ARRAY ANTENNAS UTILIZING GROUPED RADIATING ELEMENTS

Filed July 25, 1968 4 Sheets-Sheet 1

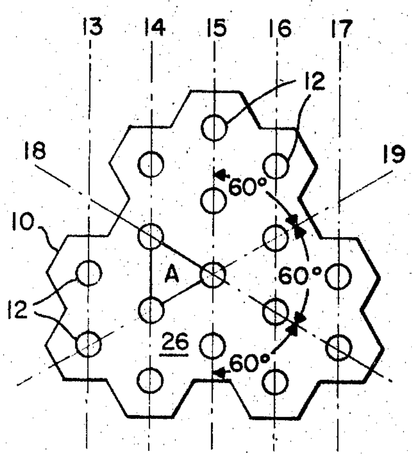

FIG. 1a

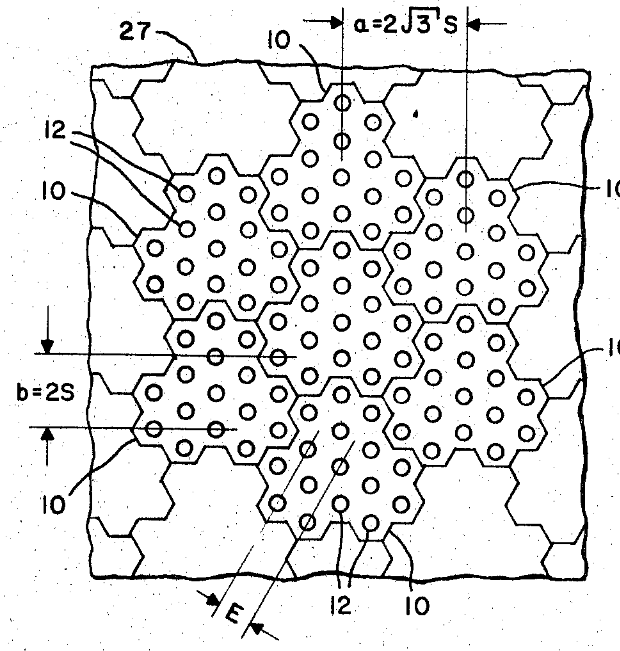

FIG. 1b

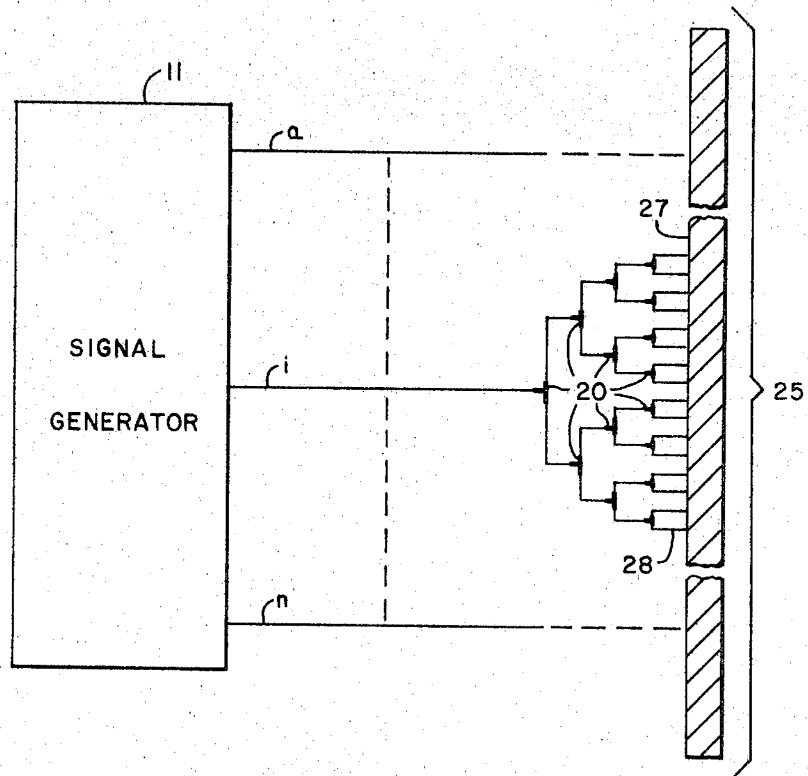

FIG. 1c

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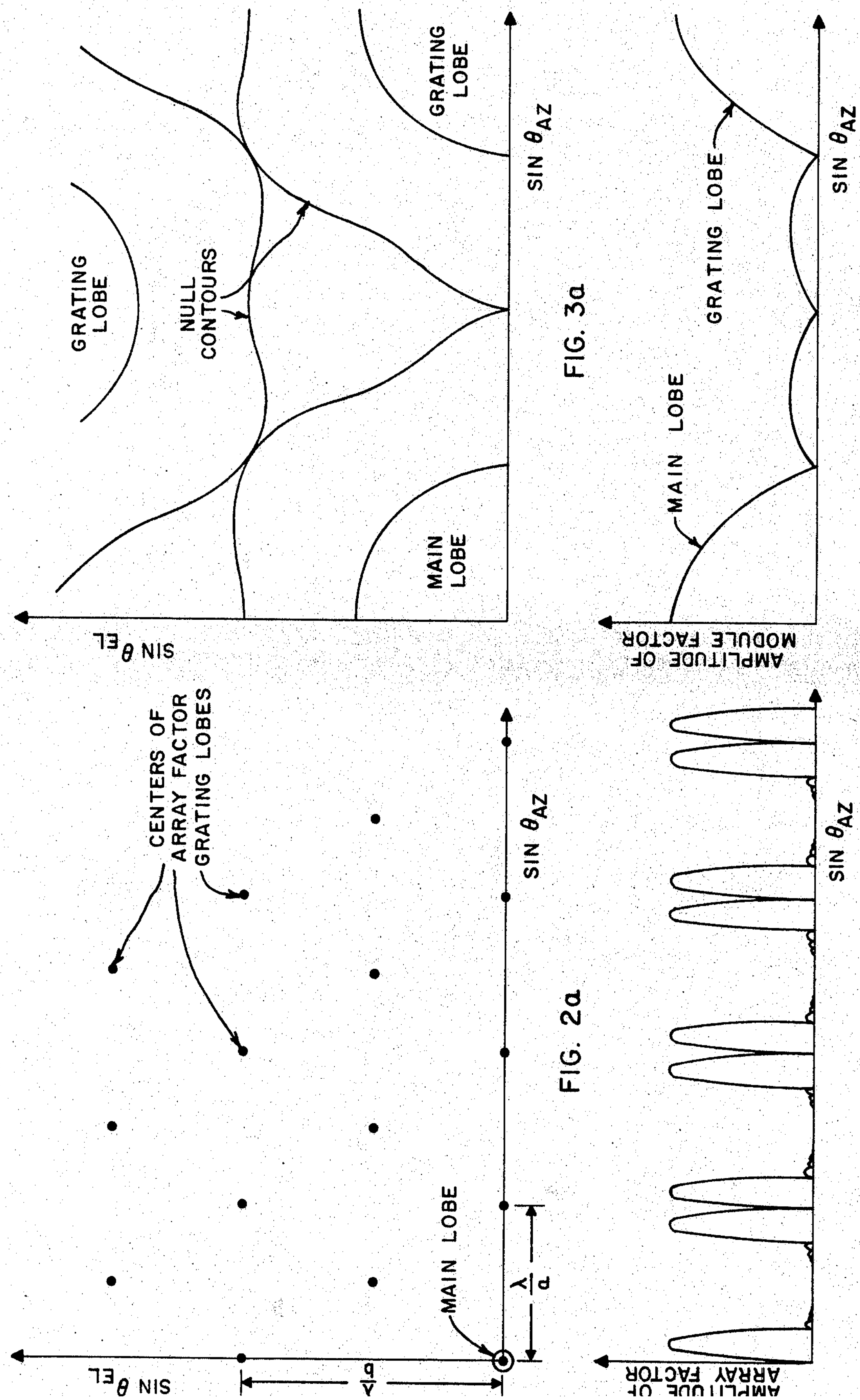

FIG. 3a

FIG. 3b

FIG. 2a

FIG. 2b

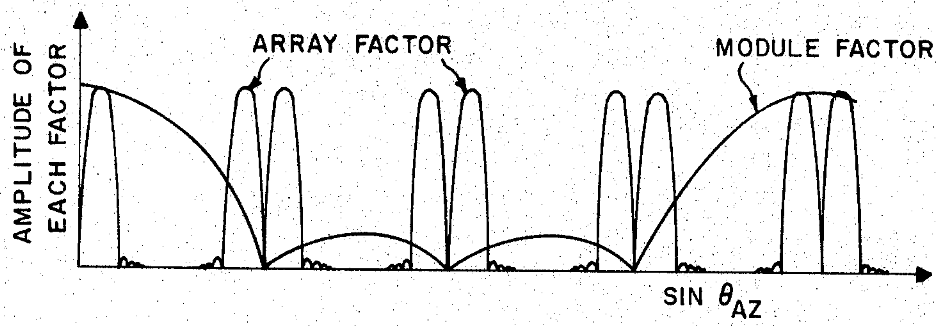

FIG. 4a

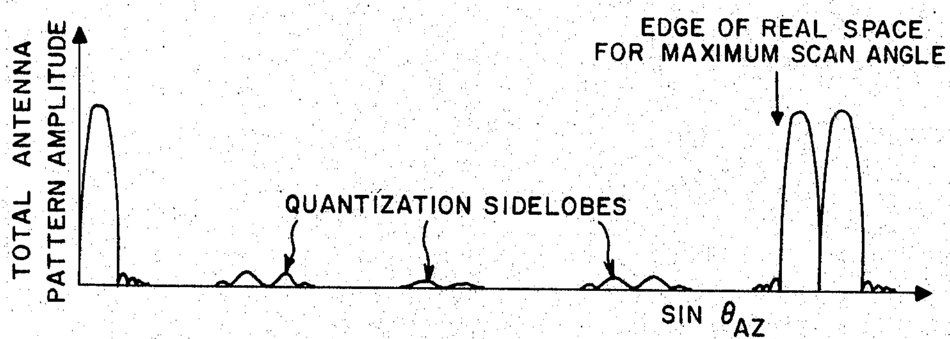

FIG. 4b

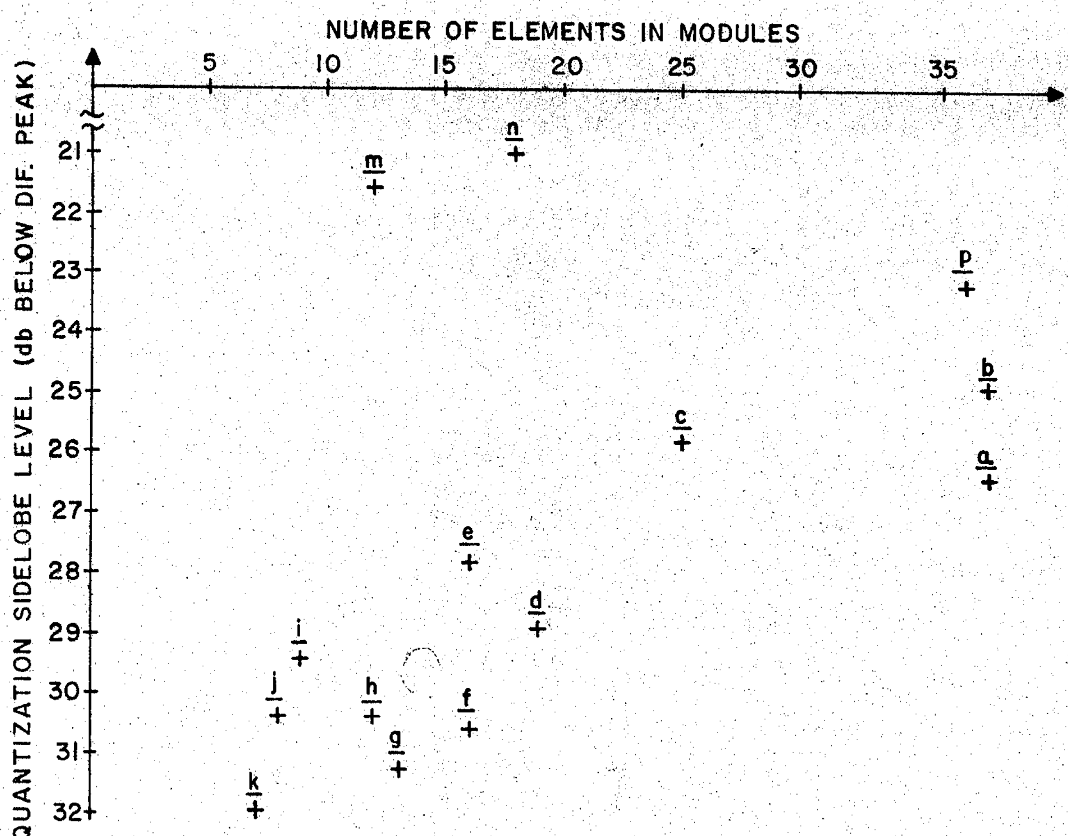

FIG. 6

ARRAY ANTENNAS UTILIZING GROUPED RADIATING ELEMENTS

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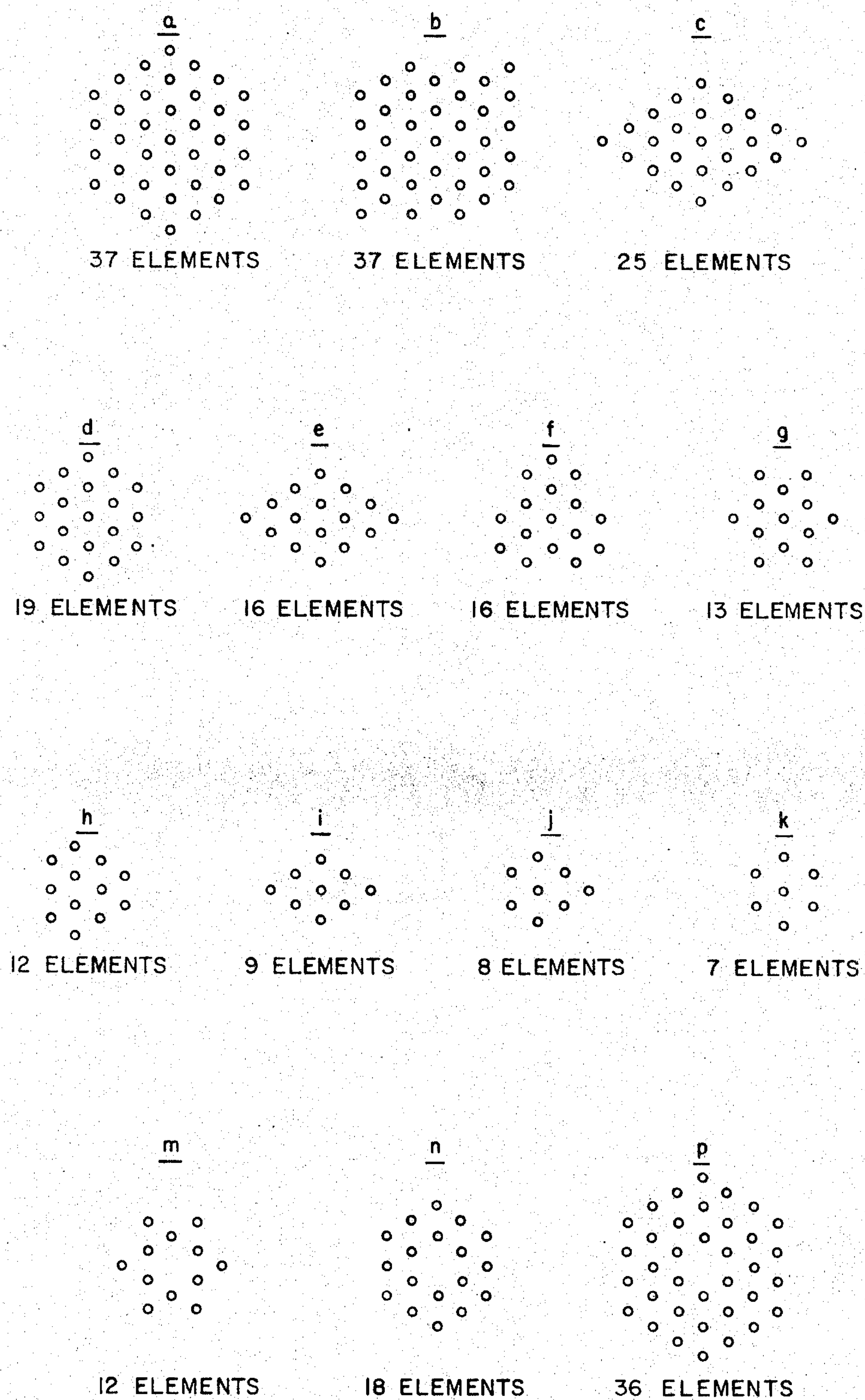

FIG. 5

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ARRAY ANTENNAS UTILIZING GROUPED RADIATING ELEMENTS

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Int. Cl. H01q *13/00*
U.S. Cl. 343—777 3 Claims

ABSTRACT OF THE DISCLOSURE

An array antenna wherein the radiating elements are quantized into groups of elements. Each group consists of sixteen elements in five adjacent columns of a triangular grid, having four elements in each of the three inner columns and two elements in each of the outer columns. In each group the elements are arranged to be symmetrical about three axes having a common intersection and separated by sixty degrees. The elements that comprise each group are commonly excited and each group of elements is excited by a diffeernt basic excitation signal. This arrangement substantially reduces the number of basic excitation signals required and provides efficient excitation of each element with low quantization sidelobes.

This invention is directed to array antennas and more particularly to large arrays having a substantial number of individual radiating elements arranged in more than one dimension. The invention is applicable to planar arrays and may also find application in spherical or other curved arrays.

For an array antenna, independently controlling the excitation amplitude of each element provides optimum performance. However, for antennas having a large number of radiating elements, independent excitation of each element requires a very complex and expensive signal generator and feeding network. The signal generator and feeding network can be simplified by quantizing the radiating elements into identical groups of modules and feeding each group independently. However, such grouping of elements can result in undesirable amplitude quantization sidelobes. Quantization sidelobes are analogous to grating lobes and result from the large spacing between the centers of each group of elements independently excited.

Objects of the present invention therefore are to provide new and improved array antennas which provide efficient, economical excitation of the radiating elements and produce minimal amplitude quantization sidelobes.

In accordance with the present invention there is provided in an array antenna, wherein grouping of the array elements reduces the number of basic excitation signals required to excite all the elements, an arrangement achieving efficient excitation of the array elements with low quantization sidelobes which comprises a plurality of identical groups of radiating elements, each group consisting of sixteen radiating elements in five adjacent columns of a triangular grid having four elements in each of the three inner columns and two elements in each of the outer columns and arranged to be symmetrical about three axes having a common intersection and separated by sixty degrees. The invention also includes means for coupling a different basic excitation signal to each group of elements, the signal coupled to each group being coupled to all of the elements in the group, whereby the prescribed grouping of elements substantially reduces the number of basic excitation signals required, provides efficient excitation of each element and substantially reduces the quantization sidelobes.

For a better understanding of the present invention together with other and further objects thereof, reference

is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings:

FIGS. 1*a*, 1*b* and 1*c* illustrate an array antenna system constructed in accordance with the present invention;

FIGS. 2*a* and 2*b* illustrate a typical array factor with the aperture excited in the azimuth difference mode;

FIGS. 3*a* and 3*b* illustrate a typical module factor;

FIGS. 4*a* and 4*b* illustrate a total antenna radiation pattern of an antenna consisting of a plurality of groups of radiating elements;

FIG. 5 illustrates a plurality of groups of elements that can be combined with identical groupings to form an array; and

FIG. 6 is a graphical representation of the quantization sidelobe rseponse of the FIG. 5 groupings.

FIG. 1*a* illustrates a group **10** of sixteen radiating elements **12** arranged in accordance with the teaching of the present invention. The elements **12** are illustrated, by way of example, as circular openings **12** in a metal ground plane **26**. Each of these openings **12** terminates a circular waveguide and each propagates electromagnetic energy coupled thereto by the corresponding circular waveguide. Any other suitable radiating element such as dipoles or slotted waveguides could also be utilized.

The group of sixteen elements **12** are arranged in five adjacent columns **13, 14, 15, 16** and **17** of a triangular grid of elements, having four elements in each of the three inner columns **14, 15,** and **16**, and two elements in each of the outer columns **13** and **17**. The elements **12** are arranged to be symmetrical about three axes **15, 18,** and **19** having a common intersection at 0 and separated by sixty degrees.

The technique of locating radiating elements in a triangular grid is well known to those skilled in the art and need not be described in detail. Briefly stated, the elements are so arranged that each element is located in a corner of an equilateral triangle of elements, as illustrated by triangle A.

FIG. 1*b* illustrates a portion **27** of an antenna consisting of a plurality of identical groups **10** of radiating elements, each group being identical to the groups illustrated in FIG. 1*a*. The groups of elements **10** are joined together to form a large planar array, the portion **27** of which is illustrated in FIG. 1*b*. The individual elements **12** that comprise each group are shown in the center **7** groups of elements in order to illustrate that the grouping of FIG. 1*a* can be combined with identical groups to form a continuous array in a triangular grid with no inactive elements. It is essential that the combining of identical groups such as illustrated in FIG. 1*a* provides a continuous array since an inactive element (a position in the triangular grid where there is no active radiating element) produces deleterious effects in the array pattern as indicated in conjunction with the discussion of FIG. 6.

FIG. 1*c* taken in conjunction with FIGS. 1*a* and 1*b* illustrates an antenna system constructed in accordance with the present invention. As previously stated, the system consists of a plurality of identical groups of radiating elements **10** with each group consisting of sixteen elements arranged as illustrated in FIGS. 1*a* and 1*b*. A front view of a portion of the antenna is illustrated at **27** in FIG. 1*b*. Element **25** is a side view of the entire group of radiating elements including segment **27**.

The system further includes means, illustrated as connections *a–n*, for coupling a different basic excitation signal from the signal generator **11** to each group of elements, the signal coupled to each group **10** being coupled to all the elements **12** in said group. The signal generator

11 also includes distribution network required to provide the desired signals to connections *a–n*.

For some applications, grouping of elements as described above is desired only as an intercoupling arrangement; i.e., to permit coupling a different basic excitation signal to each group for reducing the basic number of excitation signals required. However, for other applications it may be desirable to manufacture each group as a separate module and subsequently assemble the modules into a complete array. This is made possible in the present invention by having each group of elements consist of adjacent elements, rather than having the elements of the different groups interleaved.

In operation, a different one of the basic excitation signals is coupled from the signal generator **11** to the corresponding one of the groups of elements **10** that comprise the antenna **25**, by way of the leads *a–n*. Each of the basic excitation signals is coupled to the sixteen radiating elements **12** that comprise the corresponding group. For example, in FIG. 1*c* the basic excitation signal coupled by the lead *i* to the antenna **25** is coupled to each element of one of the groups **10** of elements illustrated in FIG. 1*b* by the fifteen T junctions **20**. As illustrated the T junctions are arranged so that the basic excitation signal is divided into sixteen substantially equal parts providing equal amplitude excitation of all the elements that comprise that group. Each of the sixteen leads **28** connected to the antenna **25** represents a portion of the waveguide which is terminated by one of the circular openings **12** illustrated in FIG. 1*b*.

Similarly, each of the remaining basic excitation signals is coupled to one of the groups **10** of radiating elements by another group of fifteen T junctions so that there is equal amplitude excitation of all the elements that comprise the corresponding group. The nature of the basic excitation signals coupled from signal generator **11** depends on the type system in which the invention is employed. The invention is equally applicable to any array; i.e., a phased array, a monopulse array, etc.

The arrangement of FIG. 1 provides sufficient improvements over the prior art. As illustrated in FIG. 1*c*, quantizing the radiating elements **12** into groups of sixteen, substantially reduces the number of basic excitation signals supplied by means **11**. Furthermore, since sixteen is a binary number, the FIG. 1 arrangement makes possible the efficient equal amplitude excitation of each element that comprises a group **10** by utilizing simple inexpensive T junctions **20** to couple the basic excitation signal from means **11** to all of the elements that comprise the group. If the number of elements in each group were other than a binary number specially designed couplers would be required to achieve equal amplitude excitation of the elements that comprise each group.

Furthermore, the grouping of elements illustrated in FIGS. 1*a* and 1*b* provides superior sidelobe performance. To illustrate this superior performance the following discussion describes the present invention embodied in a monopulse system excited in the azimuth difference mode and compares the performance with other possible grouping arrangements similarly excited. This is done only to illustrate the comparative performance of the present invention and this invention is in no way limited to monopulse systems.

In order to compare quantization sidelobes, it is necessary to obtain the total antenna radiation pattern. The total antenna radiation pattern of an array of elements which are grouped together in identical modules such as illustrated in FIG. 1*b* is determined by obtaining the product of the "array factor" the "module factor" and the "element pattern." The "array factor" is the pattern of isotropic radiators located at the center of each module **10**. The "module factor" is the pattern of one module **10** with isotropic radiators located at each element **12**. The "element pattern," which is the pattern of one element **12** in the presence of the others, can be neglected since it is slowly varying with angle.

The array factor has many grating lobes in real space since the module spacing is many element spacings E as shown in FIG. 1*b*. A typical array factor with the aperture excited in the azimuth-difference mode is shown in FIGS. 2*a* and 2*b* where *a* equals the module spacing in the azimuth plane, *b* equals the module spacing in the elevation plane, θ equals the angle from the main lobe and λ equals the free space wavelength. Both the grating lobes and the main lobe shown have approximately the shape of the main lobe for the total antenna pattern. The spacing of the grating lobe centers in a given direction depends upon the module spacing in that direction, as indicated.

A typical module factor is shown in FIGS. 3*a* and 3*b*. The contours plotted are the positions where the module factor nulls occur. The sidelobe peaks occur between these nulls.

The total antenna pattern illustrated in FIGS. 4*a* and 4*b* is the product of the array factor and the module factor. FIG. 4*a* illustrates both the array factor and the module factor in the azimuth plane from FIGS. 2 and 3. FIG. 4*b* shows their product. For the diffference mode as shown, the peaks of the quantization sidelobes occur at angles near the peaks of the array-factor grating lobe. The antenna pattern grating lobe is also shown. The element spacing is chosen to keep this grating lobe from entering real space for the maximum scan angle required.

FIG. 4*a* also indicates that the nulls of the module factor pass through the centers of the array-factor grating lobes. This can be proven by taking the array and adding many more modules to extend it to an infinite array, and then uniformly exciting it. The module factor remains unchanged, and the array factor has a zero-beamwidth main beam and grating lobes located at the same angles. Since the infinite aperture must have only a single zero-beamwidth beam and no sidelobes, the array-factor grating lobes occur at the nulls of the module factor. For the finite array, the nulls of the module factor still occur at the centers of the array-factor grating lobes; however, since the array-factor beamwidth is not zero, the quantization sidelobes are thus formed.

Since the quantization sidelobes occur in the region of the array-factor grating lobes, their level can be obtained by calculating only a small portion of the pattern. It should also be noted that the difference-mode quantization sidelobe levels are higher than that of the sum mode. This is because the difference-mode peaks occur off the array-factor grating lobe centers and therefore result in a greater product of the two factors than in the sum-mode. The sum-mode quantization sidelobe levels are about 5 db lower than the difference-mode.

The quantization sidelobe levels are not greatly dependent on the aperture illumination in the difference mode. This is because the peak of the quantization sidelobes occur about at the peak of the array-factor grating lobes of the difference mode and because the positions of difference-mode peaks are not greatly dependent on the aperture illumination. The sum-mode quantization sidelobe levels are also not greatly dependent on the aperture illumination, but do have more variation that those of the difference mode.

FIG. 5 illustrates many of the various modules or groups of elements that have been evalulated, including grouping 5(*f*), the subject of the present invention. Each of these groupings can be combined with identical groupings to form an array of a desired size. Many other groupings were given primary consideration but discarded because they could not be combined with identical groupings or they obviously had high quantization sidelobes. As in group 5(*f*) each of these modules consists of elements in a triangular grid of elements and all of the elements in each group are active elements.

Although the modules must be large enough to provide simplicity of excitation the modules with the fewer number of elements obviously give lower quantization sidelobes. The smaller modules have broader module factors and therefore have their nulls farther off broadside. This gives a lower slope in the null region and therefore a lower quantization sidelobe. However, it does not provide as much feeding simplicity.

FIG. 6 illustrates the highest difference mode sidelobes resulting from the quantization of the aperture excitation into the groups illustrated in FIG. 5. As expected, the modules with fewer elements give lower quantization sidelobes in general. However, the grouping of 16 elements illustrated in FIG. 1*b* and FIG. 1*c* provides unexpectedly good results for its size, it being kept in mind that the larger the grouping, the simpler the feeding network. The 5(*f*) grouping of elements has better quantization sidelobe response than the grouping of eight elements illustrated in 5(*j*), the grouping of seven elements illustrated in 5(*i*), and the grouping of twelve elements illustrated in 5(*h*). The only other grouping of sixteen elements that can be combined with identical groupings, grouping 5(*e*), has substantially poorer quantization sidelobes. The only grouping that provides comparable quantization sidelobes as the grouping of sixteen elements illustrated in 5(*f*) is the grouping of thirteen elements illustrated in 5(*g*). However, thirteen is not a power of two and the feeding network for an array consisting of identical 5(*g*) grouping would be considerably more complicated than that required for an array consisting of 5(*f*) groupings. Although the 5(*g*) grouping has good quantization sidelobe performance it does not provide the simplicity of excitation provided by the present invention. Similarly, the grouping of seven elements illustrated at 5(*k*) requires a complicated feeding network, would require more than double the basic excitation signals than the 5(*f*) grouping and the improvement in quantization sidelobe performance is not appreciable, considering the fact that the 5(*k*) grouping has less than half of the elements of the 5(*f*) grouping.

The points plotted at *m, n,* and *p* of FIG. 6 illustrate the consequences of having an inactive element in any of the groupings. Grouping 5(*m*), 5(*n*), and 5(*p*) are identical to 5(*g*), 5(*d*), and 5(*a*), respectively, except in the *m, n,* and *p* groupings the center element is inactive. The effect on the quantization sidelobe performance is evident from FIG. 6.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In an array antenna, wherein grouping of the array elements reduces the number of basic excitation signals required to excite all the elements, an arrangement providing efficient excitation of the array elements with low quantization sidelobes, comprising:

a plurality of identical groups of radiating elements, each group consisting of sixteen radiating elements in five adjacent columns of a triangular grid having four elements in each of the three inner columns and two elements in each of the outer columns and arranged to be symmetrical about three axes having a common intersection and separated by sixty degrees;

and means for coupling a different basic excitation signal to each group of elements, the signal coupled to each group being coupled to all of the elements in said group;

whereby the prescribed grouping of elements substantially reduces the number of basic excitation signals required, provides efficient excitation of each element and substantially reduces the quantization sidelobes.

2. An arrangement of radiating elements in an array antenna as specified in claim **1** in which each radiating element is a circular opening in a metal ground plane terminating a circular waveguide.

3. An array atenna as specified in claim **1** in which the groups of radiating elements form separate discrete modules which are mechanically joined to form a continuous array of uniformly spaced elements.

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ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

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