Wideband Array Antenna Concept[1]

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SUMMARY & CONCLUSIONS

This paper presents a unique wideband array concept that includes a wideband array aperture incorporating radiating elements of different sizes and inter-element spacings. The array is a fully-filled aperture consisting of a core region surrounded by several layers of radiating elements which increase in size. By proper selection of the core region and the number of layers, one can form a beam with specified beamwidth over a five to one frequency range. The proposed concept considerably reduces the cost and complexity by decreasing the effective number of radiating elements and the corresponding receive or transmit modules. Numerical simulation results, ignoring the mutual coupling effects, are presented for array patterns at several frequencies to prove the concept. A possible beamforming concept is also included. Additional work is planned to prove the viability of the concept by taking the mutual coupling into account.

1. INTRODUCTION

The paper describes a very wide bandwidth array antenna concept that minimizes the cost and complexity to either transmit or receive electromagnetic signals over a very wide bandwidth, at least 5 to 1 range in frequency, and to always maintain a minimum beamwidth that is specified by design over this entire frequency range. Array antennas are usually constructed using the same size radiating element and with a fixed spacing between radiating elements. Using this rationale and considering the highest frequency, the antenna would be constructed with large numbers of small but very wide bandwidth radiating elements having dimensions of roughly a half of a wavelength at the shortest wavelength. If the array were constructed with very wide bandwidth radiating elements using the longest wavelength spacing, there would be serious grating lobes in the antenna patterns at the higher frequencies. In either case, there is a problem. In the first case, the array antenna is very expensive because of the very large number of transmit or receive modules required behind each of the very large number of small radiating elements. In the second case, there is a serious performance issue. Thinned arrays are sometimes suggested to reduce cost by reducing the number of elements [1] in the array. However, thinned arrays result in lower gain and higher sidelobes for a given aperture size. This paper describes an array antenna that contains a minimal set of radiating elements with varying size and inter-element spacing yet maintains good performance over a very large frequency bandwidth.
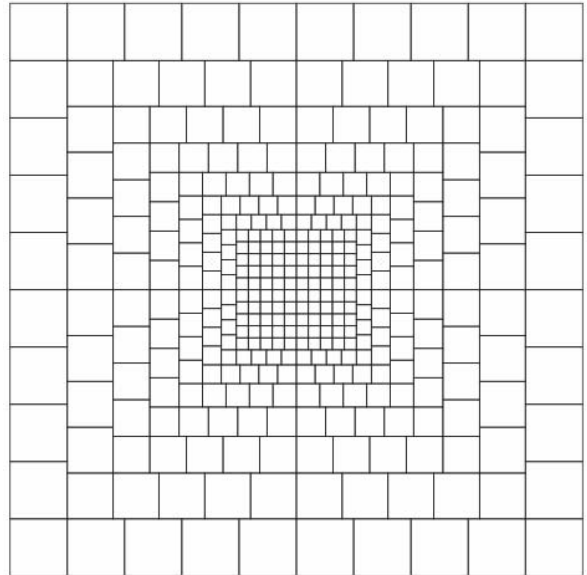
Fig. 1: Element size and locations for an array that can form a 10° x 10° beam for any frequency between 4 and 18 GHz
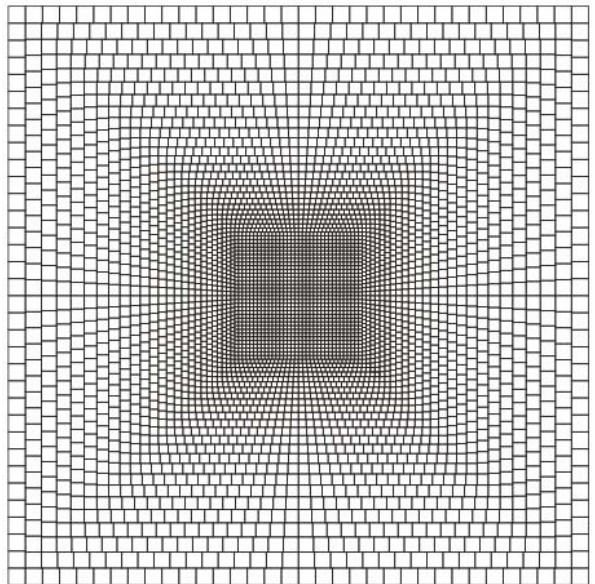

Fig. 2: Element size and locations for an array that can form a 3° x 3° beam for any frequency between 4 and 18 GHz

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2. RADIATING APERTURE

The fundamental concept is to (1) construct a core area using similar, very wideband, radiating elements with element spacing of λ/2 where λ is the shortest wavelength and (2) add layers to the perimeter of the core area such that the element size and inter-element spacing continues to increase as a function of increasing wavelength. The concept, using a 4.5 to 1 frequency range, is illustrated in Figs. 1 and 2 for 10° and 3° beamwidth cases respectively.

Fig. 3 illustrates the process of developing the wideband aperture using different sizes of radiating elements with different inter-element spacings. For the discussion here, the core region with NxN elements is considered the first layer. The number of elements in the row of the next layer is also N, except that the physical element size is determined by the assumption that only N-2 elements in the next layer will occupy the same size as N elements in the core area. This type of relationship is assumed for all layers. Only the core region will be used to generate a specified beamwidth (10º in Fig. 1) at the highest frequency. For lower frequencies, the core area plus one or more layers will be used, depending on the frequency of operation to generate the same beamwidth. Fig. 3 illustrated the element sizes and inter-element spacing in the adjacent layers. The relationship between the layers can be expressed as

$$\lambda_{i+1} = \{(N / (N-2)\} \, \lambda_i,$$

where λ_i corresponds to the lowest frequency for which all the radiating elements in the ith layer and below layers are active. The element spacings in each layer are $\lambda_i/2$.
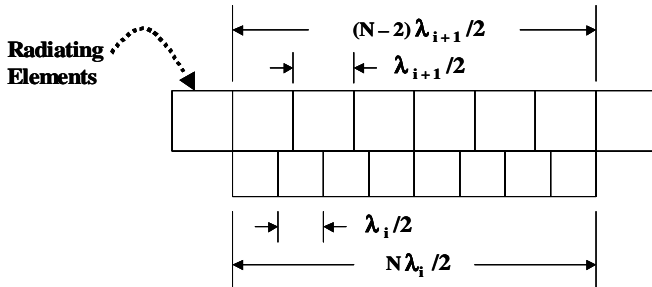

Fig. 3: Illustration of the relationship between element size and inter-element spacing in adjacent layers

Wideband radiating elements, typified by flared notches [2] are illustrated in Fig. 4.
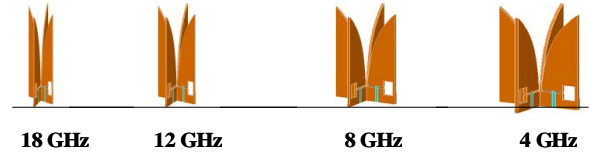

Fig. 4: Wideband radiating elements typified by dual polarized flared notches

In this case, the higher frequency flared notches are smaller in cross section than the lower frequency flared notches that could be narrower in bandwidth. What is reported in this paper is a new concept for wideband array antennas. Additional work is planned to prove the viability of the concept. The concept utilizes different sizes of radiating elements with different inter-element spacing. Some of the issues which will be addressed in the future include the performance of the various radiating elements (VSWR, element gain, etc…) when the mutual couplings are taken into account, differences in element phase centers, element phase errors – if any 0 due to mutual coupling and their effect on achievable sidelobe levels.

Table 1 shows the dramatic reduction, for square array apertures, in the number of required elements obtained by using the new design method instead of the traditional design method, which uses the same size element throughout the array.

Similar radiating structures can be constructed for rectangular arrays. One method is to use the constraint equation previously provided for only one dimension and let the other dimension vary as needed to form the "fan" beam. This method is valid for only one polarization in the dimension that fits the constraint. The other method, that is valid for both polarizations, simply removes some elements from the square array making the new aperture shape rectangular. The locations and size of the elements for apertures formed in both ways are illustrated in Figs. 5 and 6.

Table 1: Saving in number of radiating elements for square array apertures with new wideband array antenna design (constrained) versus using the smallest element throughout the aperture (no constraint)

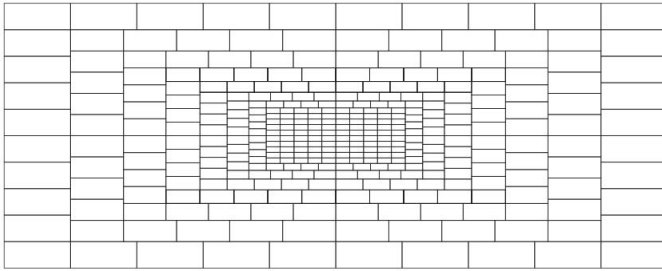| Beamwidth (Deg)	# of Elements per row/column/side	Square Dimension (cm)	Total # Elements with constraint	Total # Elements no constraint	# Elements Saved	% Savings
1	102	382.85	41108	211070	169962	80.5
2	51	194.36	10201	54397	44196	81.2
3	34	128.98	4456	23955	19499	81.4
4	26	99.15	2576	14155	11579	81.8

Fig. 5: Element sizes and locations for an array that can form a 10° x 25° beam for any frequency between 4 and 18 GHz, Horizontal polarization only
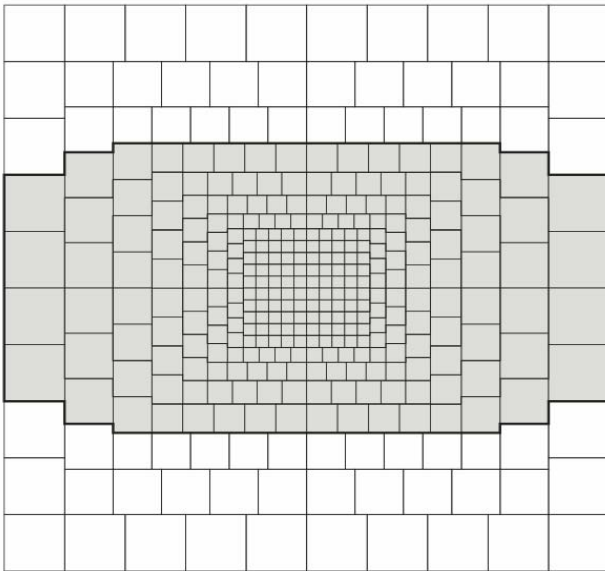

Fig. 6 Element size and locations for an array that can form a 10° x 25° beam for any frequency between 4 and 18 GHz, Dual polarization

3. ANTENNA PATTERNS

The antenna patterns, for u = sin θ cos φ and v = sin θ sin φ as shown in Fig.7, are shown in Fig. 8.
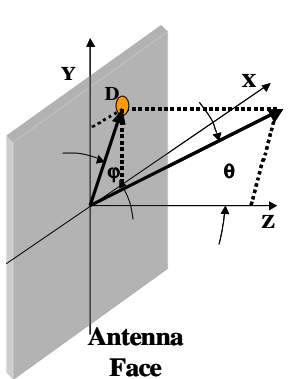

Fig. 7 Coordinate system for antenna patterns
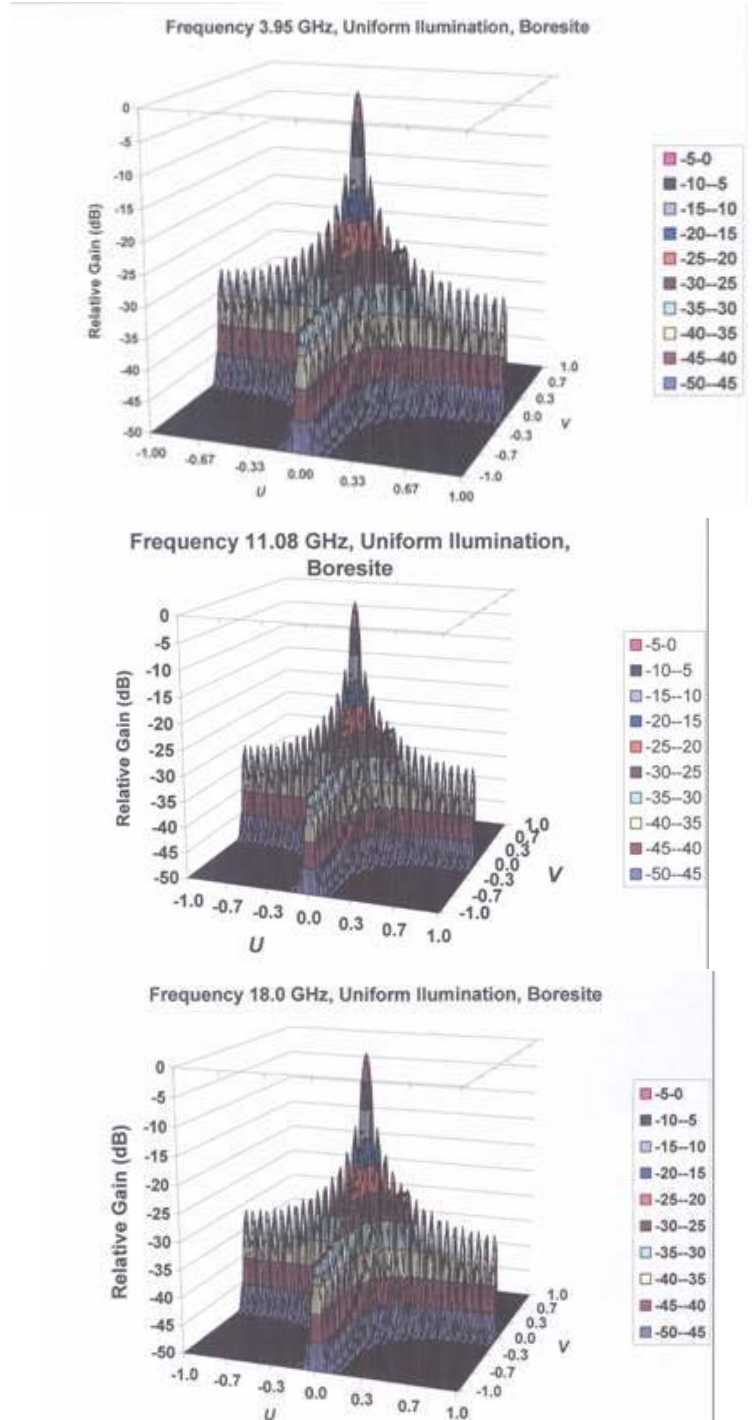

Fig. 8 Antenna patterns for the new wide bandwidth antenna using uniform illumination and for the three-degree beamwidth case having a gain of 32.55 dB

Observing Fig. 8, the antenna patterns are virtually identical for all three frequencies (3.95, 11.08, and 18.0 GHz). For the lowest frequency, all the radiating elements in the aperture are used, for the middle frequency about half of the interior elements are used, and for the highest frequency only the central region, containing only the smallest elements, is used in forming the beams.

4. BEAMFORMING CONCEPT

Multiple beams are formed using a pancake type structure as illustrated in Fig 9.

Because, it is difficult to place all the beamforming parts on a flat surface, an additional panel that is perpendicular to the each beamforming panel is incorporated to provide the space required as illustrated in Fig.11.
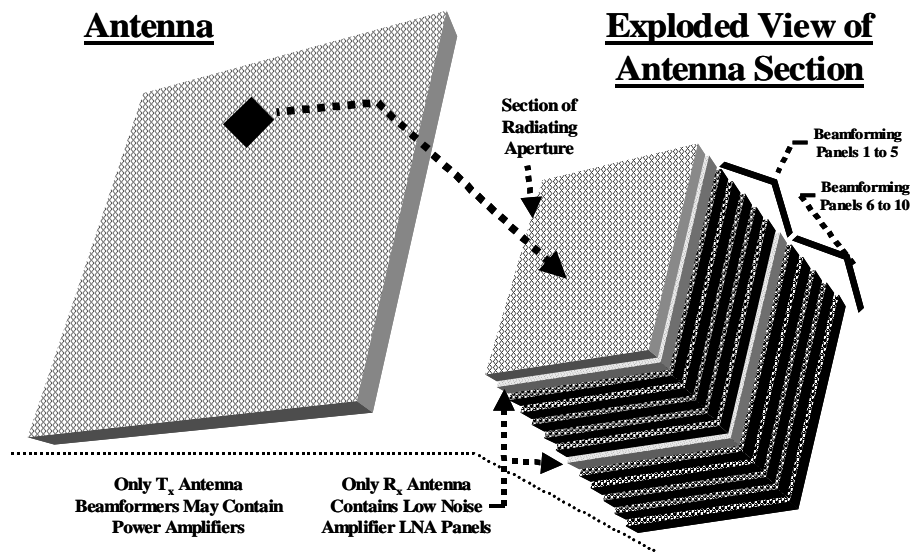

Fig. 9: Receive and/or Transmit antenna structure using stacked beamforming panels

Each panel contains a beamformer consisting of phase shifters, attenuators, and combiners. The panels are connected to the radiating aperture using transmission lines threaded through the panels. Each panel couples its signal to the threaded transmission line using either a directional coupler or a diplexer, as illustrated in Fig. 10.
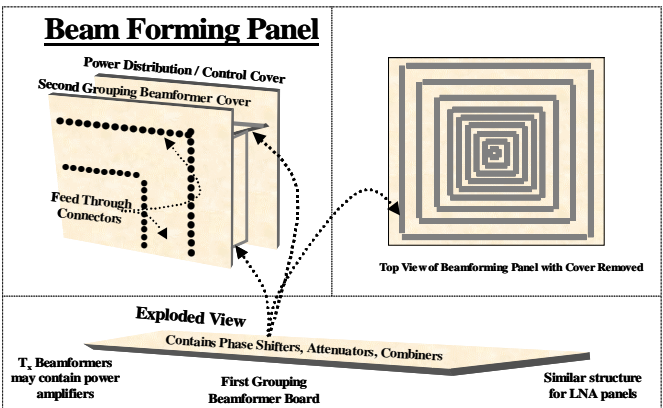

Fig. 10: Means of coupling the beamforming panels to the radiating aperture of the wide bandwidth antenna array

Fig. 11: Beamforming panels incorporating perpendicular panels such that there is ample space for the beamforming electronics.

REFERENCES

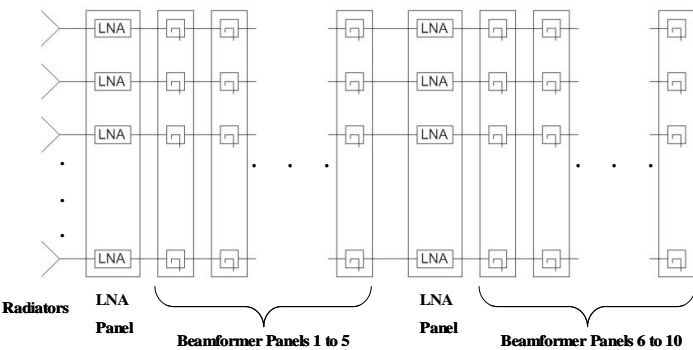1. M. Skolnik, Ed., "Radar Handbook", 2nd Edition, McGraw-Hill, Inc., 1990, pp. 7.26 to 7.27

2. J. B. L. Rao, M. Kragalott, W. R. Pickles, and C. T. Lin, "Some Recent Advances in Wideband Phased Arrays", 9th Int. Symp. On Antenna Technology and Applied Electromagnetics (ANTEM-2002), 30 July – 2 Aug 2002, Montreal, Canada, pp. 361-363