Subarray Quantization Lobe Decollimation

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***Abstract*—This paper presents a new method for the reduction of quantization lobes produced by beam scan in an array of subarrays. These quantization lobes occur at the grating lobe angles and are decreased by the subarray pattern. It is shown that they can be further reduced by adding a random phase component to each subarray. For two element subarrays the quantization lobes (QL) suppression is roughly 10–12 dB.**

***Index Terms*—Phased arrays, scanning antennas.**

I. Subarray Quantization

SCANNING an array of subarrays produces extraneous beams called quantization lobes (QL). Although these beams occur at the grating lobe angles that correspond to the separation between subarrays, they are named separately as they do not occur at broadside (as grating lobes do). Their amplitudes are reduced by the subarray pattern. For subarrays of M elements spaced d apart, an N-element array has the pattern

$$E(\theta) = E_{e\ell}(\theta) \cdot \frac{\sin NS\pi u_s}{NS \sin \pi u_s} \cdot \frac{\sin M\pi u}{M \sin \pi u} \tag{1}$$

where $u = (d/\lambda)\sin\theta, u_s = M(u - u_0), \theta_0$ is the scan angle and the number of subarrays is NS. Wavelength is λ. Clearly, the two $\sin NX/N \sin X$ terms represent, respectively, the pattern of an isotropic array with spacing equal to the subarray width and the subarray pattern itself. The element pattern is $E_{e\ell}(\theta)$ [1].

The ability to subarray is important as each subarray typically connects to a transmit/receive module; thus, the number of modules needed is reduced by M. Suppression of the QL would significantly reduce the cost and complexity of phased arrays.

II. Quantization Lobe Decollimation

The authors have not found any articles that offer QL reduction. However, the success of pseudorandomization for precision beam steering [1], [2] suggested that randomization might decollimate the QL. Collimated rays are parallel; decollimation adds phases to disperse the ray angles so that a strong beam is not formed.

The new subarray QL decollimation principle presented in this paper randomizes the positions of the phase centers of the subarrays; these centers are used to compute subarray scan phases.

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III. Results

For the calculations herein, an array of roughly 100 elements is used as an example. How the results depend upon N is not yet known, but the array should contain at least three subarrays. In all calculations, the element spacing is half-wave. Exact scan phases are used. A simple random number generator [3] was used to provide numbers between zero and one and these were applied to move each subarray phase center. The phase center was selected at the element whose position most closely matched the random number.

The array was symmetric so that N/M is always even; the random phase was spread across the entire array to maximize the number of random numbers used. Although no attempt was made to provide a random process with zero mean (actually 0.5), there appears to be no shift in main beam position or change in main beam amplitude. Only the QL decreased.

Trying different random number seeds gave a variation of several decibels in decollimated height and, of course, the seed finally used is probably not optimum. Examination of any random number table shows how difficult it is to select a small (<100) set of numbers that are not weighted in one direction or another.

Fig. 1 gives the pattern for two element subarrays and for scan of 30°. The QL is spread out into several lobes with a reduction of nearly 10 dB. For 45° scan, the results are more striking as the decollimated QL (Fig. 2) is 12 dB down. When the element pattern is applied, the main beam and the QL will be affected differently, depending upon their angle from broadside. In all figures the element pattern has been suppressed as the change in QL amplitude is of primary importance.

When discrete randomization is applied to subarrays of more than two elements, an unexpected phenomenon appears. For four-element subarrays, with 45° scan, the QL at 11.95° and −52.44° are decollimated, but some QL are unchanged! The simple explanation is that when

$$(W/\lambda)\sin\theta_0 - \sin\theta_{q\ell} = 2, 4, \cdots \tag{2}$$

where $W = Md/\lambda$, the randomization phases are all zero at $\theta_{q\ell}$ as they are at θ_0. Four-element subarrays with 30° and 45° scan have unchanged QL at −30° and −17.03°. Other QL are decollimated and suppressed. For three-element subarrays, scans of 30° and 45° produce unchanged QL at −56.44° and −38.77°, respectively. This problem is not shared by two-element subarrays, as only endfire scan will satisfy (2). These results have been verified through calculations and plots. As a result, it is clear that continuous randomization should be used for subarrays larger than two elements. In the continuous scheme, the random number located the phase center from the left element (zero) to the right element (one) and all

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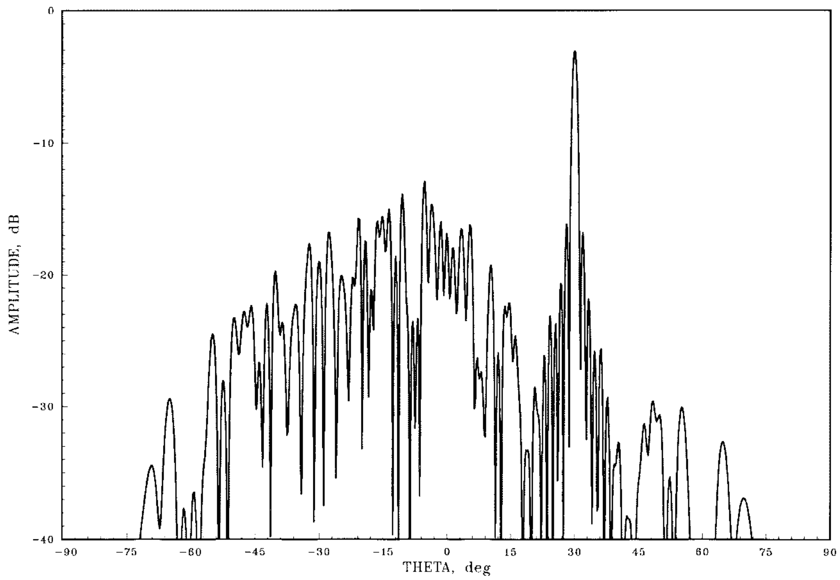

Fig. 1. Linear array, 100 EL/50 SA, $\theta = 30$, binary random phase.

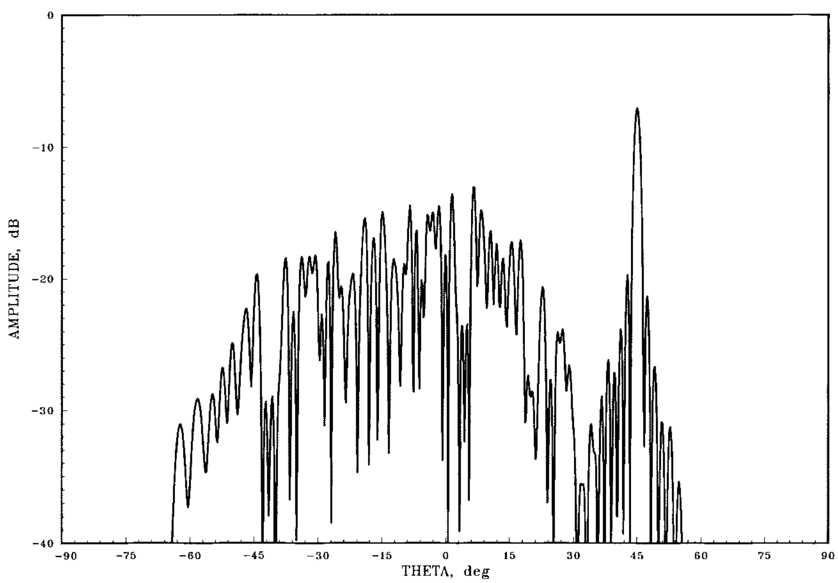

Fig. 2. Linear array, 100 EL/50 SA, $\theta = 45$, binary random phase.

points in between. Results, to be published later, show that this decollimation is as effective for large subarrays as is the discrete application to two-element subarrays. However, the narrower pattern of large subarrays suppresses the main beam; thus, such subarrays are not attractive.

IV. Conclusions

Randomization of subarray phase center for array scanning can reduce the QL by 10 dB for two-element subarrays. Binary randomization (at the subarray elements) appears best. For subarrays of more than two elements, continuous randomization is effective, but the effect of the subarray pattern in reducing main beam gain for off-axis scan makes these subarrays less attractive.

A careful choice of random numbers is critical; not all sets of random numbers are of equal utility. For some applications, randomization may allow use of two element subarrays, thereby reducing the number of phasers or transmit–receive (T–R) modules in half. These linear array results are expected to apply to planar arrays as well.

References

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Gregory G. Charlton (S'58–M'60) was born in New York, NY, in 1938. He received the B.E.E. and M.S.E.E. degrees from the Polytechnic Institute of Brooklyn (now Polytechnic University), Brooklyn, NY, in 1960 and 1967, respectively.

From 1960 to 1967, he was employed by Wheeler Laboratories (now Hazeltine Corporation), Great Neck and Smithtown, NY, where he worked on the design and development of a variety of antenna types, including array antennas, array elements and feeds, Cassegrain antennas, and conical scan antennas. His work also involved the design of strip line devices, polarization sensitive surfaces, monopulse components, and radomes. He has been employed by ITT Gilfillan, Van Nuys, CA, since 1967 in various engineering capacities including Antenna Section Manager and Staff Scientist. He is currently responsible for advanced conceptual design of antenna and microwave components and related antenna system designs, participating in proposals, through all phases of development and production. He is responsible for supporting antenna efforts in ITTG's Advanced Engineering active aperture array antenna new business thrusts. His efforts include antenna conceptual design, antenna system optimization trades, performance analyzes, multiple function integration, cost-performance trade studies, and development/production support. He has participated in the design and development of numerous antenna and microwave related systems, including techniques for two-dimensional antenna feeding and phasing for low sidelobes and multiple beams or monopulse; optimization of array element spacing and scan coverage with pitch and roll; polarization techniques and polarization sensitive dielectric surfaces; radar cross section analysis; low-profile smart-skin array antennas; wide scan angle, wide bandwidth antenna, and microwave concepts; scattering analysis and mast interference; array random error analysis; main beam/sidelobe nulling techniques, antenna synthesis, overlapping subarrays; and near-field analysis. His specialties include expertise in large aperture array antennas and related components.