United States Patent

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[73] Assignee **The United States of America as represented by the Secretary of the Navy**

[54] **MULTIAPERTURE RADIATING ARRAY ANTENNA**
4 Claims, 6 Drawing Figs.

[52] **U.S. Cl.** **343/727,** 343/778, 343/797, 343/854
[51] **Int. Cl.** **H01q 3/26**
[50] **Field of Search** 343/725, 727, 771, 776, 778, 786, 854, 797

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ABSTRACT: An integrated function microwave radiating structure capable of radiating electromagnetic energy at several selectively predetermined different frequency bands simultaneously and which can be used as an element of a large microwave array antenna is disclosed. The unitary substantially rectangular structure comprises multiple, closely spaced sets of radiating elements of various possible configurations located and supported in a defined aperture area in an interlaced contiguous manner with respect to each other. Each set of radiating elements radiates over a particular frequency band within the total band over which coverage is required. By energizing each radiating element independently in a predetermined phase and amplitude relationship with respect to the other elements, the radiated composite beam (from each of the elements) can be scanned in either the horizontal or vertical planes. Undesired mutual interaction affects between the closely spaced adjacent elements operating at different frequencies are minimized by cross-polarizing techniques.

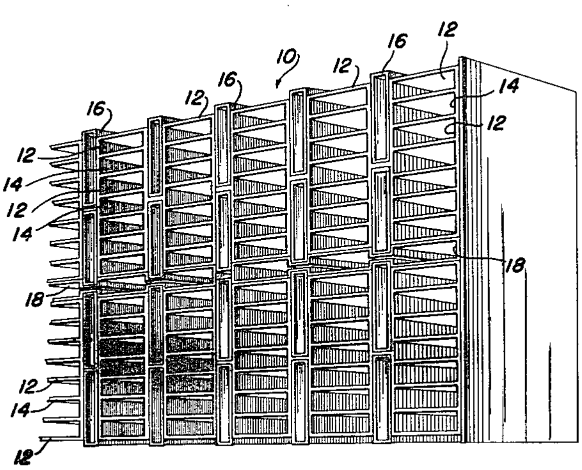
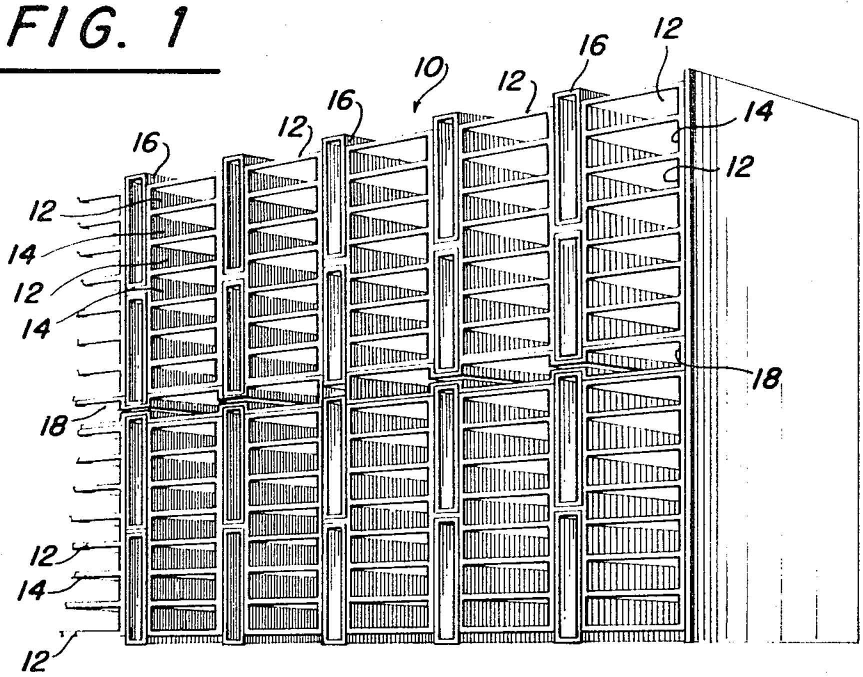


FIG. 1



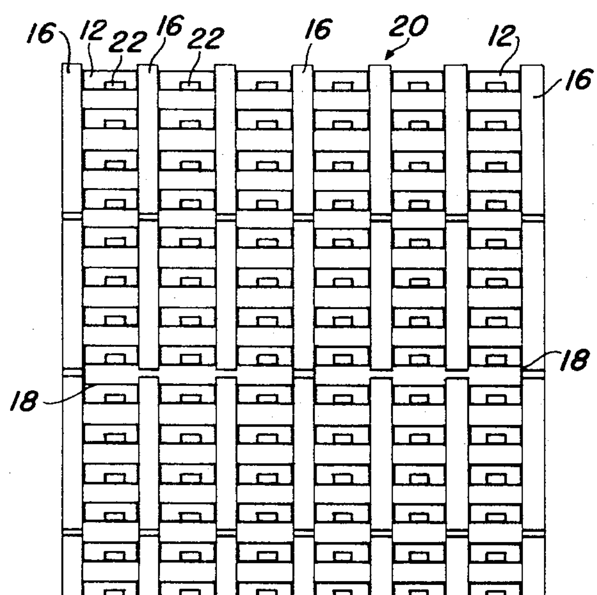


FIG. 2

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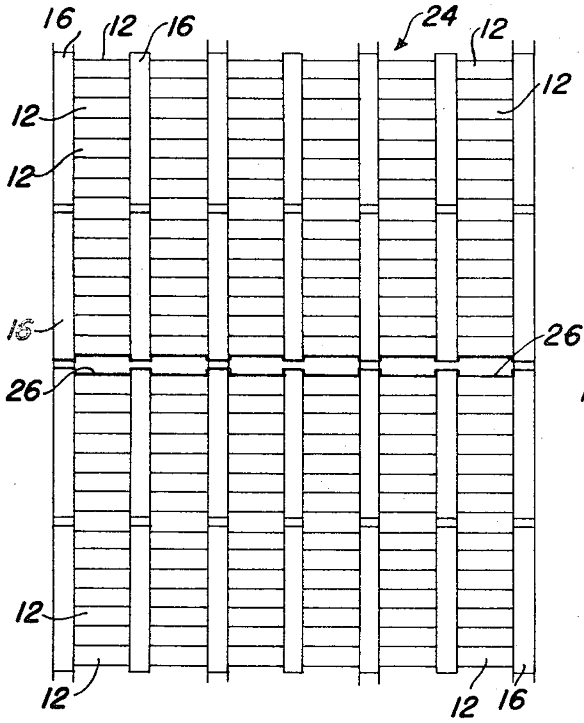

FIG. 3

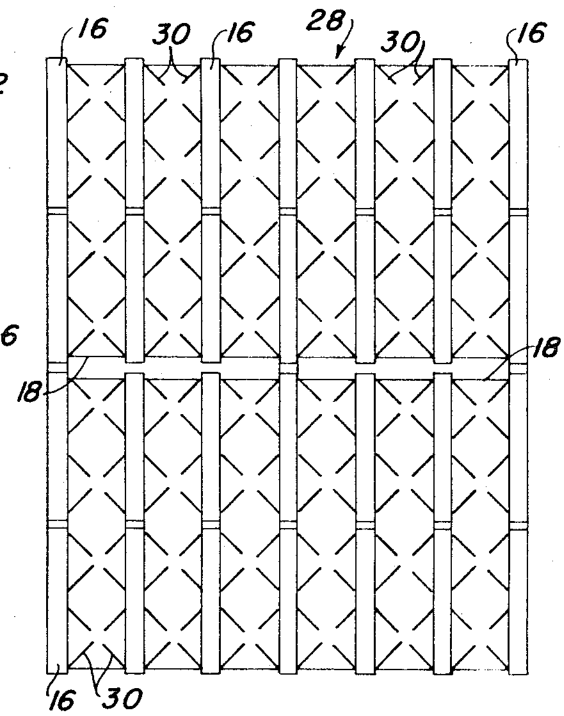

FIG. 4

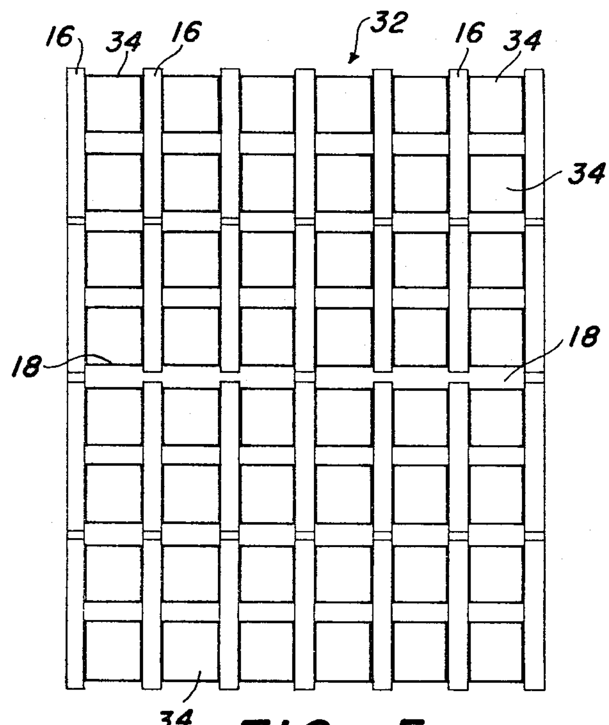

FIG. 5

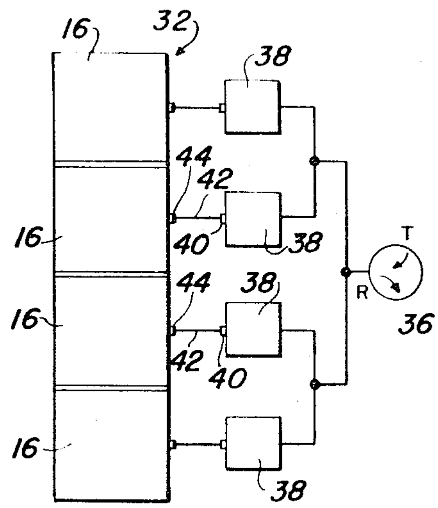

FIG. 6

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MULTIAPERTURE RADIATING ARRAY ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The continually increasing number of antennas required on Navy ships can force a compromise between shipboard antenna performance and the space available on the superstructure. If space is at a premium, antenna performance may not be optimum for all functions. One solution for improving antenna performance in limited space environments is to integrate several microwave radiating structures into a single configuration to provide multiband operation. Thus, for example, the frequency range of 0.9 to 12.0 Ghz can be utilized in a single configuration to encompass radar surveillance, ECM, identification, navigation, and microwave satellite communications. The specific functions which can be accommodated by a particular antenna are ultimately determined by the configuration, polarization, power handling capability, and other design factors known to those skilled in the art. For example, an increasing emphasis on adaptive and multifunction antenna which have the capability to adapt to changes in environment, mission, and function implies the use of rapidly scanning, highly agile, pencil-beam or simultaneous multiple-beam antennas.

Previous attempts have been made to develop integrated antennas for multifrequency applications. The prior art, however, has been unable to cope with several problems which arise in such devices. For example, the mutual interaction between closely spaced waveguide elements operating at different frequencies may be excessive such that system performance is seriously deteriorated. Also, larger waveguide elements propagate many modes and as a result, intermode coupling can result in power losses in a system. Finally, the isolation between the transmit and receive functions must be high for receiver protection, and the radiating elements must be overdesigned to withstand the power at the higher operating frequency.

SUMMARY OF THE INVENTION

An integrated function microwave radiating structure for radiating electromagnetic energy at several selectively predetermined frequency bands simultaneously is disclosed. The radiating structure comprises multiple, closely spaced, sets of radiating elements of various possible configurations located and rigidly supported in a defined aperture area in an interlaced contiguous manner with respect to each other. The interlaced sets of radiating elements are selected such that each set radiates over a particular frequency band within the total frequency band of the structure. Each radiating element is individually energized, and thus the individual radiated beams can be scanned in either the horizontal or vertical planes due to the independent control which can be provided to each radiating element. By cross-polarizing certain sets of elements with respect to the other sets, the mutual interactions between adjacent elements radiating at different frequencies is minimized. The novel radiating structures can be combined to provide a larger microwave array antenna.

STATEMENT OF THE OBJECTS OF THE INVENTION

The primary object of the present invention is to provide an integrated function, multifrequency, multiaperture radiating structure.

Another object of the present invention is to provide an integrated function antenna structure which can be used in a limited space environment.

A further object of the present invention is to provide a multifrequency radiating structure consisting of interlaced sets of radiating elements having various possible configurations.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a typical multiaperture, multifrequency microwave radiating structure embodying the inventive concept of the present invention;

FIG. 2 is a front view of an alternate configuration of FIG. 1;

FIG. 3 is a front view of a radiating structure featuring ridged S-band radiating elements;

FIG. 4 is a front view of a radiating structure featuring crossed dipole C-band radiating elements;

FIG. 5 is a front view of a radiating element featuring square-shaped C-band radiating elements; and

FIG. 6 is an illustration of the microwave energization technique of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates an electromagnetic energy radiating structure **10** embodying the inventive concept disclosed herein. The substantially rectangular radiating structure **10** consists of five columns, which are illustrated in the vertical disposition, of C-band rectangular waveguides **12** and X-band rectangular waveguides **14** arranged and rigidly supported by conventional means in a contiguous, face-to-face, i.e., horizontally stacked relationship with respect to each other. The elements of the two sets are stacked in an alternating fashion upon each other such that an X-band element **14** is stacked between two C-band elements **12**.

The five columns consisting of the vertically polarized elements **12** and **14** are arranged and rigidly supported in an interlaced contiguous manner between five columns consisting of four S-band elements **16** which are shown stacked in an end-to-end, i.e., vertically manner. The S-band elements are horizontally polarized for a very significant reason to be described hereinafter.

Symmetrically located and rigidly supported in a contiguous manner between the structure consisting of elements **12**, **14**, and **16** are two vertically polarized L-band elements **18**.

Waveguides **12**, **14** and **16** can be conventional waveguides, the design and operation of which is well known to those skilled in the art. Waveguide **18** can be of the type disclosed in U.S. Pat. No. 3,193,830, issued to Joseph H. Provencher on July 6, 1965, for a Multifrequency Dual Ridge Waveguide Slot Antenna.

By proper design selection of the waveguide elements **12**, **14**, **16**, and **18**, the structure **10** can, for example, provide a frequency coverage from approximately 1 to 10 Ghz To provide this frequency coverage, the dimensions of the various sets **12**, **14**, **16**, and **18** would be selected such that the elements **18** radiate over the frequency band of 1 to 2 Ghz, elements **16** radiate over 2 to 5 Ghz, elements **12** radiate over 5 to 8 Ghz, and elements **16** radiate over 8 to 10 Ghz.

It should be understood that FIG. **1** is merely exemplary of one of the many possible configurations of multifrequency, multiaperture radiating elements as taught by the inventive concept disclosed herein. For example, FIG. 2 illustrates a radiating structure **20** which, as can be seen, is very similar to the radiating structure **10** of FIG. **1**. In the structure **20** of FIG. 2, however, X-band coverage is provided by ridge elements **22** located and rigidly supported within C-band elements **12**. The S-band elements **16** and the L-band elements **18** located and supported in approximately the same manner as shown in FIG. **1**.

In FIG. **3**, a radiating structure **24** is illustrated which consists of six columns of C-band elements **12** which are vertically spaced and seven columns of S-band elements **16** which are vertically stacked in an end-to-end manner. Located and supported symmetrically with respect to the above described columns of vertically polarized C-band elements **12** and horizontally polarized S-band elements **16** are three ridged S-band radiating elements **26**. As can be seen the L-band elements **18** of FIGS. **1** and **2** have been replaced by the ridged S-band **26**, and X-band coverage is not provided in this particular configuration.

In FIG. **4**, a radiating structure **28** comprises seven columns consisting of vertically polarized S-band elements **16** stacked in an end-to-end manner and six columns consisting of a plurality of crossed-dipole C-band elements **30**. Each of the six columns of elements **30** is located and supported in a contiguous manner between two of the seven columns of elements **16**; located and supported symmetrically with respect to both sets of columns are two L-band dual ridge elements **18**. The C-band elements **30** could be, for example, printed circuit dipoles.

In another possible configuration shown in FIG. **5**, a radiating structure **32** is shown as consisting of seven columns of horizontally polarized S-band elements **16**. Located and supported between two of each of the seven columns is a column of vertically spaced C-band elements **34** which, as can be seen, may have a square shape. Again, L-band coverage is provided by elements **18**.

In another possible configuration (not shown) the square-shaped C-band elements **34** could be circular waveguides.

FIG. **6** illustrates the novel microwave energization technique which constitutes an important aspect of the inventive concept disclosed herein. In FIG. **6**, a side view of the radiating structure **32** of FIG. **5** is shown. For purposes of describing the energization technique it is only necessary to consider the S-band elements **16** since the technique would be identical for the remaining radiating elements. In the FIGURE, sending apparatus **36**, which can be either transmitting or receiving means, is connected to the input of four power divider means **38** which are shown connected in parallel. An output terminal **40** of each power divider **38** is connected by means of a coaxial connector **44** located and supported at the closed end of the waveguides **16** such that the waveguides are "end-fed." Each power divider can feed a selectively predetermined number of radiating elements. For example, each power divider **38** could have seven output terminals **40** such that each power divider could be used to energize a row of seven S-band elements **16**.

The power dividers **38** can be either uniform distribution power dividers or tapered distribution power dividers. If a uniform distribution power divider is used, input energy from sending apparatus **36** is equally divided at each power divider into, for example, seven parts. Equal parts are then fed to each of the seven S-band elements **16** to, in effect, form an array. If a tapered distribution power divider is used, input energy from sending apparatus **36** is divided into discrete parts having different phase and amplitude characteristics. Tapered parts are then fed to each of the seven S-band elements **16**. Thus, it can be seen that by using a tapered distribution power divider, each radiating element can, in effect, be energized independently of the other radiating elements.

As is well known, the size, shape, and position of the elements in an array are set within closely defined limits by the space requirements of the individual subarrays. The efficiency of each subarray in turn depends upon a number of factors: the matching of the elements, the radiating efficiency, the coupling between the elements and the elements in other subarrays, and the resulting higher-order modes which are excited. The design of transitions for coupling energy out of unconventional waveguides and the design of multiple probes to extract energy propagating in the higher-order modes are very dependent upon the field configurations in the waveguides. The far field pattern of these elements must not be so highly directive as to excessively reduce antenna gain at large scan angles.

The mode behavior of the individual conventional radiating elements **12**, **14**, and **16** of FIG. **1** is well known and will not be discussed. However, the conventional methods of determining mode behavior are somewhat ineffective for the lower frequency band (L-band) waveguide element **18**. Consequently, computers can be utilized to aid in the determination of the mode behavior of the L-band element **18**. This knowledge is essential since the L-band element **18** will have many propagating modes in the total bandwidth of the antenna, whereas the other waveguides **12**, **14**, and **16** will only propagate over the upper half of the band and are not likely to do so in more than one mode. The higher modes of the L-band waveguide **18**, on the other hand, are likely to couple energy from the other arrays and re-radiate it in such a manner as to possibly severely degrade the overall performance of the structure **10**.

Different sectors of the array can be used in such a manner as to reduce the effects of mutual coupling. For example, a fan beam requires only a few rows of elements and a small part of the overall array. Another sector of the array can be used for some other function in the same frequency band and at a different polarization. Synchronization of the different functions offer other means of minimizing the coupling. It should be noted that in accordance with the inventive concept, the choice of the array geometry is arbitrary since the interlacing technique is applicable to either a planar or curved geometry. However, as is well known to those skilled in the art, benefits can accrue from certain curved configurations which are not possible with planar geometries. The type of beam steering or beam switching to be used would ultimately be determined by the choice of array geometry.

As previously mentioned, the mutual coupling effects associated with interlaced radiating elements can be severe and thus create operational problems. One such problem is concerned with the effects of mutual coupling between the various radiating elements **12**, **14**, **16**, and **18** and the generation and possible propagation of undesired higher order modes. Judicious choice of the dimensions and orientation of the waveguide elements **12**, **14**, **16**, and **18** can be used to reduce the undesired modes. For example, the C-band waveguide **12** and the X-band waveguide **14** can be cross-polarized with respect to the S-band waveguides **16**, and thus the mutual coupling effects between these elements can be reduced by at least an order of magnitude. It should be noted that the L-band waveguide **18** has the same polarization as the elements **12** and **14** and that the L-band is capable of supporting the dominant mode as well as higher-order modes operating in C-band.

In order to adequately analyze the coupling behavior between these two frequency bands, a detailed knowledge of the fields that can exist within the various waveguides must be obtained. By determining the functional shape of the fields propagating in the unconventional, doubly ridged waveguide **18**, a good prediction of the radiation patterns can be made. In addition, an indication of the magnitude of the coupled energy can be obtained experimentally by probing techniques.

Until the particular functions to be integrated and implemented in a multi-aperture structure have been clearly defined, a discussion of the techniques required to place the proper amplitude and phase distribution at the individual antenna element terminals can only be of a general nature. The techniques of feeding and scanning planar and linear arrays are well known and will not be discussed here. However, some of the methods of feeding and steering circularly symmetrical arrays which are not generally known will be given.

The common type of radiation patterns used for operational microwave radiation systems include the fan beam, the pencil beam and the quasi-omnidirectional type pattern.

The fan beam pattern usually requires a relatively small number of radiating elements in the elevation plane and generally does not require coverage for higher elevation angles. Beam to beam switching times on the order of twenty-five microseconds can be achieved using both true time delay and hybrid matrix methods in combination with PIN diodes switches. Such techniques are readily adaptable to the steering of circular arrays. For example, one approach recently developed by the Government utilizes a microwave, parallel-plate lens operating over a 20 percent frequency band, thus assuring that the proper phase is applied to the terminals and that it is scanned through 128 azimuth beam positions by means of diode switches. This technique is disclosed in pending U.S. Pat. application, Ser. No. 802,008, filed on Feb. 25, 1969, by Jerry E. Boyns et al., for a Parallel-Plate Feed System for a Circular Array Antenna.

Another approach utilizes diode phase shifters in combination with diode switches to scan a ring array through one hundred and twenty-eight beam positions. This technique is disclosed in pending U.S. Pat. application, Ser. No. 838,730, filed June 30, 1969, by John Reindel, for a Vector Transfer Feed System for a Circular Array Antenna. Both of these techniques have been demonstrated using a fan beam and have been successfully operated over a relatively narrow bandwidth.

The pencil-beam pattern requires a large number of radiating elements in both planes, and for most applications requiring this type of radiation, the coverage of the entire half-hemisphere is desired. The techniques discussed above can be extended to provide this coverage, but, as previously discussed, certain geometries are preferred. None of the techniques have been shown for scanning in the elevation plane.

Quasi-omnidirectional coverage for air navigation functions generally requires a symmetrical array for forming the azimuth beam. Coverage above 60° in elevation is generally not necessary. A ring array can be used and fed with a power distribution network with some form of modulation superimposed to produce the desired azimuth radiation pattern. The hybrid matrix or a microwave lens device can be used for a power distribution network. The pattern can be electronically scanned by means of diodes switches and phase shifters, or ferrite switches and phase shifters.

The above discussion briefly describes some of the lesser known techniques for circular symmetric-array feeding and steering. Many of the techniques used for linear or planar arrays can also be advantageously used and in some applications can be found to yield good results with less complicated hardware. It must be emphasized that the array feed system and scanning mechanisms must be tailored to the particular function to be implemented and that in some instances compromise must be made.

The concepts which have been discussed are many faceted and present many engineering problems. Many of these problems can be analyzed using a large scale computer and well known mathematical techniques. The major problem, that of mutual inter-element effects, can only be resolved by empirical approach. The values of the coupling coefficients and their effect on impedance and ultimately on the array excitation can only be arrived at by experimental models. However, it should be noted that simulation techniques have received considerable attention in recent years and for a single frequency band have been effective in predicting array impedance and performance under scanning conditions. Direct impedance measurements can be made from a partial multifrequency array to provide impedance data.

The structure 10 shown in FIG. 1 can be designed to function in conjunction with PIN diode phase shifters and switches which are used with either a microwave lens feed or a corporate feed structure for beam scanning for the L-band and S-band, and ferrite phase shifters for the C-band and X-band. Both azimuth and elevation beam scanning should be provided to obtain the maximum number of data. Furthermore, the use of the modular construction, such as that shown in the drawing, allows the assembly of the modules into several configurations, both planar and circular, so that valid comparisons between the various techniques can be made.

It should be noted that lens feeding techniques can be used to implement the fan beam functions for the circular configurations. If this is done, the various components should be designed for maximum bandwidth, consistent with the array excitation hardware, and integrated circuit techniques should be investigated.

Thus it can be seen that an integrated function microwave antenna structure for radiating electromagnetic energy simultaneously at several selectively predetermined different frequency bands has been disclosed. The novel structure comprises multiple interlaced sets of waveguides having various possible configurations which are arranged and supported in a stacked manner with respect to each other in a defined aperture area. Each of the multiple sets of waveguides radiates over a particular frequency band and each of the waveguides is energized independently of the other waveguides. Thus the radiated beam from each of the waveguides can be steered in either the horizontal or vertical plane.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An integrated function antenna array structure comprising:

a plurality of columns of vertically polarized, C-band rectangular waveguides and X-band rectangular waveguides;

each of said X-band waveguides in each of said columns being disposed and rigidly supported in a contiguous, face-to-face stacked relationship between two of said C-band waveguides;

a plurality of columns of horizontally polarized, S-band rectangular waveguides;

said S-band waveguides in each of said columns being disposed and rigidly supported in a contiguous, end-to-end stacked relationship with respect to each other;

each of said columns of C-band and X-band waveguides being disposed and rigidly supported in a contiguous manner between two of said columns of S-band waveguides;

whereby all of said columns of C-band, X-band and S-band rectangular waveguides comprise a substantially rectangular, unitary antenna structure;

and electromagnetic energy source means connected to each of said C-band, X-band, and S-band waveguides at the closed end thereof in an end-fed manner whereby each of said waveguides can be energized independently of the other waveguides.

2. The antenna array structure of claim 1 further including a row of closely spaced, vertically polarized L-band rectangular waveguides;

said row of L-band waveguides being symmetrically disposed and rigidly supported in a contiguous manner with respect to said columns of C-band, X-band, and S-band waveguides.

3. A multifrequency antenna structure comprising:

a plurality of columns of rigidly supported, vertically disposed, and horizontally polarized S-band rectangular waveguides;

a plurality of columns of crossed dipoles;

each of said columns of crossed dipoles being disposed and rigidly supported in a contiguous manner between two of said S-band rectangular waveguides;

a row of closely spaced, vertically polarized L-band rectangular waveguides;

said row of L-band waveguides being symmetrically disposed and rigidly supported in a contiguous manner with respect to said columns of S-band waveguides and crossed dipoles;

and electromagnetic energy source means connected to each of said S-band and L-band waveguides and crossed dipoles at the end thereof in an end-fed manner.

4. The antenna structure of claim 3 wherein said crossed dipoles comprise printed circuit dipoles.

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