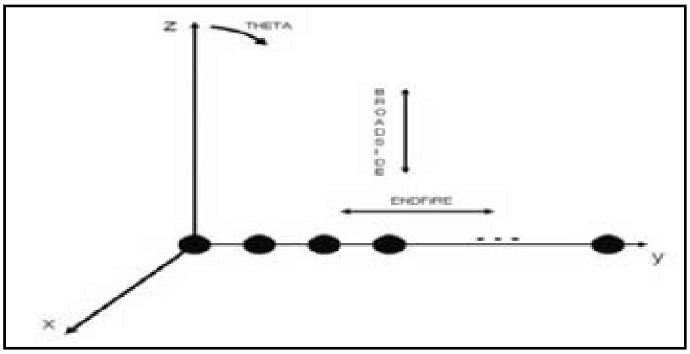

Fig. 1 : Topology of a Linear Array

A. Linear Array

The elements in a linear array are distributed over a one dimensional straight line and are often equidistantly positioned to achieve radiation pattern.

B. Planar Arrays

A Planar array consists of antenna elements spread over two dimensions where the position compose a planar lattice. The radiation field from a planar array is a summation of the radiation from each element , just like for the linear array.

C. Scanned Arrays

Scanned arrays are categorised into two main groups. Electronically scanned array (ESA) and mechanically scanned array (MSA). Again Electronically scanned array having two types. Passive Electronically scanned array (PESA) and Active Electronically Scanned Array (AESA).

III. Design Methodology

Antenna is an interface between the signal source and the air for any wireless application. The efficiency of an antenna is a prominent figure of merit of any radar system. Antenna efficiency can be in the terms of gain, directivity, return loss [1].Beamforming mainly depends on the design of corresponding antenna. Port impedance is normally chosen as 50 Ω. To design an antenna array at a desired frequency , the first step is to design single antenna. FR-4 material can be used which is cheap and readily

available [1].
Design of microstrip array is divided into four steps
I. Defining specifications
II. Design of single patch
III. Design of an array
IV. Simulation of the array
Feeding is another important aspect in the design of patch antennas. Some feeding techniques are given below.
I. Microstrip Line
II. Co-axial Line
III. Aperture Coupling
IV. Proximity Coupling

IV. Beamforming

Beamforming or Spatial filtering is a signal processing technique used in sensor arrays for directional signal transmission or reception. This is achieved by combining elements in a Phased array in such a way that signals at particular angle experience constructive interference while other experience destructive interference. Beamforming can be used at both the transmitting and receiving end in order to achieve spatial selectivity. It has numerous applications in Radar , Sonar , Seismology, Wireless Communication ,Radio Astronomy, Biomedicine.
To change the directionality of the array when transmitting a beamformer controls the phase and relative amplitude of the signal at each transmitter in order to create a pattern of constructive and destructive interference in the wavefront. Fig.2 shows pattern of adaptive beamforming.

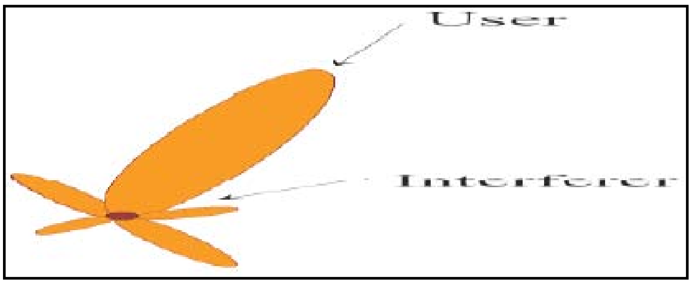

Fig. 2 : Adaptive Beamforming

A. Active Phased Array

Active phased array elements incorporate transmit amplification with phase shift in each antenna element. Passive Phased array typically use large amplifiers that produce all of microwave transmit signal for the antenna. Adaptive array antenna system are currently the subject of intense research interest for Radar and Communication applications. In this paper the authors investigate the Least Mean Square (LMS) and Normalised Least Mean Square (NLMS) algorithm and proposed new scheme to overcome the shortcomings of existing algorithm for a robust smart antenna system [8].

V. Array Design Procedure

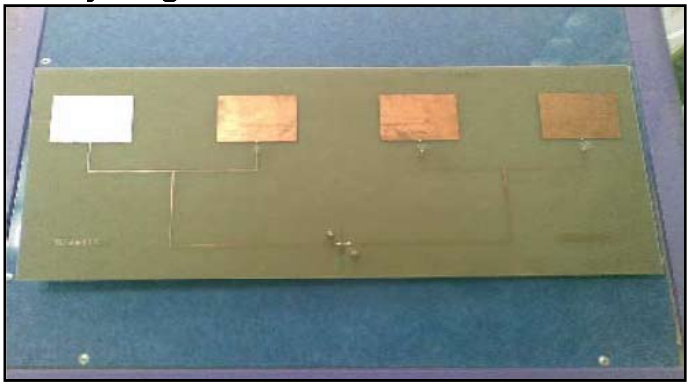
Fig. 3 Array Configuration [5]

Fig. 3 shows antenna array of four elements. In this design, the beam is steered by changing the phase between elements. The phase between the elements is changed by changing the length of the feeders between elements. Antenna array gives resonance frequency 9.9 GHz, return loss -26dB. The bandwidth of antenna is 5.5 %.
In this work, four element phased array using microstrip antenna and transmission line phase shifter has been presented. In this research, the phase shift is obtained through the introduction of additional path length of co-axial cable. The use of co-axial delay lines is impractical due to increased cost, complexity and weight. When elements are spaced greater than λ/2 apart , greating lobes are possible. Increased the spacing between elements less than λ/2 will reduce the HPBW and increase the antenna directivity to increase size. Increased number of elements will decrease HPBW so will increase directivity. The bandwidth is smaller as the array is made larger.

A. Series fed taper antenna array design

The sidelobe level is reduced by using the taper structure. The seven element series fed taper microstrip antenna array is shown in fig. 4. The array is designed to resonate at 10GHz [9]. The dielectric substrate of the microstrip array

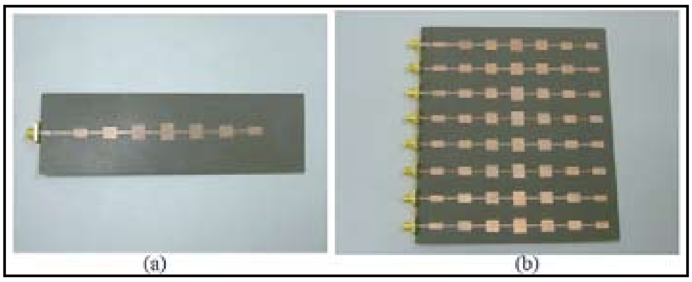

Fig. 4 **(a)** Configuration of single series-fed taper antenna array **(b)** Configuration of the 7x8 series-fed taper antenna arrays [9]

has a relative dielectric constant of 2,2 and thickness of 31 mil, The sidelobe level can be reduced by introducing a taper in the amplitude of the elements [10]. When tapering the amplitude distribution, the excitation is highest at the center of the array and then decrease as one move forward the edge. If the array has an odd number of elements , then the center element has the largest excitation. For an even number , the two elements adjacent to the center share the largest excitation. With end-fire arrays, the elements nearest the feed couple only a small amount of power. In this case, 80 Ω feed line is used.

B. Corporate Fed Antenna Array

This paper designed array antennas having multiband characteristic at 77 GHz. This paper is proposed the possibility of prototyping by design and analysis of microstrip array antennas for mm-wave radar with U-shaped slots [11].

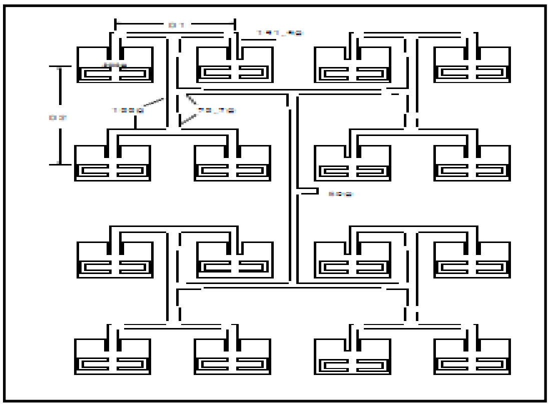

Fig 5 : Corporate fed antenna array [11]

Fig. 5 Shows the geometry of the proposed 4 × 4 array antennas fed by corporate feed network connected to 50 Ω feedline. The proposed antennas are designed using FR4 substrate having dielectric constant €r = 3.9 and thickness 0.1 mm. Corporate feed network is used for power delivered to each patch element is controlled by altering the width of the lines and maintaining the lengths equal. Width of the transmission line are calculated based on the line impedance.

VI. Adaptive Beamforming

The basic concept of adaptive beamforming is shown in fig.6. Complete digital data from each antenna, at the system sample rate is multiplied by a complex weight calculation algorithm which differ in their complexity , accuracy and speed of convergence. Similarly there are various beamformer architectures which differ what data is used , what algorithm computes the weights and how the data is combined [12].

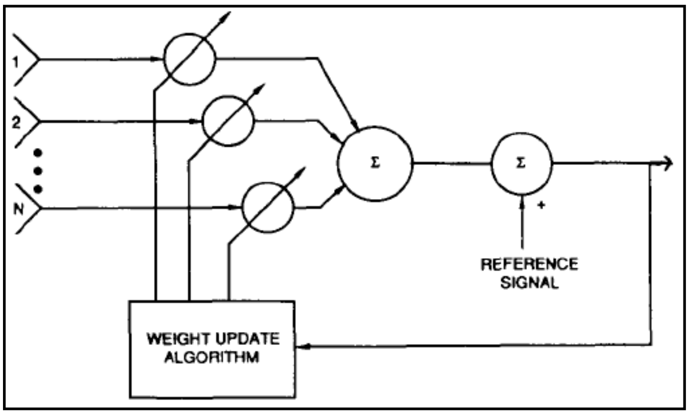

Fig. 6 : Adaptive Beamforming Block Diagram [12]

A. Weight Computation

The optimal weight vector for the narrowband beamformer of fig. 6 is Weiner solution

$$w = R_{xx}^{-1} r_{xd}. \quad (1)$$

The optimal weights require exact knowledge of the autocorrelation matrix Rxx and crosscorrelation vector rxd. The adaption process may be performed continuously or may be performed in a block approach. The addition may computed either in time domain or frequency domain; the results are identical when the sampling rates and bandwidths are chosen appropriately.

A beamformer may be fully adaptive i.e. all the degree of freedom are available. If an array is partially adaptive, it may use either an element space or beam space approach. In the beam space approach, cancellation beams are formed in jammer directions. In the element space approach , selected subset of the antenna are used to null jammer. The element spaced approach has a simple implementation. It can be achieved by gradient descent or recursive Least Squares (RLS) algorithm.

B. LMS Algorithm

The Least Mean Square algorithm is a stochastic approximation algorithm which adjusts the weights in an adaptive beamformer based on minimum mean square error criterions.

The LMS algorithm is given by

W (n+1) = w (n) + u e x * (n) ---- (2)

Where e is a scalar error signal defined as

E = d (n) – w H (n) x (n) ---- (3)

W(n) is the weight vector at nth iteration, x(n) is the signal vector at nth iteration, d (n) is a model of desired signal at nth iteration , u is a scalar that controls the rate of convergence.

The performance of LMS algorithm is based on the weight error and convergence time [12]. A drawback of LMS algorithm is slow convergence when the maximum to minimum eigen value spread of the input autocorrelation matrix is large. A speedup to LMS convergence may be obtained by scaling the convergence parameter u by a power estimate.

C. Recursive Least Squares (RLS)

A recursive least squares technology (RLS) may be used to compute the adaptive weights. The RLS estimate is based on the previous estimate and the difference between the current and desired output. The RLS is similar to the kalman equation.

D. LCMV Beamformer

The Linear constrained Minimum Variance (LCMV) beamformer is a generalized LMS algorithm. The structure of LCMV beamformer is shown in fig. 7.

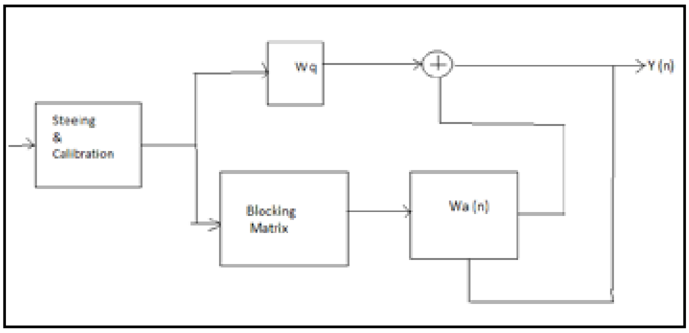

Fig.7 : LCMV Beamformer

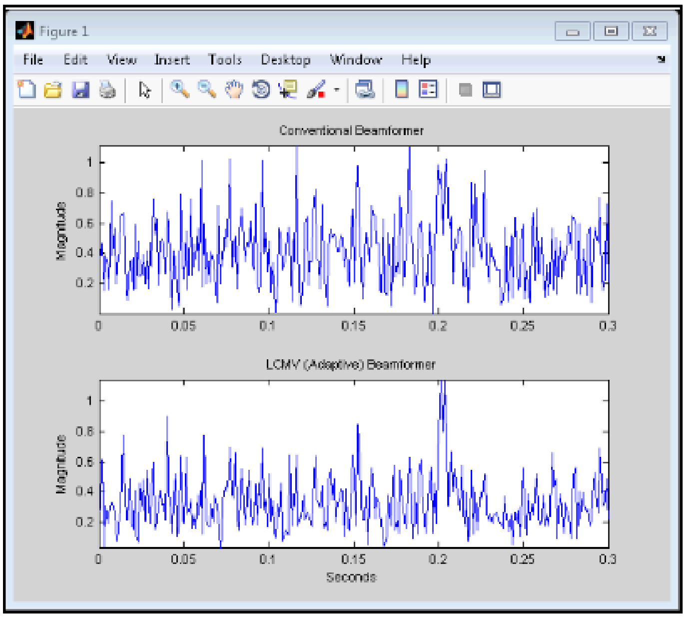

Fig. 8 : SNR plot of conventional Beamformer and LCMV Beamformer

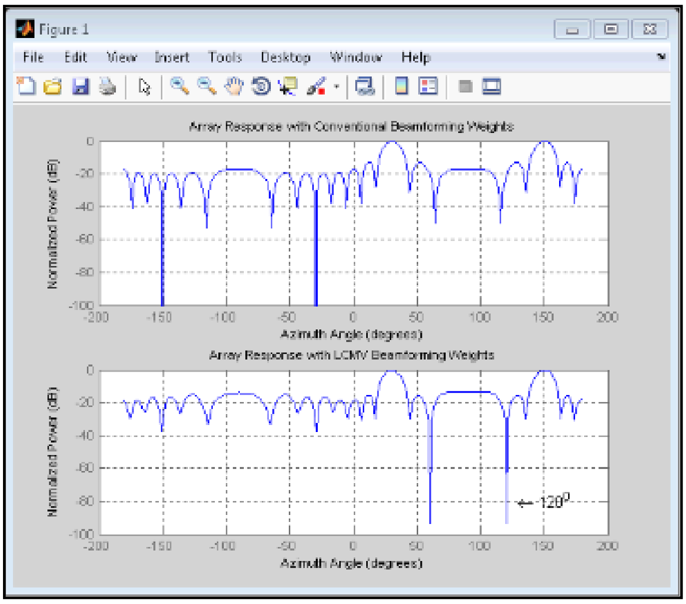

Fig. 9 : Array response with conventional and LCMV beamformer weights

Code for narrowband phase shift beamformer with a ULA is written and simulated in MATLAB. Some low level Gaussian noise is added and then LCMV beamformer is implemented and beamformer weights has been observed. From fig. 8 it is concluded that adaptive beamforming significantly improves the SNR of the rectangular pulse at 0.2 s. Fig. 9 shows the plot of array normalized power response for the conventional and LCMV beamformers. The LCMV beamforming weights place a null in the array response as the arrival angle of the interference signal.

Conclusions

It is concluded that microstrip antenna array resonance frequency depends on the array configuration and feeding techniques. In first design of antenna Phase shift can be obtained through the introduction of additional path length of coaxial cable. The use of coaxial delay lines is impractical due to increased cost, complexity and weight. There are some drawbacks of the design with coaxial cable as a feed. In the second design, an antenna is feed with taper series fed. In this design sidelobe level is reduced by introducing taper fed in the amplitude. In the third design antenna array is design using U shaped slots. Patch antenna with slots gives multiband characteristics. Code is generated for LCMV beamformer in MATLAB. It is concluded that adaptive beamforming significantly improves the SNR as compared to conventional beamformer.

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