Decollimation of Sub Array Quantization Lobes for Circular Polarized Phased Arrays

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Abstract — **A technique for suppression of quantization lobes produced by beam scan in an array of sub arrays working with circular polarization is presented. These quantization lobes occur at grating lobe angles that correspond to separation between sub arrays. It is shown that if quantization lobes occur on orthogonal polarization to the circular polarization of the main beam application of rotation of the radiating elements on modular basis can decollimate quantization lobes. Using four steps of rotation and eight antenna modules 6 dB reduction on simulation level is achieved.**

Keywords — **Phased arrays, scanning antennas, sub array structure of a phased array**

I. Introduction

Scanning an array of sub arrays produces extraneous beams called quantization lobes (QL) [1], [2]. Although these beams occur at grating lobe angles that correspond to separation between sub arrays, they are named separately as they do not occur at broadside (as grating lobes do) [1]. Analysis of the pattern of an array of sub arrays is presented in [2], [3]. The ability to sub array is important as each sub array typically connects to a transmit/receive module; thus, the number of transmit/receive modules is reduced by number of elements per sub array. Suppression of QL can significantly reduce the cost and complexity of phased arrays. A method for suppression of sub array QL is presented in [1]. It utilizes pseudo randomization of sub array centers that results in adding of random phase component to each sub array. Procedure is very effective, but it faces difficulties in selecting sequence of random numbers not weighted in one or another way.

This paper emphasizes on a deterministic technique for suppression of sub-array quantization lobes for circular polarized phased arrays.

II. Mathematical Formulation of Decollimation Procedure

Consider a linear array of dual port linear polarized radiating elements (each port radiates linear polarization). Sub-arraying is performed separately for horizontal polarized (H-pol) and vertical polarized (V-pol) ports with one element offset between H-pol and V-pol sub-arrays as it is seen on Fig. 1.

Combination between H-pol and V-pol sub-arrays with ±90 degrees phase offset produces circular polarization with direction of rotation depending on the sign of the phase offset.

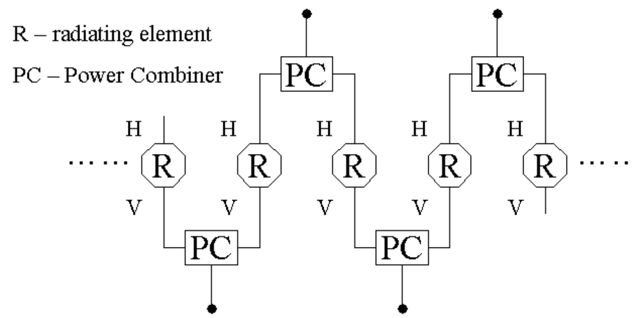

Fig. 1. Sub-array structure of linear array of dual port elements

If pattern of the radiating element for H and V ports are denoted as E_H^e and E_V^e respectively, phased array antenna from Fig. 1 can be considered as two overlapped linear polarized phased arrays with one element offset between them. Far field horizontal and vertical polarized radiation is given with [3]:

$$\begin{aligned} E_H &= E_H^e F(u) \\ E_V &= E_V^e \exp(jkdu) F(u) \\ F(u) &= \sum_{n=1}^{N} A_n \exp[jkd(n-1)u] \end{aligned} \qquad (1)$$

Where A_n represent complex excitation of each radiating element; d is distance between radiating elements; k is wave number; N is the total number of radiating elements; $u = \sin(\theta)$ represent tilt angle from boresight. The term $F(u)$ is the array factor for one of the phased arrays with sub-array architecture. Exponential term for vertical polarized radiation represent offset between two overlapped phased arrays. For uniform excitation of the phased arrays the term $F(u)$ is given with [1], [3]:

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$$F(u)=\frac{\sin\left[\pi\frac{d}{\lambda}N_S M(u-u_0)\right]}{N_S\sin\left[\pi\frac{d}{\lambda}M(u-u_0)\right]}\cdot\frac{\sin\left(M\pi\frac{d}{\lambda}u\right)}{M\sin\left(\pi\frac{d}{\lambda}u\right)} \quad (2)$$

Where M is the number of elements per sub-array; N_S is the total number of sub-arrays; $u=\sin(\theta_0)$ is the scan angle. The two **sin(NX)/Nsin(X)** terms represent, respectively, the pattern of an isotropic array with spacing equal to sub-array width and the sub-array pattern itself. Peaks of $F(u)$ are determined from the following condition:

$$\pi\frac{d}{\lambda}M(u-u_0)=-p\pi \quad (3)$$

Where p is the number of the peak. First peak occurs for $p=0$ and represent main lobe of the pattern, while second ($p=1$) represent quantization lobe due to sub-array architecture. Angle of the quantization lobe θ_q is determined from:

$$\sin\theta_q=\sin\theta_0-\frac{\lambda}{Md} \quad (4)$$

Circular polarization requires additional phase shift φ to be applied to the vertical polarized component of the far field given with (1) so that phase quadrature to be obtained for the main beam. Total far field radiation is:

$$E=\left[E_H^e+E_V^e\exp(jkdu+j\varphi)\right]F(u) \quad (5)$$

Phase difference between two orthogonal components of the far field at the direction of the main beam (θ_0) is

$$\delta\varphi_0=2\pi\frac{d}{\lambda}\sin\theta_0+\varphi=\pm\frac{\pi}{2} \quad (6)$$

Phase difference between two orthogonal components of the far field at the direction of the quantization lobe (θ_q) is:

$$\delta\varphi_q=2\pi\frac{d}{\lambda}\sin\theta_q+\varphi= 2\pi\frac{d}{\lambda}\sin\theta_0+\varphi-\frac{2\pi}{M}=\pm\frac{\pi}{2}-\frac{2\pi}{M} \quad (7)$$

If the number of elements per sub-array is $M=2$, sign of the phase difference at the direction of quantization lobe is opposite than at the direction of the main beam as it can be seen from Eqs. (6) and (7). This means that producing left hand circular polarization (LHCP) at the direction of the main beam results in producing right hand circular polarization (RHCP) in the direction of the quantization lobe.

Consider a phased array antenna built from several modules. Each module has sub-array architecture as described on Fig. 1 and rotation of all radiating elements on same unique angle. Rotation angle differs between modules. Circular polarization produced form each module is with unique phase depending on rotation angle of the radiating elements. Upon summation of the energy from all modules equalization of the phase difference should be performed so additional phase shift on each module should be applied. Sign of this additional phase shift depends on direction of the circular polarization and is opposite for LHCP and RHCP. If compensation is adequate for circular polarization at the direction of the main beam, it is not adequate for the direction of the quantization lobe since two circular polarizations are opposite. Thus compensation of element rotation between modules is adequate for the direction of the main beam and not adequate for the direction of quantization lobe and acts as decollimating factor for the radiation at the direction of quantization lobe.

III. Construction of an Antenna for Technical Realization of the Procedure

A phased array antenna is considered for verification of the proposed technique. The antenna has modular architecture Fig. 2 and contains eight modules. Each module is with sub-array structure as described in the previous section. Rotation of the radiating elements is introduced on module basis. In a module orientation of the radiating elements is equal, but between modules rotation is implemented with 90 degrees step. Rotation angle is random for each module.

Antenna module contains dual port radiating elements that produce horizontal and vertical linear polarizations. Structure of the module is shown on Fig. 2 (a). Adjacent vertical polarized ports (V ports) are combined and common phase control device (PCD) is used. The same takes place for adjacent horizontal polarized ports (H ports). As a result two-element sub array structure is obtained for H ports and for V ports. One element offset between sub array structures for V ports and for H ports is obtained. Due to this offset polarization of the QL is orthogonal to the polarization of the main beam and application of the decollimation procedure is possible.

Linear array is constructed using eight modules for approval of the procedure. Structure of the array is shown on Fig. 2 (b). Random rotation with 90 degrees step between radiators of the modules is implemented. Energy from all the modules is combined with proper phase correction according to the circular polarization of the main beam that takes into account rotation angle of the radiating elements within the module.

The same antenna is considered without rotation of the radiating elements for comparison Fig. 2 (c).

IV. Simulation Results

Constructed linear array is simulated with and without rotation of the radiating elements between modules for approval of the concept. Far-field patterns of the phased array are obtained using equations. (1) and (2). Tilt of the main beam θ_0 is selected to be in the quantization lobe region (magnitude of the QL is comparable with the main beam or θ_q is in visible space). Pattern of the phased array antenna without rotation of the radiating elements is shown on Fig. 3 for 12.5 GHz. It is seen that QL is on orthogonal to the main beam circular polarization (Fig. 3 (b), Fig. 3 (c)). Tilt of the main beam is selected to be 30 degrees. Performance of the antenna with rotation of the radiating elements between modules for the same tilt angle is shown on Fig. 4 again for 12.5 GHz. Fig 4 (b) and Fig. 4 (c) show that QL is decollimated, while the main beam is unchanged. All simulations are performed with uniform magnitude excitation of the radiating elements. The same result is observed for other tilt angles.

V. Discussion and conclusion

Application of radiating element rotation between modules of circular polarized phased array antenna can decollimate sub array quantization lobe if they occur on orthogonal to the main beam circular polarization. One element offset between vertical polarized sub-arrays and horizontal polarized sub-arrays and subsequent production of circular polarization results in difference between circular polarizations of the main beam and quantization lobe. For two elements sub array structure reduction of QL with more than 6 dB is obtained. Total number of transmit/receive modules for two element sub arrays is 2N/2+M (where N is number of dual port radiating elements, M is total number of used antenna modules) compared with 2N modules for the antenna without sub array architecture. If number of sub array modules is small, reduction of transmit/receive modules is almost two times.

References

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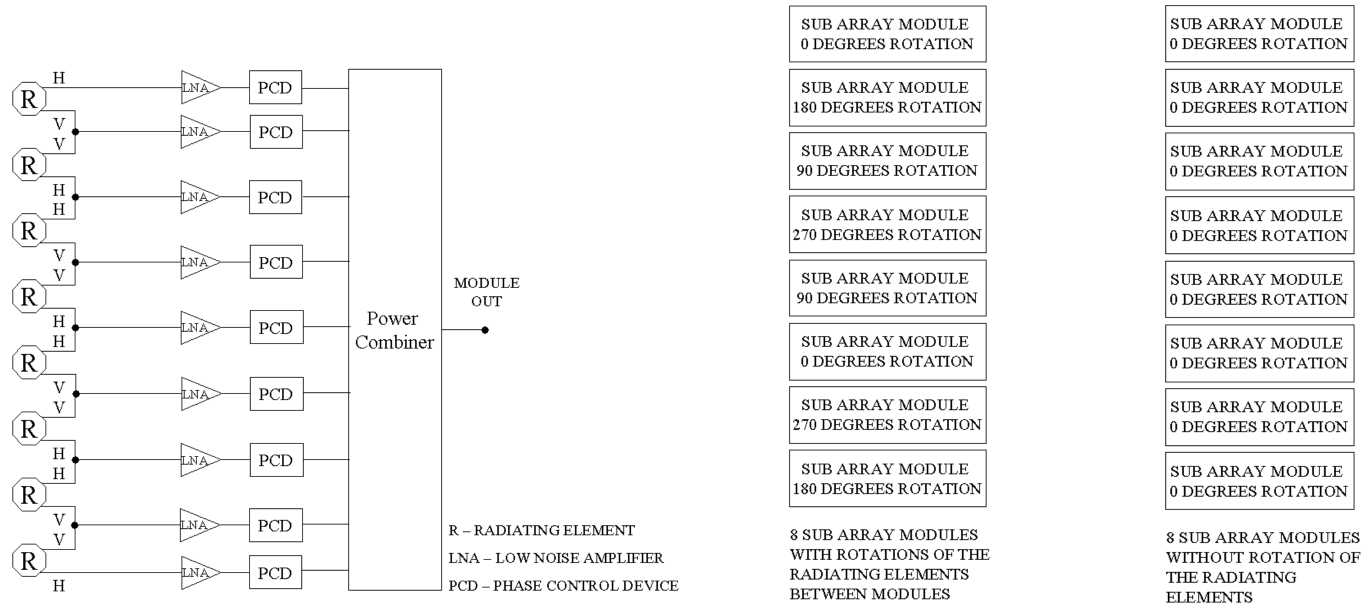
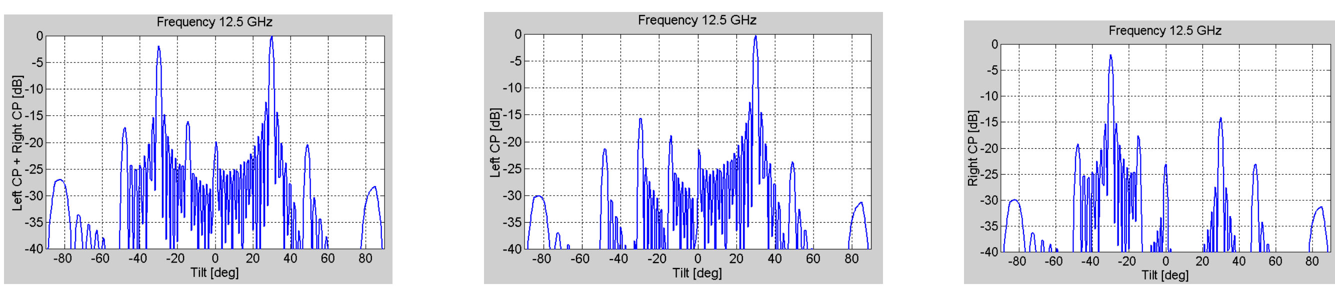


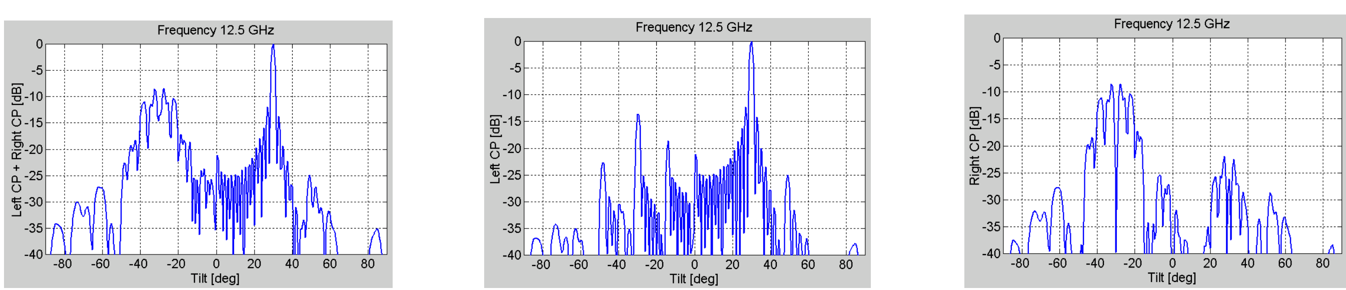
(a) (b) (c)

Fig. 2. Structure of the simulated linear phased array antenna – (a) structure of the module and sub arrays for vertical (V) and horizontal (H) polarizations; (b) modular structure of the antenna with rotations of the radiating elements within each module; (c) modular structure of the antenna without rotations of the radiating elements



(a) (b) (c)

Fig.3. Pattern performance of the array without rotations of the radiating elements between modules for tilt angle 30 degrees – (a) Total radiation; (b) Left hand circular polarized main beam; (c) Right hand circular polarized QL



(a) (b) (c)

Fig.4. Pattern performance of the array with rotations of the radiating elements between modules for tilt angle 30 degrees – (a) Total radiation; (b) Left hand circular polarized main beam; (c) Right hand circular polarized decollimated QL