Grating Lobe Mitigation in Scanning Planar Phased Array Antennas

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***Abstract*—This paper presents the grating lobe reduction in a planar phased array antenna with a rectangular lattice and large element spacing in the order of one wavelength for scan angles up to ±45°. A dual-mode circular microstrip patch antenna is considered as the constitutive element of the phased array, in which two different transverse magnetic modes are exploited simultaneously. The numerical analysis shows that the achieved grating lobe reduction is well below 25 dB for scan angles up to ±45° with large element spacing in the order of one wavelength.**

***Keywords*—Phased array, scanning arrays, grating lobe, circular microstrip patch.**

I. Introduction

Microstrip patch phased array antennas have become widely popular in the modern wireless communication and radar systems as they require planar, compact and low-cost phased array antenna designs with scanning capabilities. In order to design a low-cost phased array, one may reduce the number of elements by increasing the element spacing or by array thinning. However, element spacing more than half-a-wavelength generally generates grating lobe in the visible region [1], which gets worse for wide scan angles, thus limiting the array performances in terms of efficiency and directivity [2]. Solutions based on different optimization methods, namely Genetic Algorithm (GA) [3], Least Square Algorithm (LSA) [4] to create sparse array, subarray amplitude tapering [5], subarray synthesis [6] and rotation [7], and non-uniform element separation [8] have been proposed to reduce grating lobes in scanning phased array antennas. However, the achieved grating lobes reduction was only in the order of 15 dB for limited element spacing, wherein conventional single-mode antenna elements were used to design the phased arrays.

More recently, a seven-element hexagonal phased array with a triangular lattice, consisting of dual-mode patch elements that were spaced about one-wavelength apart was reported by the authors in [9] with reduced grating lobes. Herein, the grating lobe issue is further investigated in a planar phased array antenna with a rectangular lattice. In particular, a 7×7 subarray with large element spacing in the order of one wavelength is studied for scan angles up to ±45°. The antenna element under study is the dual-mode circular microstrip patch antenna used in [9], which is capable of generating the dominant TM_{11} and higher-order TM_{21} modes. It will be shown that the grating lobes can be reduced well below -25 dB by simultaneously exciting these two modes with a proper excitation ratio for a specific scan angle. Representative examples in terms of different scan angles, as well as physical insights into the grating lobe reduction technique, will be presented and discussed in this paper.

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II. Grating Lobe Reduction Technique

The grating lobe reduction technique is based on the utilization of dual-mode antenna elements, as opposed to single-mode ones in conventional phased array antennas. More specifically, the self-scanning and nulling properties of the antenna elements are effectively utilized to nullify the grating lobes and provide better radiation-matched elements in scanning phased array antennas. The phased array under study has a planar configuration, comprising of circular microstrip patch antenna elements, each capable of producing broadside and conical radiation patterns operating at the dominant TM_{11} and higher order TM_{21} modes, respectively [10]. For example, by simultaneously exciting the TM_{11} and TM_{21} modes with a proper excitation ratio, a self-scanned radiation pattern can be realized at the element level, as shown in Fig. 1(a), where the modes are excited with a magnitude excitation ratio of 1.2 (TM_{21} to TM_{11}) and a -90^o phase shift

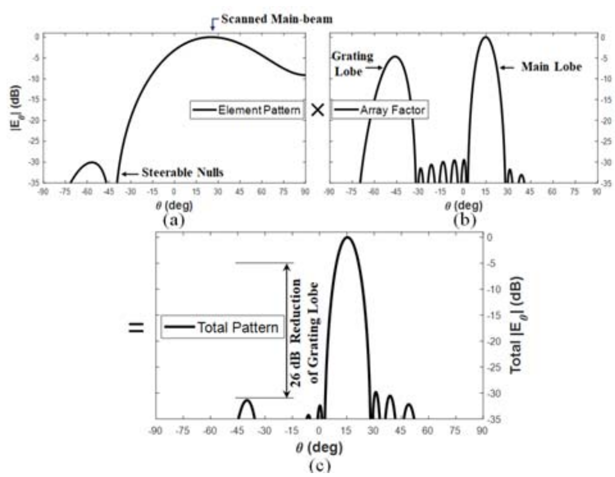

Fig. 1. Normalized (a) element pattern of a dual-mode circular microstrip patch with combined TM_{11} and TM_{21} modes with an excitation ratio of 1.2∠-90° (b) array factor a seven-element linear Dolph-Tschebyscheff (SLL<-30dB) phased array for 15° scan angle with $d = \lambda$ (c) total radiation pattern of the array in Fig. 1(b).

between the modes. Additionally, a minimum of one steerable null is formed in the element pattern, as per Fig. 1(a). The main beam scan angle and the null position of such a dual-mode circular microstrip patch antenna can be controlled by the magnitude excitation ratio and the phase shift between the TM_{11} and TM_{21} modes. Thus, for a given scan angle a radiation-matched element pattern can be realized and a steerable null can be projected at or in close proximity to the grating lobe position. This will in turn facilitate the reduction of unwanted grating lobes in the visible region. As a representative example, the normalized array factor (AF) of a seven-element linear Dolph-Tschebyscheff array with -30dB sidelobe levels and element spacing of one wavelength is depicted in Fig. 1(b), for the 15° scanned main beam. As it is observed, the secondary major lobe, denoted by grating lobe in Fig. 1(b), appears around θ_o = -45°. By utilizing the null and the radiation-matched pattern of the antenna element, the grating lobe in the overall array radiation pattern is suppressed well below -25 dB as shown in Fig. 1(c).

III. Numerical Results

Geometry of the 7×7 planar subarray with a rectangular lattice is shown in Fig. 2, which consists of the dual-mode antenna elements. The array factor of the planar subarray with uniform excitations can be written as [1],

$$AF(\theta,\phi) = \sum_{m=1}^{7}\sum_{n=1}^{7} e^{j2(m-1)X}\, e^{j2(n-1)Y} \qquad (1)$$

where,

$$\begin{cases} X = \pi \dfrac{d_x}{\lambda}(\sin\theta\cos\phi - \sin\theta_o\cos\phi_o) \\ Y = \pi \dfrac{d_y}{\lambda}(\sin\theta\sin\phi - \sin\theta_o\sin\phi_o) \end{cases} \qquad (2)$$

In (2), d_x and d_y are the inter-element spacing along the x- and y-axes, respectively; λ is the wavelength and (θ_o,ϕ_o) corresponds to the main-beam scanning direction.

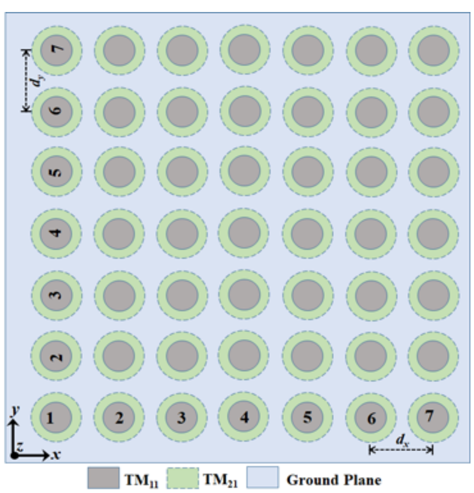

Fig. 2. Geometry of the 7×7 subarray of a scanning phased array antenna with element spacing $d_x = d_y = \lambda$. The antenna element is a dual-mode circular microstrip patch antenna operating at the TM_{11} and TM_{21} modes.

For the broadside and small angles scanning, the dominant TM_{11} mode is needed to excite because the TM_{11} mode produces a broadside radiation pattern. However, an amplitude distribution is not sufficient to reduce grating lobes beyond the small scan angles. Thus, to effectively reduce grating lobes for the scan angles beyond ±8°, a dual-mode antenna element with self-scanning and self-nulling capabilities needs to be used. To do so, the higher order mode TM_{21} is excited along with the dominant TM_{11} mode in the microstrip patch antenna element. The total radiation pattern of the 7×7 planar subarray with one-wavelength element spacing is shown in Fig. 3 for the scan angle of 20°. To produce a radiation-matched element pattern for this selected scan angles of 20°, the required magnitude excitation ratio is set to 1.3 with a -90° quadrature phase shift between the modes. Now, to demonstrate the effectiveness of the proposed technique, the radiation pattern of the dual-mode 7×7 subarray is compared with a reference case, which is a 7×7 subarray consisting of only single-mode TM_{11} antenna elements with the one-wavelength element spacing. Both of the conventional single-mode and proposed dual-mode 7×7 subarrays are excited using Dolph-Tschebyscheff (SLL<-30dB) amplitude distribution. The grating lobe level for the reference case is quite high, i.e., -2.5 dB for 20° scan angle. However, as observed from Fig. 3, for the proposed dual-mode case, the grating lobe is suppressed well below -30dB from the radiation pattern.

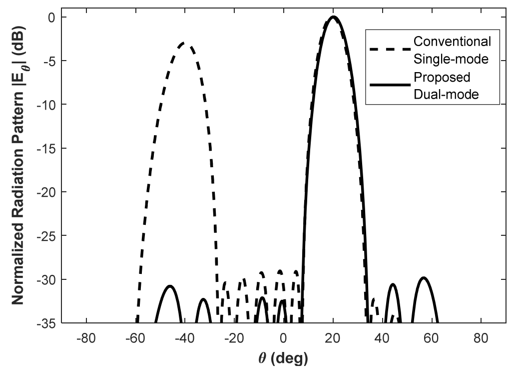

Fig. 3. Comparison of the normalized radiation patterns of the proposed dual-mode (TM_{11} and TM_{21}) 7×7 planar subarray with the conventional single-mode (TM_{11}) 7×7 planar subarray excited by Dolph-Tschebyscheff (SLL<-30dB) amplitude distribution for a scan angle of 20°, when $d_x = d_y = \lambda$.

As the main beam of the 7×7 subarray scans toward the low elevation angles, the grating lobe level further rises as shown in Fig. 4. Thus, the element pattern should be accordingly designed to match the scan angle. This now necessitates a stronger excitation of the higher order TM_{21} mode in the element pattern to reduce grating lobe effectively. Fig. 4 depicts the total normalized radiation patterns of the 7 × 7 planar subarray with element spacing $d_x = d_y = \lambda$, for the scan angle of 30°. It is observed that a grating lobe as large as the main beam is emerged in the visible region at θ_o = -30°, for the conventional subarray with the dominant TM_{11} mode excitation. Interestingly enough, by utilizing the self-scanning and nulling properties of the dual-mode elements, the grating

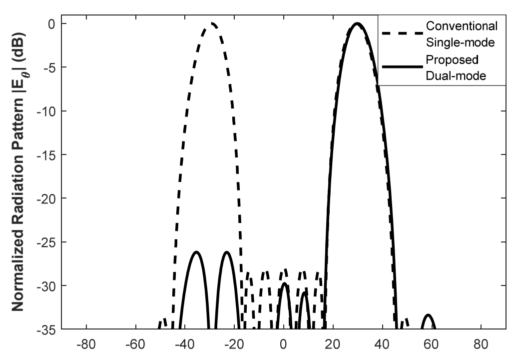

Fig. 4. Comparison of the normalized radiation patterns of the proposed dual-mode (TM_{11} and TM_{21}) 7×7 planar subarray with the conventional single-mode (TM_{11}) 7×7 planar subarray excited by Dolph-Tschebyscheff (SLL<-30dB) amplitude distribution for a scan angle of 30°, when $d_x = d_y = \lambda$.

lobe is now reduced to well below -26 dB. The important factor to enable such grating lobe reduction is the judicious selection of the excitation ratio at the element level as it controls the null position and the main beam tilt angle of the element pattern. For the selected 30° scan angle as shown in Fig. 4, the magnitude excitation ratio is 1.65 with a -90º quadrature phase shift between the modes. To the best of our knowledge, 26 dB reduction of grating lobe is unprecedented for these scan angles in phased array antenna design with large element spacing of one wavelength.

IV. Conclusion

The excitation of higher order modes in the circular microstrip patch antenna elements was further investigated to address the grating lobe issue in a scanning planar phased array antenna with a rectangular lattice and large element spacing in the order of one wavelength. A combination of the dominant TM_{11} and higher order TM_{21} modes was excited to effectively suppress grating lobes to well below -25 dB for the scan angles up to ±45°. The novel concept behind such grating lobe reduction in scanning phased array antennas was based on the utilization of radiation-matched antenna elements with steerable null positions and self-scanning capabilities for a specific scan angle. Different case studies in terms of scan angles along with the element design will be presented and discussed in the conference.

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