Nov. 7, 1961 S. B. COHN ET AL 3,008,141

SCANNER ANTENNA SYSTEM

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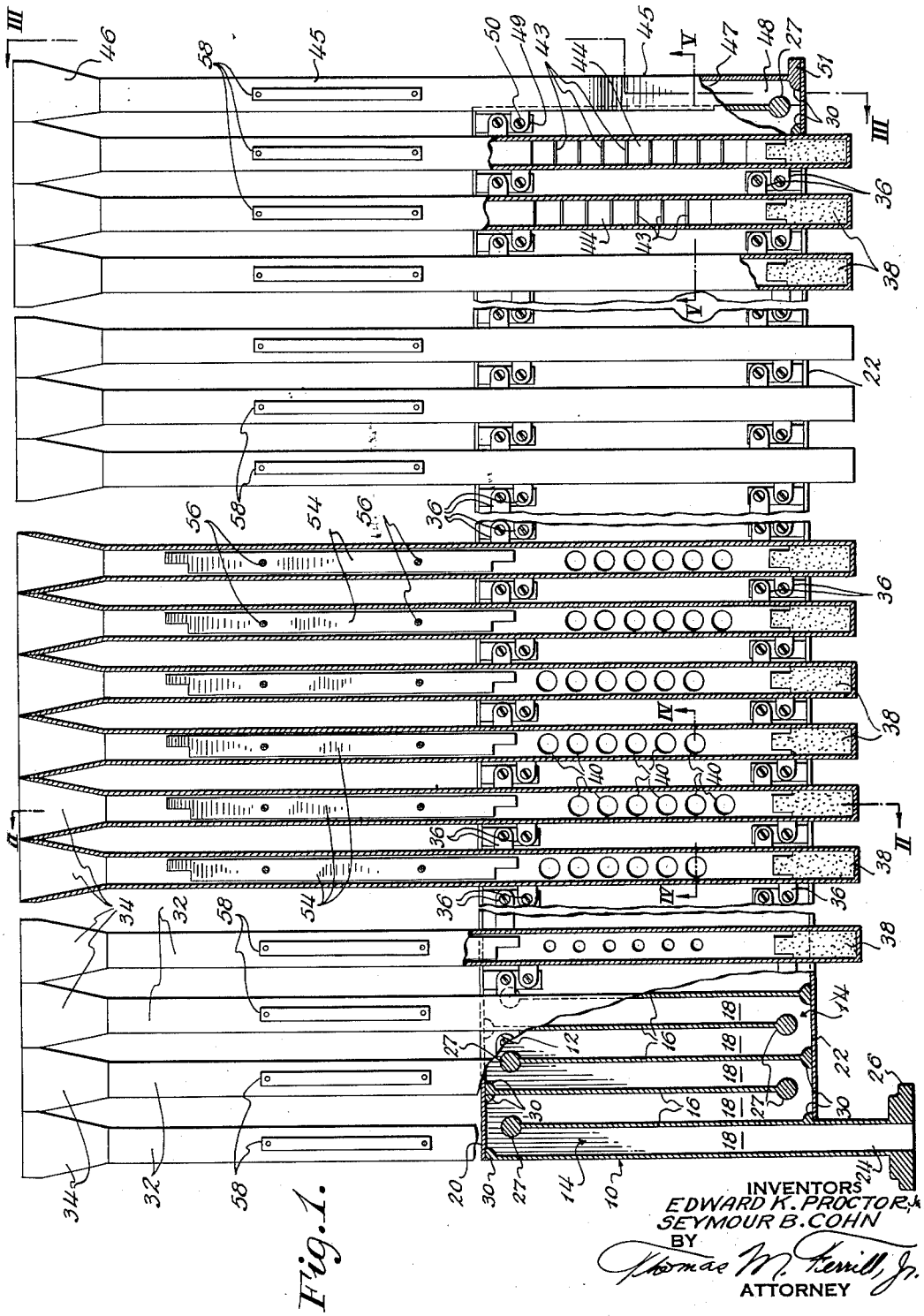


Fig. 1.

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Fig. 2.

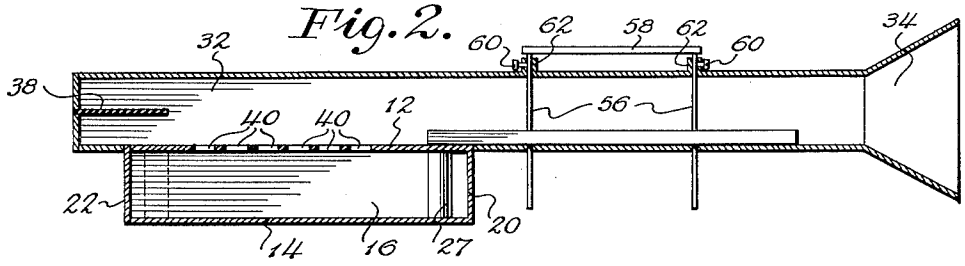


Fig. 3.

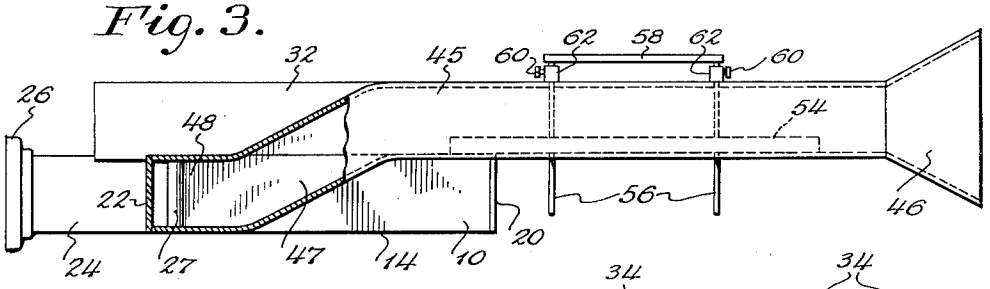


Fig. 4.

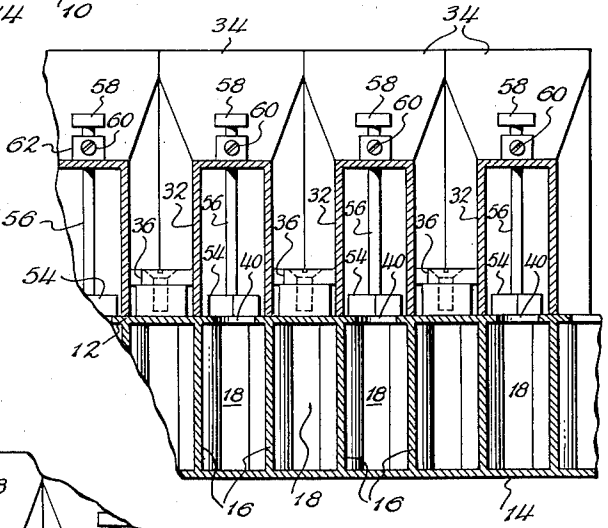
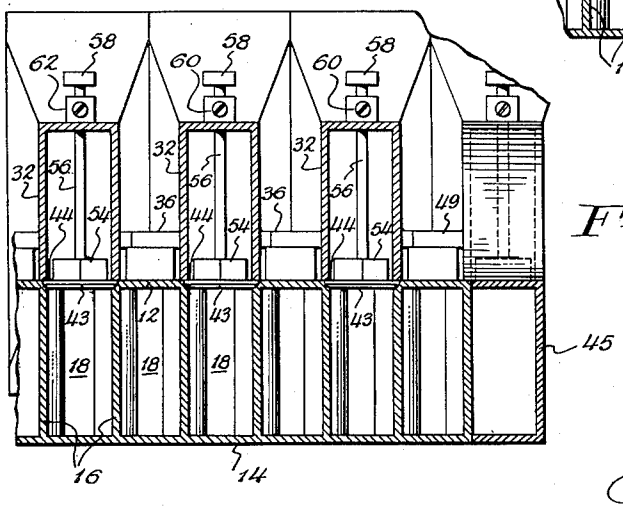


Fig. 5.



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SCANNER ANTENNA SYSTEM

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16 Claims. (Cl. 343—772)

This invention relates to a microwave antenna system, and more particularly, is concerned with a rapid linear scanner which utilizes changes in frequency to control the sweep of a scanning beam.

Broadside arrays are well known in the prior art and have been utilized heretofore in providing beam scanning by changing the frequency of the radiated energy. When the energy from each radiating element of a linear array is in phase with that from each of the other elements, a beam is produced which is normal to the broadside of the array. If the relative phase of energy radiated from successive elements is shifted slightly, the resulting beam is displaced or tilted from the normal. The greater the shift in phase between successive elements, the farther the beam is displaced from the normal. This shift in phase is most easily accomplished by changing the frequency of the microwave input to the array while the path length between radiating elements remains the same. In such a scanning array it is desirable that a high degree of beam angle change be effected with a minimum change in frequency to reduce the operating bandwidth of the system, and at the same time produce a sharp beam with a minimum of side-lobe energy.

In order to reduce the side-lobe energy of the array, the radiating elements of the array must be slightly less than a wavelength apart for a beam normal to the array to prevent energy from each of the elements adding in phase with energy from other elements in a direction other than the desired direction of maximum radiation. (For beams directed away from the normal, the spacing must be further reduced from a wavelength.) To keep the spacing between the elements at less than the free space wavelength and yet excite the elements in phase at mid-band frequency to get a beam normal to the broadside of the array has been a problem for which various solutions have been offered. If the elements are spaced a guide wavelength apart to excite them in phase, they must necessarily be spaced more than a free space wavelength apart since the wavelength within the guide is normally longer than the free space wavelength. This results in high energy side lobes.

One means of overcoming this difficulty which has been used is to decrease the guide wavelength. This may be accomplished by either filling the guide with a dielectric material, or loading the line periodically with reactance elements. Both of these latter methods are generally undesirable because they reduce the power-handling capacity and increase the loss of the antenna system. Another well-known means is to couple the radiating elements in reversed phase relationship and to space them at intervals of a half guide wavelength.

Where any of the above means are used in a frequency scanning system, the frequency shift necessary to get an appreciable change in beam direction is quite large, since the ratio of phase shift between elements to change in frequency is small. This ratio can be improved somewhat by proportioning the feed line so as to operate near cutoff in the operating frequency range. Near cutoff, the phase velocity changes most rapidly with change in frequency. Although this improves the ratio of phase shift change to frequency change, operation near cutoff has the disadvantage that the guide wavelength increases greatly, again posing the problem of high energy

side lobes. Furthermore, the attenuation of the wave guide increases to serious proportions near cutoff.

It is the general object of this invention to avoid and overcome the foregoing and other difficulties of and objections to the prior art practices by the provision of a broadside antenna array which is characterized by high efficiency, low standing wave ratio over a wide frequency band, large shift of beam angle with a small change in microwave frequency, and low side-lobe energy.

Another object of this invention is to provide a compact non-reflecting low-loss folded-type wave guide for feeding energy to a plurality of radiating elements of a broadside array.

Another object of the invention is the provision of an antenna system in which the phase at each of the radiating elements of the array can be individually adjusted to provide a substantially flat phase front.

These and other objects of the invention which will become apparent as the description proceeds are achieved by providing an antenna system including a folded feed line comprising a plurality of parallel adjacent wave guide sections joined at their ends by 180° E-plane wave guide corners. The corners have specially designed rounded edges and bends to reduce reflection and to increase the power-handling capacity of the feed line. A plurality of wave guide sections, each flared at one end to form a horn, are positioned to provide a linear array of radiating elements. The radiating elements are coupled to alternate wave guide sections of the feed line. Apertures in the wall portion common to the wave guide sections of the feed line and the wave guide sections of the radiating elements provide directional coupling of the transmitted energy. Phase shifters in the form of adjustably positioned dielectric strips in each wave guide section of the radiating elements are provided to correct for any phase errors in the system so that the system radiates energy with a substantially straight phase front across the extent of the array.

For a better understanding of the invention, reference should be had to the accompanying drawings, wherein:

FIG. 1 is a fragmentary plan view of an antenna array incorporating the features of the present invention;

FIG. 2 is a cross-sectional view taken on line II—II of FIG. 1;

FIG. 3 is an end view partially in section of the embodiment of FIG. 1;

FIG. 4 is a fragmentary sectional view taken substantially on the line IV—IV of FIG. 1; and

FIG. 5 is a fragmentary sectional view taken substantially on the line V—V of FIG. 1.

With particular reference to FIG. 1, the numeral **10** indicates generally an input feed line for an antenna array and is in the form of a folded wave guide that extends the length of the array. The folded wave guide includes an upper plate **12** and lower plate **14** which lie in parallel planes. A plurality of walls in the form of partitions **16** extend between the upper and lower plates **12** and **14** to form the broad walls of a plurality of parallel rectangular wave guide sections indicated generally at **18**. Side plates **20** and **22** between the longitudinal edges of the top and bottom plates **12** and **14** are provided, alternate partitions extending to one of the side plates with the remaining partitions extending to the opposite side plate. The partitions **16** and top and bottom plates **12** and **14** may be cast in a single unit. However, it is within the purview of the present invention to build up the folded wave guide from individual plates which are brazed or otherwise fabricated into a unitary structure.

The folded wave guide includes an input portion **24** which is provided with a suitable coupling flange **26** by means of which the array may be coupled to a source (not shown) of microwave energy. Energy is coupled

to successive sections **18** of the folded wave guide by the 180° E-plane wave guide corners formed at the ends of the parallel wave guide sections by spacing the edge of each of the partitions **16** forming the common wall between the adjacent wave guide sections **18** from the appropriate side plate **20** or **22** of the folded wave guide. The partitions **16** are terminated in the region of the 180° corners in edges **27** of substantially cylindrical form which increases the voltage breakdown level of the folded wave guide and reduces reflection at the bends. A fillet **30** is provided in each of the corners formed by the junction of the opposite edge of the partitions **16** from the cylindrical edges **27** with the side plates **20** and **22**, the fillets serving to improve the bandwidth of the folded wave guide.

A plurality of output wave guide sections **32** are positioned in parallel relationship and are each flared at one end, as indicated at **34**, to form a series of radiating horns. Adjacent horns are aligned in side-by-side relationship to provide a radiating array. The wave guide sections are spaced so as to be positioned adjacent alternate sections **18** of the folded wave guide. The output wave guide sections **32** are secured to the upper plate **12** of the folded wave guide by means of lugs **36** integrally formed with the output wave guide sections **32**, the lugs being bolted or otherwise secured to the top plate **12**. The top plate **12** provides a common wall between the output wave guide sections **32** and the adjacent sections **18** of the folded wave guide. The ends of the output wave guide sections **32** opposite the flared ends **34** each have a resistive card **38** mounted therein to provide a non-reflecting termination.

By providing suitable coupling between the output wave guide sections and the adjacent sections of the folded wave guide, as for example, by a plurality of circular apertures **40**, it will be seen that the folded wave guide and output wave guide sections **32** combine to form a plurality of directional couplers. By positioning the output wave guide sections adjacent alternate parallel sections of the folded wave guide, energy is always coupled from the folded wave guide in the same direction in the output wave guide sections, namely, in the direction of the flared ends **34**.

As energy is coupled from the folded wave guide by successive output wave guide sections, th ioreopnortp successive output wave guide sections, the proportion of energy coupled out of the folded wave guide by successive directional couplers increases. Thus, near the input end of the folded wave guide where the energy level is high in the folded wave guide, proportionately little energy is coupled out, whereas at the other end of the folded wave guide where the energy level has been greatly diminished, the amount of energy coupled out must be proportionately greater. For this reason, the coupling apertures **40** are made quite small at the input end of the folded wave guide and are made progressively larger in diameter at successive output sections. In fact, it has been found desirable where the proportion of energy that must be coupled out of the folded wave guide exceeds 10% to use a different type of directional coupler. A preferable type of coupler consists of a grid of wires **43** spaced across a rectangular aperture **44** in the common wall between the folded wave guide and the adjacent output wave guide section. This type of directional coupler is described in detail in the copending application, S.N. 197,064, filed November 22, 1950 by Kiyo Tomiyasu and Seymour B. Cohn as inventors and assigned to the same assignee as the present invention. The amount of energy coupled from the folded wave guide at each successive output wave guide section is determined by the desired energy distribution across the array. Preferably, the energy at each of the horns of the array is proportioned so as to provide a Dolph-Tchebyscheff energy distribution across the extent of the array. Any desired distribution, however, may be obtained by proper proportioning of the output coupling along the folded wave guide.

The last section of the folded wave guide remote from the input end **24** is connected directly to an output wave guide section **45**. The output wave guide section **45** is terminated at one end in a flared portion **46** which is positioned in line with the rest of the horns forming the radiating array. The wave guide section **45** has a double bend portion, indicated at **47**, that brings the end **48** opposite the flared portion **46** in parallel adjacent relationship with the last section of the folded wave guide. The output wave guide section **45** is held in position by means of a lug **49** secured by means of a screw **50** to the top plate **12** of the folded wave guide, while a flange **51** is secured to the side plate **22**. All the energy transmitted by the last section of the folded wave guide is radiated by the output wave guide section **45**, thus eliminating the need for any terminating energy-dissipative load. The coupling characteristic of successive directional couplers are designed so that the energy remaining at the end of the folded wave guide is at such a level that when radiated through the last output wave guide section, the energy from the end horn **46** corresponds to the proportion required for the desired energy distribution across the array.

One of the features of the present invention is that by using directional couplers for energizing each of the radiating elements of the array from the folded wave guide the distances between groups of the coupling apertures in successive output wave guide sections can be varied or staggered to provide for cancellation of reflections along the feed line without affecting the phase of the energy at the flared ends of the output wave guide sections, since the position of a group of apertures in the common wall between a particular output wave guide section and section of the folded wave guide does not change the path length from the flared ends **34** back to the source. Thus, the path length along the folded wave guide between groups of apertures in successive directional couplers can be varied to minimize the total reflection back toward the source from the antenna array. The spacing in terms of odd or even numbers of wavelengths between discontinuities required to prevent reflections from adding in phase at any point along the folded wave guide may be readily incorporated without affecting the relative phasing of the radiated signals at each of the horns.

For tuning the array to obtain a flat phase front across the extent of the array, it is desirable that adjustable phase-shifting means be provided in each of the output wave guide sections to permit practical tolerances in the construction of the array. Suitable phase-shifting means in each output wave guide section is preferably of a type described in the patent application Serial No. 656,201, filed March 22, 1946 by Robert B. Muchmore, now Patent No. 2,630,492, and includes a strip **54** of dielectric material within each of the output wave guide sections. Adjustable support of the strips is provided by means of a pair of parallel rods **56** which pass through the narrow walls of the respective output wave guide sections. A bar **58** in the form of a yoke connects the upper ends of the rods **56**. Movement of the bar **58** positions the rods **56** up and down simultaneously for positioning the dielectric strip **54** within the output wave guide section. Set screws **60** secure the rods **56** in position after the desired phase adjustment is achieved, the set screws threadedly engaging collars **62** secured to the walls of the output wave guide sections, the rods **56** passing through the collars **62**.

From the above description it will be recognized that the various objects of the invention have been achieved by the provision of an improved antenna array. The folded wave guide provides a low-loss feed so that it can be made relatively long without serious dissipation loss. The folded wave guide provides a relatively long path

length between successive radiating elements, so that a large phase shift is possible between successive elements with a small change in frequency for improved scanning performance. The close spacing of the radiating elements makes it possible to obtain a low side-lobe energy level. A substantially flat phase front across the array may be achieved by means of the adjustable phase shifters. These adjustments can be made independently of the phase and amplitude in the folded wave guide feed, permitting relaxed tolerances on the manufacture of the antenna.

While one embodiment of the invention has been described in detail, it is to be understood that certain latitude in design is possible within the broad principles of the invention. For example, the folded wave guide has been described as having E-plane corners. However, the folded wave guide can be constructed with the broad walls of the wave guide sections lying in a common plane, with H-plane corners being provided to form the folded feed line. The construction illustrated is preferable because the resulting structure is more compact and gives better performance. The type of phase shifter employed, for example, may as well take any of several well-known forms other than the type illustrated. It is to be understood that while the antenna has been particularly described as a radiating structure, it is bilateral in its operation and therefore may be used as a receiving structure as well.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A microwave radiator comprising a folded wave guide including a first pair of spaced parallel plates, a second pair of parallel plates extending between adjacent longitudinal edges of said first pair of plates, a plurality of parallel partition members extending between said first plates at substantially right angles to said second plates, alternate partition members being joined at one edge to one of said second plates and being spaced at the opposite edge from the other of said plates, the remaining partition members being spaced at one edge from said one of the second plates and being joined at the opposite edge to said other of the second plates, the partition members combining with said plates to provide a plurality of parallel wave guide sections, the edges of said partition members spaced from said second plates being cylindrical in form and of a diameter greater than the thickness of said partition members, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous wave guide section having one of said first plates as a common wall portion, directional coupling means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns, the last section of the folded wave guide being terminated in a flared portion positioned as part of said array, and adjustable phase-shifting means positioned in each of the output wave guide sections.

2. An array comprising a first pair of spaced parallel plates, a second pair of parallel plates extending between adjacent longitudinal edges of said first pair of plates, a plurality of parallel partition members extending between said first plates at substantially right angles to said second plates, alternate partition members being joined at one edge to one of said second plates and being spaced at the opposite edge from the other of said plates, the remaining partition members being spaced at one edge from said one of the second plates and being joined at the opposite edge to said other of the second plates, the partition members combining with said plates to provide a plurality of parallel wave guide sections, the edges of said partition members spaced from said second plates being cylindrical in form and of a diameter greater than the thickness of said partition members, fillets of conductive material being positioned in each of the corners formed by the junction of said partition members with said second plates, and radiating means coupled at spaced intervals along the wave guide sections.

3. A folded wave guide feed line for an antenna array comprising a plurality of hollow rectangular wave guide sections having their longitudinal axes parallel, the sections having their broad walls in common with adjacent sections, each of the sections having one of its narrow walls in a first plane and the other of its narrow walls in a second plane parallel to the first plane, and a pair of side plates extending across the ends of said wave guide sections, alternate common broad walls of said wave guide sections being spaced from one of said side plates with the remaining broad walls being spaced from the other of said side plates, the spaced edges of said broad walls being cylindrical in form with a diameter larger than the thickness of said broad walls.

4. An antenna array comprising a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners to form a continuous folded wave guide, adjacent wave guide sections having a common wall between, the common wall being terminated in an edge of cylindrical form with a diameter greater than the thickness of the common wall, and radiating means positioned at spaced intervals along the folded wave guide.

5. A microwave radiator comprising a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° E-plane wave guide corners, adjacent wave guide sections having a common wall between, the common wall being terminated in the region of the associated corner in an edge of cylindrical form, the diameter of the cylindrical edge being greater than the thickness of the wall, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, directional coupling means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns, the last section of the folded wave guide being terminated in a flared portion positioned as part of said array, and adjustable phase-shifting means positioned in each of the output wave guide sections.

6. A microwave radiator comprising a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners, adjacent wave guide sections having a common wall between, the common wall being terminated in the region of the associated corner in an edge of cylindrical form, the diameter of the cylindrical edge being greater than the thickness of the wall, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, and directional coupling means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns, the last section of the folded wave guide being terminated in a flared portion positioned as part of said array.

7. A microwave radiator comprising a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners, adjacent wave guide sections having a common wall be-

tween, the common wall being terminated in the region of the associated corner in an edge of cylindrical form, the diameter of the cylindrical edge being greater than the thickness of the wall, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, and directional coupling means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns, the energy path length in the folded wave guide between successive directional coupling means being staggered to cancel energy reflection in the folded wave guide.

8. A microwave radiator comprising a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners, adjacent wave guide sections having a common wall between, the common wall being terminated in the region of the associated corner in an edge of cylindrical form, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, and coupling means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns.

9. A microwave radiator comprising a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners, adjacent wave guide sections having a common wall between, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, and means in each of said common wall portions for coupling energy from the folded wave guide to the array of radiating horns.

10. A microwave radiator comprising a folded wave guide, a plurality of output wave guide sections terminated at one end in a flared portion to provide an array of radiating horns, and directional coupling means for coupling energy from the folded wave guide to the array of radiating horns.

11. In an antenna array, a plurality of directional couplers, each coupler having a main wave guide section and a branch wave guide section and being positioned parallel to adjacent couplers, wave guide means connecting one end of the main wave guide section of each coupler with the opposite end of the main wave guide section of the adjacent coupler, and a plurality of radiating horns positioned in a line, each of the horns being connected to a branch wave guide section of the directional couplers.

12. In an antenna array, a plurality of directional couplers, each coupler having a main wave guide section and a branch wave guide section and being positioned parallel to adjacent couplers, wave guide means connecting one end of the main wave guide section of each coupler with the opposite end of the main wave guide section of the adjacent coupler, and radiating means coupled to each of the branch wave guide sections.

13. An antenna system comprising a wave guide, a plurality of directional couplers at spaced intervals along the wave guide, all of the directional couplers being selectively responsive to energy traveling toward one end of the wave guide, an array of radiating elements coupled to respective ones of the directional couplers, and a further radiating element in the array coupled to said one end of the wave guide.

14. An antenna system comprising a wave guide, a plurality of directional couplers at spaced intervals along the wave guide, all of the directional couplers being selectively responsive to energy traveling toward one end of the wave guide, and an array of radiating elements coupled to respective ones of the directional couplers.

15. A microwave antenna comprising a linear array of radiating means, a wave guide comprising a plurality of interconnected alternate first and second portions, wherein a wave launched into one end of said wave guide alternately approaches the line of said array in said first portions and recedes from the line of said array in said second portions, a plurality of wave guide sections, each of said sections being connected at one end thereof to a respective one of said array of radiating means, and means directionally coupling each of said wave guide sections near the other end thereof to one of corresponding respective wave guide portions.

16. A microwave radiator comprising an array of radiating means, a folded wave guide including a plurality of parallel wave guide sections coupled at their ends by 180° wave guide corners, adjacent wave guide sections having a common wall between, a plurality of output wave guide sections, each of said output wave guide sections being terminated at one end in a radiating means, the output wave guide sections being contiguous with alternate sections of the folded wave guide, each of the output wave guide sections and the contiguous folded wave guide section having a common wall portion, and means in each of said common wall portions for directionally coupling energy from the folded wave guide to a respective one of said radiating means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,283,935	King	May 26, 1942
2,297,202	Dallenbach et al.	Sept. 29, 1942
2,477,510	Chu	July 26, 1949
2,628,311	Lindenblad	Feb. 10, 1953

FOREIGN PATENTS

493,695	Great Britain	Oct. 13, 1938