ARRAY RADARS

A Survey Of Their Potential And Their Limitations

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Editor's Note — The array type of antenna has come from a little used concept in World War II to an item of major importance today. Fixed beam arrays with electronic lobing are being used to replace fire control dish antennas, multiple beam arrays are being used for airport surveillance, large electronic scanning arrays are being used for target detection and tracking. The Microwave Journal is pleased to announce a series of articles on Phased Arrays and Electronic Scanning. Covered in the series will be electronic lobing, simultaneous scanning, tubes for distributed amplifier arrays, and other subjects. The following article by J. L. Allen initiates the series.

I. Introduction

The present traffic of satellites, space probes and missiles has placed increasing demands upon radar performance. More radiated power, larger precision antennas, greater receiver sensitivity and improved extraction of information are required. Thus, radars have grown from the "heavy" radars of World War II, of which Figure 1 is typical, to "space age" installations such as that of Figure 2 in which the surveillance radar antenna area is greater than that of a football field.

As the demands continue to grow, the radar designer is forced into ever more conflicting requirements, such as the simultaneous need for larger, more precise antennas and for faster scanning until he is led to consider approaches so radical as to have been considered impractical in the light of previous demands. One approach, the first significant realization of which predates World War II (10**), is the use of the array antenna configuration in which a large number of antennas are used, interconnectetd to radiate coherently. By incorporating phase shifters with each antenna, a beam can be formed and "steered" over quite wide angles without antenna motion; and by the use of electronically variable phase shifters, the beam can be moved in microsecond times. Thus, we have come to another "new look" in radar, the "array radar," of which Figure 3 is representative.

The purpose of this paper is to explore in a qualitative way the potentials and limitations of array radars, with emphasis on ground-based, long range radar applications.

* *Operated with support from the U.S. Air Force.*
** *The numbers refer to the references in the Bibliography.*

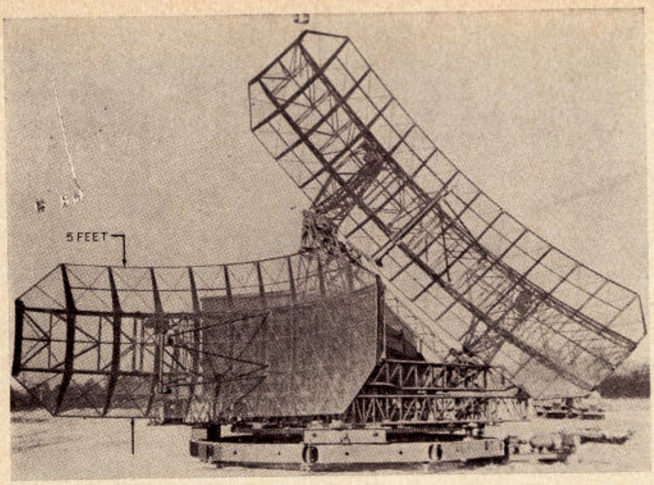

Figure 1 — World War II "heavy" radar.

To lay the groundwork for such an exploration, we will first briefly review some fundamental array types and limitations. The parameters of a radar that are most basic to its ability to successfully perform the three radar functions of detection, resolution and measurement will then be reviewed. The capacity of array configurations to perform these functions will be compared with the capacity of more conventional radars, and the resultant complexities and costs pointed out. Areas of research which offer promise of reduction of these costs will be indicated.

II. Some Background Data

While we will not delve into the technical details of array antennas*, it will be useful as grounding for later discussion to briefly point out the size (number of antennas) of arrays likely in radar applications and some fundamental array configurations. It will be seen that while the performance objective largely determines the number of elements, arrays still come in different degrees of complexity, capability and, axiomatically, cost.

A. The Number of Antennas Required for Array Radars

The complexity of an array is certainly proportional to the number of individual antennas (elements).

As a crude, but useful guide, a flat (planar) array, with half-power beamwidths θ and ϕ degrees in elevation and azimuth planes, requires a number of elements, N, of the order of

$$N \approx \frac{10^4}{\theta\,\phi}$$

indicating that, for example, a pencil beam 1° x 1° requires roughly 10,000 antenna elements. Further, the usable angle of scan of a single planar array is limited by the decrease in the projected size of the antenna at wide angles. As wider angles of scan are attempted, the number of elements required to realize a desired system sensitivity increases so rapidly that it would be economically more practical to

Some of the references contain detailed discussions of theory as well as further references; see particularly Refs. 2, 3, 27, 28, 30.

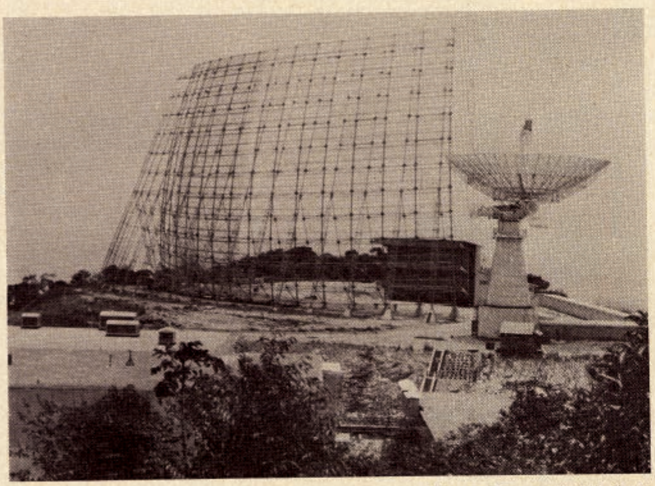

Figure 2 — Missile surveillance and tracking radars.

build more than one array with faces pointed at different angles, with each array having less stringent scanning requirements. For arrays on a flat surface, a scanning cone of 90° to 100° central angle is achievable. Thus, to scan a hemisphere, as most present aircraft surveillance radars do, would require at least four arrays.

How about arrays on cylinders or spheres? Investigation of these configurations will show that the limitations on the percentage of the surface that can be used to produce a beam at one instant are such that about the same number of elements are required for a given surveillance volume, regardless of the geometry.

Thus, in the following discussion, the reader should bear in mind that for two-dimensional arrays, the number of elements involved is likely to be of the order of thousands and several array faces may be required to survey the volume.

B. *Some Typical Array Configurations**

Figures 4 and 5 distinguish between two basic classes of arrays (using linear arrays as examples, although most of the techniques can be extended to other surfaces).

The configurations of Figure 4 represent fundamental versions of what might be termed "steerable" arrays, in that they produce a single beam at the terminal point which can be scanned by varying the element phasing. Shown in the Figure are the simplest forms of the basic techniques: frequency variation, the use of variable phase shifters and the use of variable delays, roughly in order of both increasing complexity and increasing capability for handling broadband signals. Many embellishments of these basic techniques exist[27,28] but will not be discussed here.

Figure 5 shows three fundamental configurations of "multi-beam" arrays[5,6,27]. These devices form many simultaneous beams fixed in spatial position. Each beam has the full gain normally associated with an array of the size used, subject to some limitations on beam shapes and closeness of beam spacing (cross-over levels)[1].

Since the multi-beam feeds are fabricated entirely of non-variable, passive circuitry, they can be made more reliable, cheaper and more reproducible than steerable arrays. On the other hand, as a result of the fixed nature of the beams, angular information is inherently somewhat** less accurate on the average than from a steerable beam array. This decreased accuracy arises from the fact that angular measurement accuracy varies, depending upon the target's location in the beam. With steerable arrays, this position may be optimized for each target; with the basic multi-beam arrays, one must settle for whatever comes.

For two-dimensional scanning, one can use "arrays of arrays," as indicated for the multi-beam type array in Figure 6. Further, it is often profitable to employ "hybrid" systems in which one technique is used for combining rows of elements and another for columns in a planar array. Thus, for example, one might use frequency variation to scan along the rows with each row schematically resembling Figure 4a, with each row acting as an "element" of a feed of the type of Figure 4b, using variable phase shifters. Another useful combination might be to use multi-beam feeds in rows with phased feeds in columns to implement a steered stack of beams, and so forth. Separate transmitting and receiving arrays using different techniques may also be advantageous.

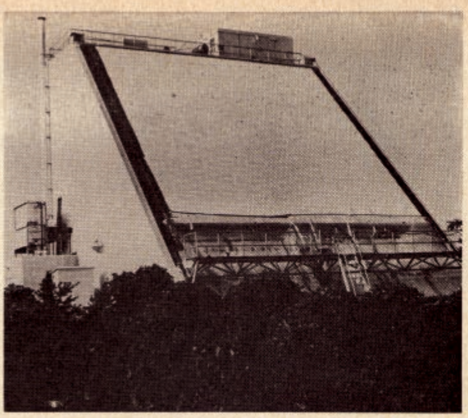

Figure 3 — ESAR — An electronic scanning L-band radar. The rectangular panels on the sloping face contain over eight thousand antennas imbedded in plastic.
(*Courtesy of the Bendix Corporation*)

C. *"Passive-Element" and "Active-Element" Arrays*

Any of the foregoing arrays can be constructed in such a manner that no "active"+ components are introduced into the system until after (using receiving terminology) the beam terminals of Figures 4 and 5. Such arrays will be referred to as "passive-element" arrays. That is, one could realize an array radar with such techniques "merely" by the replacement of the antenna assembly of a conventional radar by an array assembly of the proper number of elements and the installation of the necessary control equipment. While such a replacement permits the use of electronic ("inertialess") scanning, it may lead to decreases in transmitted power and receiver sensitivity due to increased RF losses. Further, the phase shifters themselves may be lossy and/or power limited.

An appreciable extension of radar performance can be obtained by integrating the active electronics into the array itself, enlarging our previous concept of an "element" to include part or all of a radar transmitter and/or receiver, as schematically indicated in Figure 7. Such an array will be referred to here as an *active-element* array. The active electronics associated with each element "module" may range from a simple single-stage amplifier (medium to high power for active-element transmitting arrays and/or a low-noise amplifier for active-element receiving arrays) with associated phasing devices, as indicated in Figure 7, to an almost complete radar, as indicated in the block diagram of Figure 8. To impart some physical significance to this concept, some experimental active-element 900 Mcps modules, in which little attempt has been made at compact packaging, are shown in Figure 9[2,3].