Implementation of Array Synthesis using LABVIEW for Radar Applications

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Abstract: **Pattern synthesis is one of the most important aspects of antennas. Radiation pattern shape plays a major role in all communication and modern radar systems. It is of interest to note that it is possible to generate and shape the overall radiation characteristics by a suitable design of antennas. In view of above facts, an attempt is made to propose new amplitude distributions to reduce first sidelobe level for synthesis of sum patterns. For this purpose classical synthesis methods are widely used to address this problem providing low side lobe levels and narrow beam-width. The desired radiation patterns can be carried out with the help of LabVIEW2014 software and are presented.**

Index terms **Array Antennas, Pattern Synthesis, Tailor Synthesis, Side lobe level.**

I. INTRODUCTION

Antenna designers always keep on devising new and advanced techniques to improve the existing designs and introduce new antenna models to achieve better radiation characteristics at reduced cost, size and weight [1]. As we know that on demand, array antennas are able to produce any type of beam shape depending on its application. The major advantage of antenna arrays over a single antenna element is their electronic scanning capability; that is, the major lobe can be steered towards any direction by changing the phase excitation at each array element. Basically, there are five controlling parameters that directly or indirectly affect the total radiation pattern of the array [2]-[3].

- The geometrical shape of an array (linear, planar, circular etc.,)
- The relative spacing between elements of an array.
- The excitation amplitude of each individual element.
- The excitation phase of each individual element.
- The radiation pattern of each individual element.

The main aim of this present work is to design a monopulse antenna having low sidelobe levels which provides high accuracy, higher directivities and narrow beamwidth. The linear array antenna has been modeled, formulated and extensively employed with classical method of tailor synthesis for the reduction of side lobe level by varying the number of elements. The proposed method is used to generate the desired radiation patterns.

Jafar [4] have given an idea on the design of linear arrays for the sum and difference pattern with low sidelobes using Bayliss patterns. Samuel et al. [5] has presented accurate formulas in a closed form that makes possible an easy examination and computation of directivity and beamwidth for large scanning Dolph-Chebyshev arrays.

Tailor [6]-[7] has described about accurately modelling monopulse antenna patterns which is key for achieving accurate tracking, especially off-boresight tracking, and correctly understanding the operation of monopulse radars. Bayliss [8] has given an overview on array pattern control and synthesis. He proposed that antenna array distributions and their associated patterns are now designed on physical principles, based on placement of zeros of the array polynomial. However, the proper amplitude excitation weights of the elements are used to control the beamwidth and sidelobe level [9] for the desired radiation patterns. For the sake of easy reference and completeness, the details of Tailor synthesis method and implementation of proposed method for the considered problem are presented in the following sections.

II. PATTERN SYNTHESIS METHOD

Antenna pattern synthesis usually requires that first an approximate analytical model is chosen to represent, either exactly or approximately, the desired pattern. The second step is to match the analytical model to a physical antenna model. Generally speaking, antenna pattern synthesis can be classified into three categories.

1. One group requires that the antenna patterns possess nulls in desired directions - The method introduced by Schelkunoff can be used to accomplish this.
2. Another category requires that the patterns exhibit a desired distribution in the entire visible region. This is referred to as beam shaping - it can be accomplished using the Fourier transform and the Woodward-Lawson methods.
3. A third group includes techniques that produce patterns with narrow beams and low sidelobes - the binomial method, the Dolph-Tschebyscheff method, Taylor line-source (Tschebyscheff-error) and the Taylor line-source (one parameter)

The synthesis methods will be utilized to design line-sources and linear arrays whose space factors and array factors will yield desired far-field radiation patterns. The total pattern is formed by multiplying the space factor (or array factor) by the element factor (or element pattern). For very narrow beam patterns, the total pattern is nearly the same as the space factor or array factor.
The Taylor design yields a pattern that is an optimum compromise between beamwidth and sidelobe level. In an ideal design, the minor lobes are maintained at an equal and specific level.
The normalized space factor that yields a pattern with equal-ripple minor lobes is given by

$$SF(\theta) = \frac{\cosh\sqrt{(\pi A)^2 - u^2}}{\cosh(\pi A)} \qquad (1)$$

where $u = \pi\frac{l}{\lambda}\cos\theta$
whose maximum value occurs when u=0
l= length of the source
λ= wave length
A=constant related to the maximum desired side lobe level R_0 by
$\cosh(\pi A) = R_0$ (Voltage ratio)
The above Space factor equation can be realized physically. So Taylor suggested the following approximation for the space factor.

$$SF(u, A, \bar{n}) = \frac{\sin(u)}{u}\frac{\prod_{n=1}^{\bar{n}-1}[1 - \left(\frac{u}{u_n}\right)^2]}{\prod_{n=1}^{\bar{n}-1}[1 - (\frac{u}{n\pi})^2]} \qquad (2)$$

where $u=\pi\vartheta = \pi\frac{l}{\lambda}\cos\theta$
$u_n = \pi\vartheta_n=\pi\frac{l}{\lambda}\cos\theta_n$
$\bar{n}$ is a constant chosen by the designer so that the minor lobes for
$|\vartheta| = |u/\pi| \leq \bar{n}$ are maintained at a nearly constant voltage value
$|\vartheta| = |u/\pi| > \bar{n}$ decay at a rate of $1/\vartheta = \pi/u$

The normalized line source distribution which yields the desired pattern is given by

$$a(z') = \frac{\lambda}{l}[1 + 2\sum_{p=1}^{\bar{n}-1} SF(p, A, \bar{n})\cos(2\pi p\frac{z'}{l})] \qquad (3)$$

$a(z')$ is the total current
z'=element spacing
In this present work the side lobes are considered as exponentially decayed. Hence we go for Taylor Line-Source (One parameter) which is discussed below.
A continuous line-source distribution that yields decaying minor lobes and, in addition, controls the amplitude of the sidelobe is that introduced by Taylor in an unpublished classic memorandum. It is referred to as the Taylor (one-parameter) design and its source distribution is given by

$$a_n(z') = \begin{cases} J_0\left[j\pi B\sqrt{1 - \left(\frac{2z'}{L}\right)^2}\right] & -l/2 \leq z' \leq +l/2 \\ 0 & \text{elsewhere} \end{cases} \qquad (4)$$

Where 'J_0' is the Bessel function of the first kind of order zero, 'L' is the total length of the continuous source, and B is a constant to be determined from the specified sidelobe level.
The space factor associated with can be obtained by using mathematical manipulations for a Taylor amplitude distribution line-source with uniform phase [$\phi_n(z') = \phi_0= 0$] can be written as

$$SF(\theta) = \begin{cases} L\frac{\sinh\left[\sqrt{(\pi B)^2-u^2}\right]}{\sqrt{(\pi B)^2-u^2}}, & u^2 < (\pi B)^2 \\ L\frac{\sin\left[\sqrt{(\pi B)^2-u^2}\right]}{\sqrt{(\pi B)^2-u^2}}, & u^2 > (\pi B)^2 \end{cases} \qquad (5)$$

Where $u=\pi\frac{l}{\lambda}\cos\theta$
B= constant determined from sidelobe level
L= line-source dimension
λ= wave length
When $(\pi B)^2 > u^2$, represents the region near the main lobe. The minor lobes are represented by $(\pi B)^2 < u^2$.Either form of can be obtained from the other by knowing that

$$\sin(jx) = j\sinh(x)$$
$$\sinh(jx) = j\sin(x)$$

When u = 0 (θ = π/2 and maximum radiation), the normalized pattern height is equal to

$$(SF)_{max} = \frac{\sinh(\pi B)}{\pi B} = H_0 \tag{6}$$

H_0= Normalized pattern height
For $u^2 \gg (\pi B)^2$ the normalized form reduces to

$$SF(\theta) = \frac{\sin\left[\sqrt{u^2 - (\pi B)^2}\right]}{\sqrt{u^2 - (\pi B)^2}} \cong \frac{\sin u}{u} \quad u \gg \pi B \tag{7}$$

The equation (7) is identical to the pattern of a uniform distribution. The maximum height H_1 of the sidelobe is H_1 = 0.217233 (or 13.2 dB down from the maximum), and it occurs when

$$[u^2 - (\pi B)^2]^{1/2} \cong u = 4.494$$

The maximum voltage height of the sidelobe (relative to the maximumH_0 of the major lobe is equal to

$$\frac{H_1}{H_0} = \frac{1}{R_0} = \frac{0.217233}{\sinh(\pi B)/(\pi B)}$$

or

$$R_0 = \frac{1}{0.217233}\frac{\sinh(\pi B)}{\pi B} = 4.603\frac{\sinh(\pi B)}{\pi B}$$

The above equation can be used to find the constant *B* when the intensity ratio 'R_0' of the major-to-the-sidelobe is specified.

III. ARRAY SYNTHESIS METHODOLOGY

Consider an array of isotropic elements positioned symmetrically along the X-axis. Suppose the distance between any two adjacent elements is 'd', and the array is operated at λ/2, a symmetric linear array is shown in figure (1).

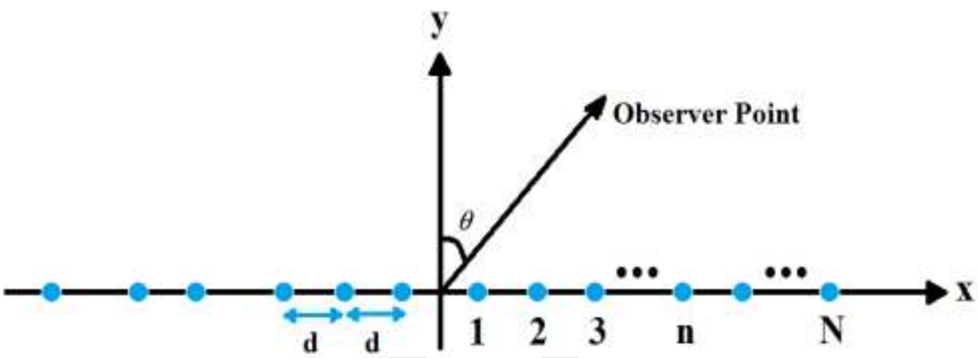

Figure 1: Geometry for symmetric structure of linear array

To show the approach, consider a linear array of N equally-spaced elements whose array factor AF(θ) is given in the following equation

$$AF(\theta) = \sum_{n=-N}^{-1} a_n e^{j\left(n+\frac{1}{2}\right)kd\cos\theta} + \sum_{n=1}^{N} a_n e^{j\left(n-\frac{1}{2}\right)kd\cos\theta} \tag{8}$$

Where, 'a_n' are the complex excitation coefficients.
'k' is the wave number.
'θ' defines the angle at which AF(θ) is calculated with respect to the broadside direction.
'd' is the inter-element distance and 'N' is the number of elements.

The sum pattern of array factor AF(θ) is obtained starting by a set of excitation coefficients, a_n, (n=-N, . . .,-1, 1, . . ., N) which are assumed to be symmetric i.e., $a_{-n}=a_n$, (n=1,. . ., N) and are fixed. In this case, the sum array factor is given by

$$AF(\theta) = \sum_{n=1}^{N} a_n \cos[\frac{1}{2}(2n-1)\,k\,d\cos\theta] \tag{9}$$

IV. SIMULATION RESULTS AND DISCUSSIONS

Inorder to validate the effectiveness of proposed method, we first investigate the array of 20, 60 and 100 elements that are spaced $\lambda/2$ distance apart. The excitation coefficients a_n for the sum pattern are calculated from the tailor synthesis method. The desired radiation patterns are obtained by using the equation (9) and the corresponding simulation results of 20, 60 and 100 elements for $\bar{n} = 4$ with SLL= -30 dB are shown in the figures 2, 3 and 4.

In the next case investigations are carried out for $\bar{n} = 4$ with SLL= -20dB in tailor synthesis method using LABVIEW software. The desired radiation patterns of 20, 60 and 100 elements are shown in the figures 5, 6 and 7.

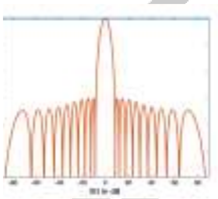

Figure 2: Radiation Pattern with $\bar{n} = 4$ for 20 elements

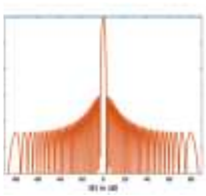

Figure 3: Radiation Pattern with $\bar{n}$ = 4 for 60 elements

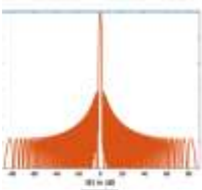

Figure 4: Radiation Pattern with $\bar{n}$ = 4 for 100 elements

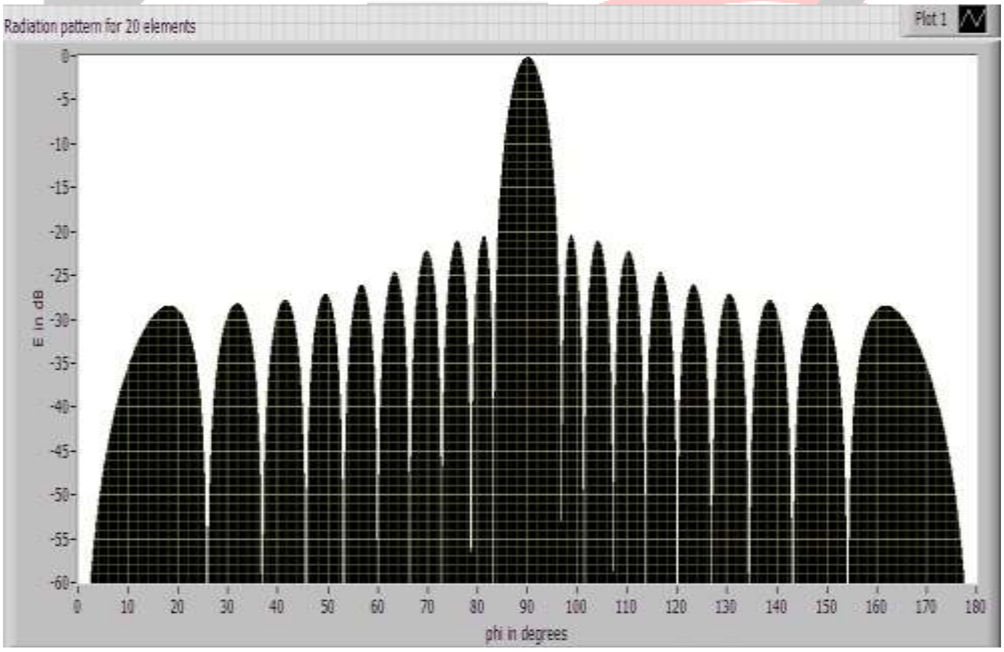

Figure 5: Radiation Pattern with $\bar{n}$ = 4 for 20 elements in LABVIEW

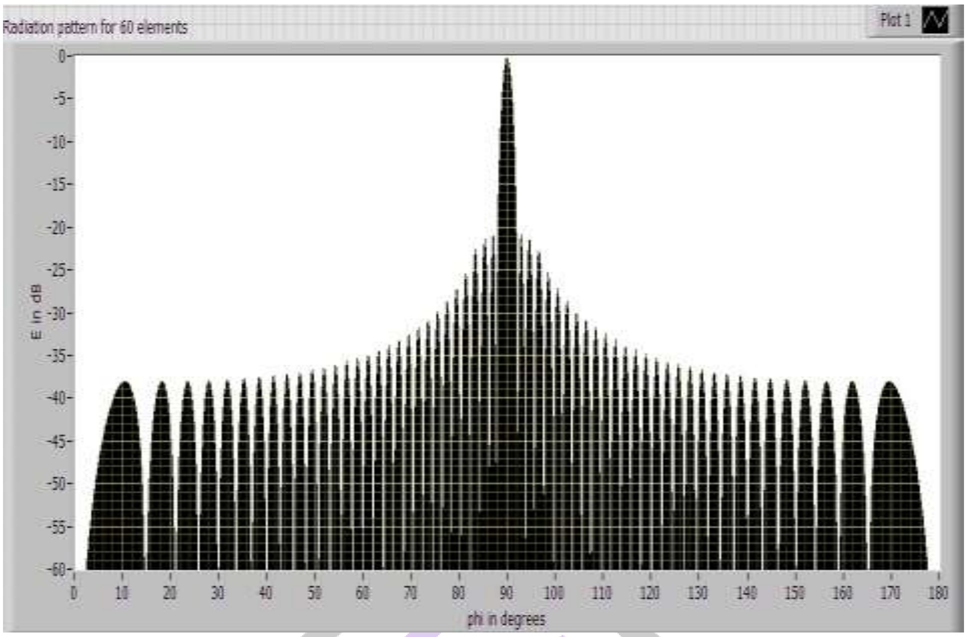

Figure 6: Radiation Pattern with $\bar{n}$ = 4 for 60 elements in LABVIEW

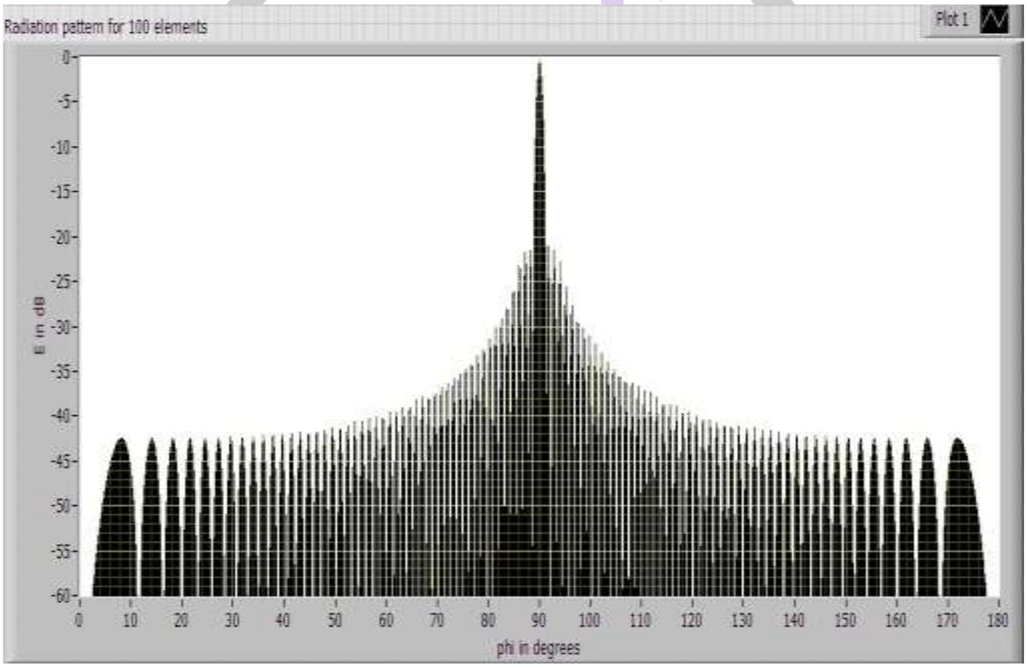

Figure 7: Radiation Pattern with $\bar{n}$ = 4 for 100 elements in LABVIEW

V. CONCLUSION

It is observed that the proposed method is a compromise solution between the sidelobe levels and beamwidth of the antenna. It produces patterns with narrow beam and low sidelobes. This helps in detecting the signal with high accuracy and improves the resolution capabilities of the antenna. The same technique is extended to the array of antennas.

The synthesis method is carried with the help of both MATLAB and LabVIEW simultaneously and the simulation results are demonstrated in this present work. The radiation characteristics and amplitude distributions for different array of antennas are obtained. The obtained results prove the effectiveness of the proposed approach. These specialized softwares help anyone to test their ideas in the best and cheapest way. Mathematical expressions are used in achieving the desired results. This principle can be extended to various types of antenna.

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