United States Patent [19]

Ajioka

[11] **3,720,953**

[45] **March 13, 1973**

[54] DUAL POLARIZED SLOT ELEMENTS IN SEPTATED WAVEGUIDE CAVITY

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[73] Assignee: **Hughes Aircraft Company,** Culver City, Calif.

[22] Filed: **Feb. 2, 1972**

[21] Appl. No.: **222,787**

[52] **U.S. Cl.** **343/771,** 343/840, 343/854

[51] **Int. Cl.**.....**H01q 13/10**

[58] **Field of Search**.....343/771, 840, 854

[56] **References Cited**

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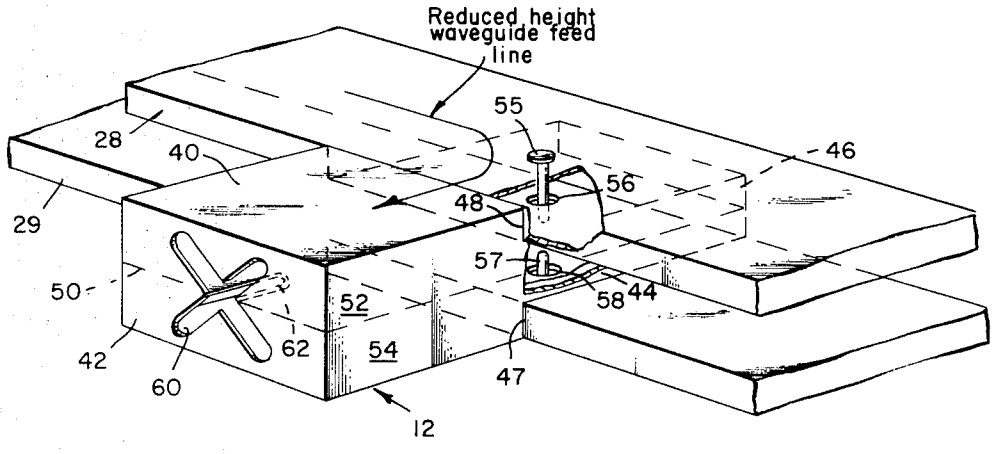
Primary Examiner—Eli Lieberman

Attorney—W. H. Macallister, Jr. et al.

[57] **ABSTRACT**

A slot radiating element for use in a two-dimensional phased array is in the "end" wall of a septated waveguide which is stepped-down in back of the radiating element to allow for excitation by means of reduced-height waveguide, stripline, coaxial line or other feeding networks without requiring additional vertical or horizontal spacing between the radiating elements. The radiating element constitutes a crossed or vertical slot or circular hole in the end wall centered over the septum with an additional slot in the septum extending into the cavity from the radiating element to excite the horizontal component (component in the plane of the septum) of polarization. Opposite sides of the septum are excited in antiphase (odd mode) to cause excitation of an electric field parallel to the septum in the radiating slot or hole and are fed in-phase (even mode) to cause excitation of an electric field perpendicular to the plane of the septum in the radiating element. Thus, polarization of the radiating slots or hole and, hence, the antenna is controlled by controlling the phase and/or amplitude relationship between the two excitations. In view of the arbitrary height of the slotted end wall, arrays can be stacked close enough to allow the capability of being scanned by phase shift in that plane, without formation of grating lobes.

15 Claims, 14 Drawing Figures



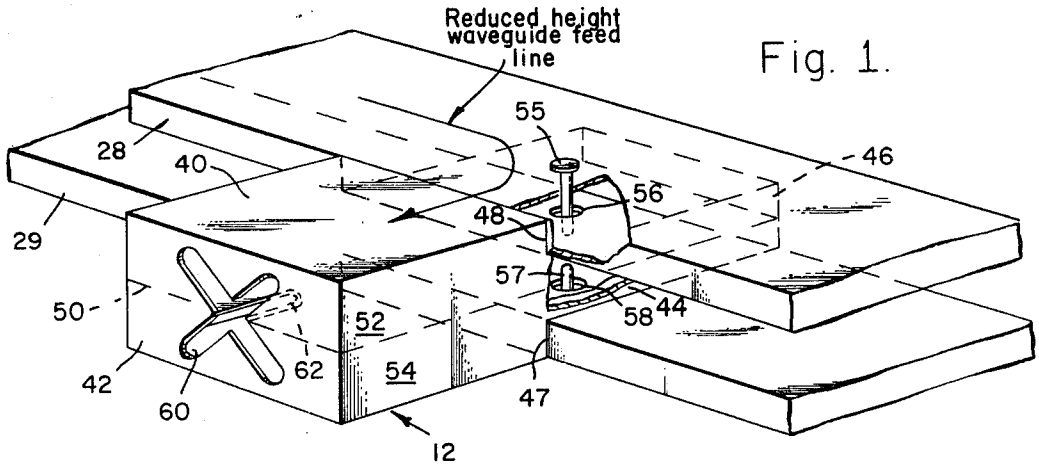


Fig. 1.

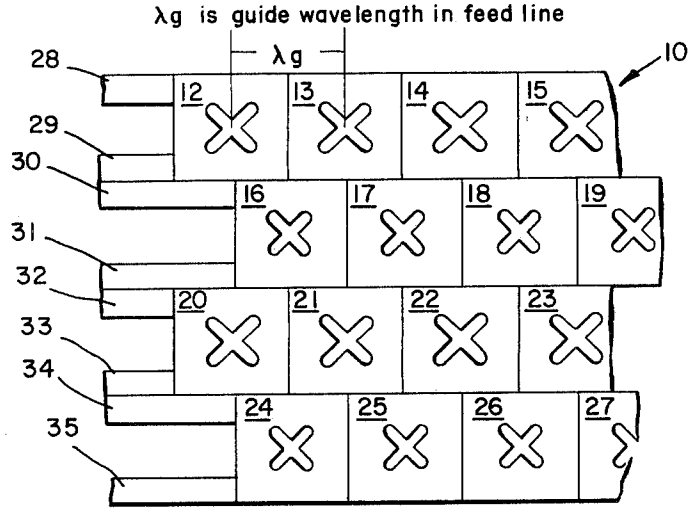
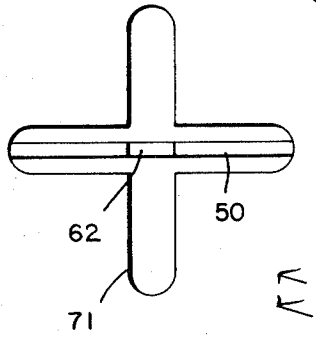


Fig. 2.

Fig. 3a.



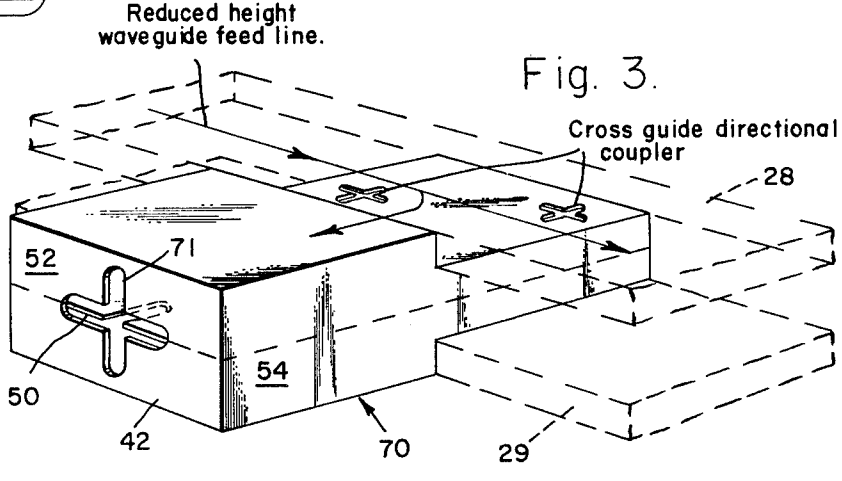


Fig. 3.

Fig. 4.

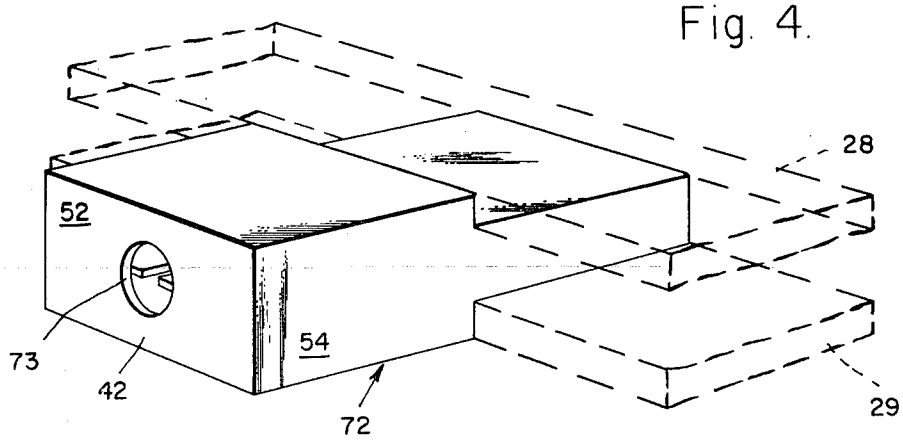


Fig. 12.

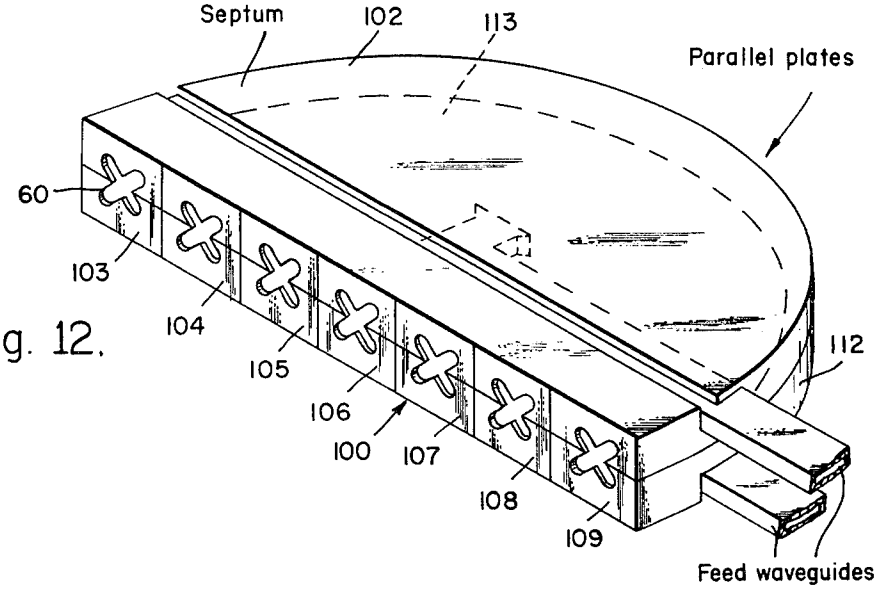
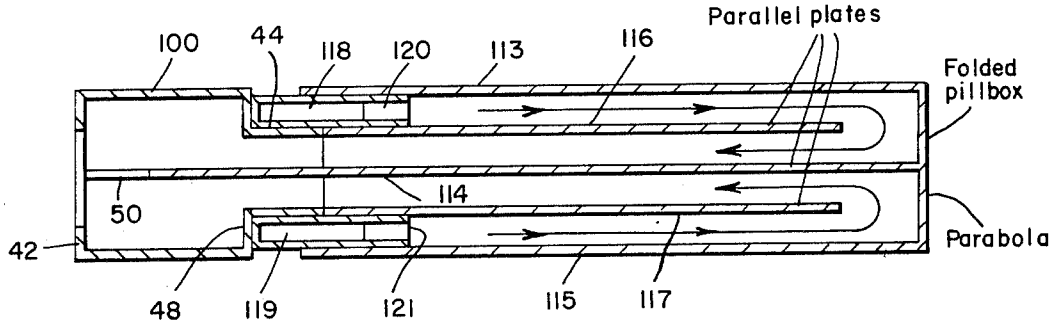


Fig. 13.



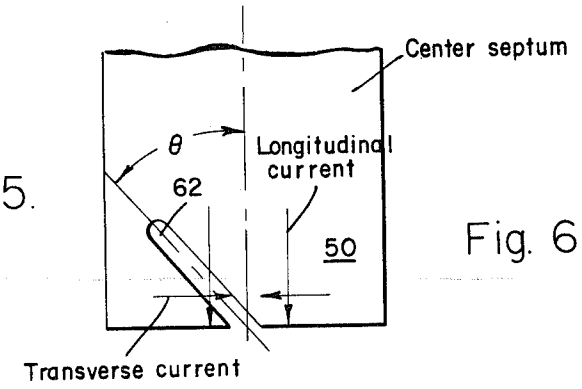


Fig. 5.

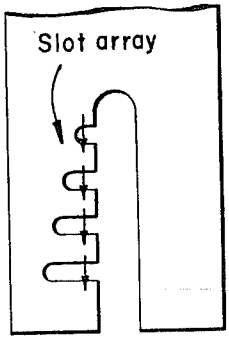


Fig. 6.

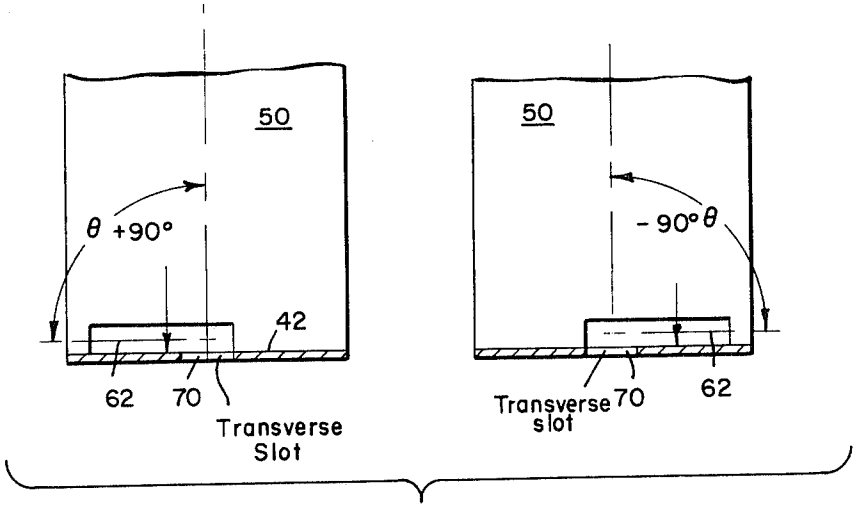


Fig. 7. Shunt Slots

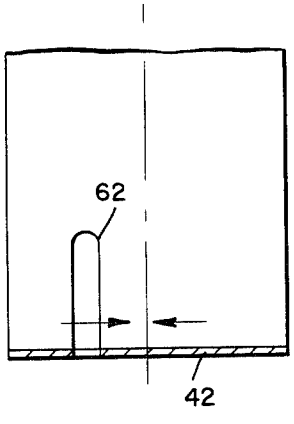


Fig. 8.
Series Slot

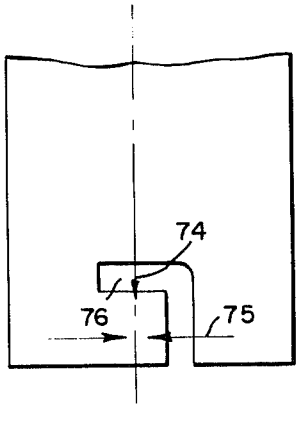


Fig. 9.
Complex Slot

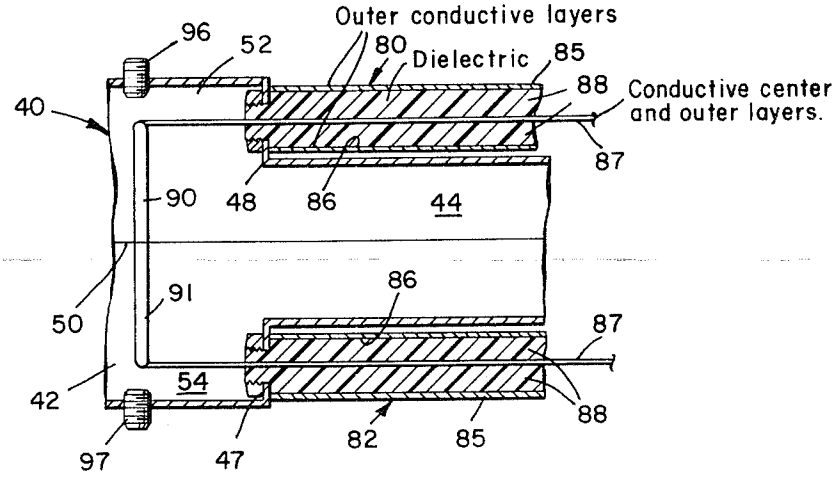

Outer conductive layers
96
52
80
Dielectric
85
88
Conductive center and outer layers.
40
87
90
48
86
44
50
91
86
87
54
42
88
97
47
82
85

Fig. 10.

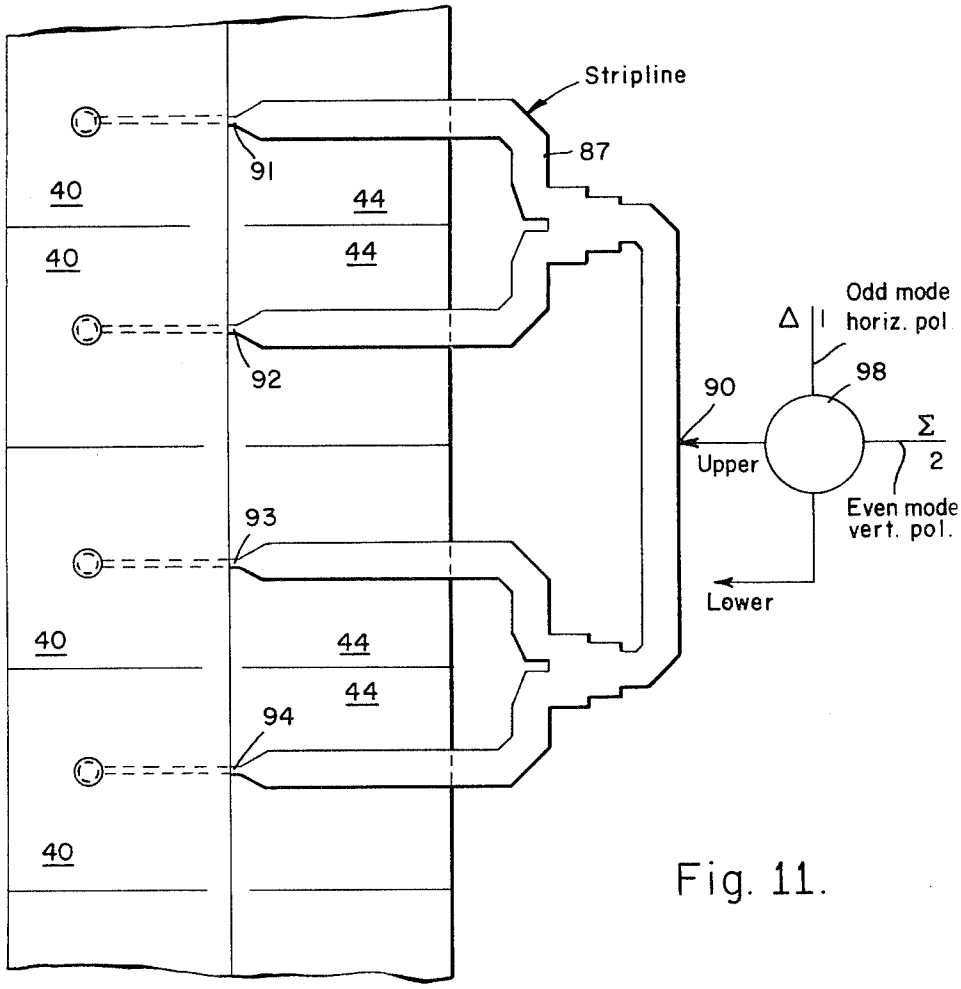

Stripline
87
91
40
44
40
44
92
Odd mode
horiz. pol
Δ
1
98
90
Σ
Upper
2
Even mode
vert. pol.
93
Lower
40
44
44
94
40

Fig. 11.

DUAL POLARIZED SLOT ELEMENTS IN SEPTATED WAVEGUIDE CAVITY

BACKGROUND OF THE INVENTION

This invention is directed to two-mode waveguide slot array antennas, particularly arrays having the capability of being scanned by phase shift and is an extension of the teachings in U.S. Pat. No. 3,503,073, entitled "Two-Mode Waveguide Slot Array," by James S. Ajioka, filed Feb. 9, 1968, and assigned to the same assignee as is the present case. In this patent the slot elements were an integral part of the waveguide feedline, whereas in the present case the radiating elements are completely independent of the feeding lines thereby allowing corporate or multiple beam network or parallel plate feeding techniques.

Other contemporary dual polarized two-dimensional arrays use essentially two separate antenna systems with superposed or interleaved elements for each polarization. In the case of the orthogonally superposed dual edge slot arrays, polarization purity cannot be maintained because of the required inclined slots. Also, the superposed orthogonal array techniques are very narrow band because the antenna beams corresponding to each of the polarizations frequency scan in planes at right angles to each other so that the beams coincide at only one frequency. Otherwise, very narrow band standing wave arrays must be used. Still other systems use dual polarized crossed dipoles which are more complex and more expensive to manufacture than machined slots in the wall of a waveguide cavity.

SUMMARY OF THE INVENTION

The present invention is directed towards a radiating element with controllable polarization (i.e., circular, linear, elliptical, dual orthogonal polarization) for use in a two-dimensional phased array that can be fed by waveguide, strip-line, coaxial line or parallel plate (e.g., pillboxes and other geodesic feeds) feeding networks. In general, the phase of the odd mode is controlled by the geometry of the odd mode excitation slot in the septum of the septated waveguide cavity. Since the longitudinal currents in the septum are in phase quadrature with the transverse currents, any phase from **0°** to **180°** with respect to the feedline power may be achieved by slanting the slot in the septum so that it interrupts both components of current in the desired ratio to effect the desired phase. A "bent slot" or "crossed slot" may also be used so that a portion of the slot intercepts the longitudinal current and another portion of it intercepts the transverse current in the desired ratio to effect the desired phase.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view of a dual polarized element with a crossed slot fed by probes from dual reduced-height waveguide feedlines;

FIG. **2** shows a front view of an array composed of the dual polarized radiating elements of the type shown in FIG. **1**;

FIGS. **3** and **3A** show a dual polarized element with a crossed vertical and horizontal slot fed by a reduced-height waveguide coupled by means of a cross guide directional coupler;

FIG. **4** shows a dual polarized element with a circular hole fed by a reduced-height waveguide;

FIGS. **5** to **9** show different configurations of slots in the center septum;

FIG. **10** shows a cross-sectional view of a waveguide cavity with center septum of the type illustrated in FIGS. **1** and **3** fed with stripline;

FIG. **11** shows a plan view of several waveguide cavities fed with stripline with hybrid for combining the odd and even modes; and

FIGS. **12** and **13** show perspective and cross-sectional views, respectively, of a linear array of dual polarized radiating elements in accordance with the invention, with a parallel plate antenna feed.

DESCRIPTION

Referring to FIG. **2**, there is illustrated a segment of a slotted array **10** of dual polarized slot elements **12–27** fed by reduced-height waveguides **28–35**. In particular, dual polarized slot elements **12–15** are fed by reduced-height waveguides **28, 29**; dual polarized slot elements **16–19** are staggered over the elements **12–15** and are fed by reduced-height waveguides **30,31**; dual polarized slot elements **20–23** are in alignment with elements **12–15** and are fed by reduced-height waveguides **32,33**; and dual polarized slot elements **24–27** are in alignment with elements **16–19** and are fed by reduced-height waveguides **34,35**. Embodiments of the dual polarized slot element **12** together with the manner in which the reduced-height waveguides **28,29** are coupled thereto are shown in perspective in FIGS. **1, 3,** and **4**.

The dual polarized slot elements **12–27** are substantially identical, whereby element **12** is described by way of example. Referring to FIG. **1**, a preferred embodiment of dual polarized slot element **12** includes a section of waveguide **40** having an end wall **42** disposed transversely thereacross at the left extremity thereof, as viewed in the drawing, and a symmetrically stepped-down extension **44** at the opposite extremity thereof terminated with an end wall **46** and having steps **47, 48**. In the present case, the length of the stepped-down extension **44** is made equal to the width of the reduced-height feed waveguides **28, 29** and steps **47, 48** are each made equal to or greater than the height of the reduced height waveguides **28, 29**. Thus, the dual polarized slot elements **12–27** may be stacked with corresponding waveguide portions **40** thereof in actual contact. A septum **50** divides the section of waveguide **40** together with the extension **44** thereto into an upper cavity **52** and a lower cavity **54** of substantially equal volume, as viewed in the drawing.

The reduced-height waveguide **28** is coupled to the upper cavity **52** by means of a conductive probe **55** which extends from the outside broad wall of reduced-height waveguide **28** through an aperture **56** in the common wall between reduced height waveguide **28** and stepped-down extension **44** into the upper cavity **52**. Similarly, reduced-height waveguide **29** is coupled to the lower cavity **54** by means of a conductive probe **57** which extends from the outside broad wall of reduced-height waveguide **29** through an aperture **58** in the common wall between reduced-height waveguide **29** and stepped-down extension **44** into the lower cavity **54**. The probes **55,57** are generally located opposite each other within the central portion of the stepped-down portions of cavities **52,54**.

Next, a radiating element constituting a crossed-slot **60** is centrally disposed in the end wall **42** with the angle between the legs thereof bisected by the septum **50**. Lastly, a slot **62** commencing from the edge of septum **50** coextensive with or within the crossed-slot **60** extends into the septum **50** away from the end wall **42**. The slot **62** has any one of the configurations shown in FIGS. **5 – 9**. As shown in the drawing, odd mode excitation of the dual feedlines **28,29**, i.e., the dual feedlines **28,29** fed in antiphase, produces horizontally polarized excitation of the crossed slot **60**. Alternatively, feeding the feedlines **28,29** in phase produces vertically polarized excitation of the crossed slot **60**.

Referring again to FIG. **2**, the dual polarized slots **12-27** are dispersed along the feedline **28-35** at intervals approximating the guide wavelength, λ_g, thereof so as to produce a beam in the vicinity of broadside to the array. Since the guide wavelength, λ_g, spacing is too great to prevent grating lobes in the horizontal plane as viewed in the drawing, alternate arrays, such as arrays **16–19** and **24–27** are staggered to suppress grating lobe formation in that plane. In the plane normal to feed lines **28–35**, the spacing is arbitrary and can be made close enough to approximate one half free space wavelength, $\lambda_0/2$ at the frequency f_0, i.e., at the frequency which produces a beam normal to the array to suppress grating lobes even for wide angle scanning in that plane.

Referring to FIGS. **3** and **3***a*, there is shown a dual polarized radiating element **70** having a vertical slot **71** in the end wall **42** in place of the crossed slot **60**. Other elements of the radiating device of FIG. **3** remain the same as the radiating device of FIG. **1**. Referring to FIG. **4**, there is shown a dual polarized radiating element **72** having a circular hole **73** in the end wall **42** in place of the crossed slot **60**. As before, other elements of the radiator remain the same as the radiating device of FIG. **1**. Referring to FIG. **5**, there is shown a plan view of slot **62** in the center septum **50**. Current which flows parallel to the centerline of center septum **50**, i.e., normal to the end wall **42**, is designated as longitudinal current and current which flows normal to the longitudinal current is designated transverse current. The phase of the field in the septum slot **62** depends on the angle θ that the slot **62** makes with the centerline, because θ determines the relative amounts of longitudinal and transverse currents interrupted by the slot. Inasmuch as the longitudinal and transverse currents are 90° out of phase, the phase of the horizontally polarized component (component parallel to the septum) can be controlled by the angle θ of the slot **62** in center septum **50**.

FIG. **6** shows a "slot array" in the system **50** to excite the horizontally polarized component. The array which is similar to an endfire antenna array allows for precise coupling over a larger bandwidth.

Referring to FIG. **7**, there is shown the position of slot **62** with $\theta = 90°$ and with $\theta = -90°$. Under these circumstances, the relative phase difference between the respective horizontally polarized components is 180°. Referring to FIG. **8**, the septum slot **62** is shown normal to end wall and displaced from centerline **42**, whereby only transverse current is interrupted.

Referring to FIG. **9**, there is shown a complex slot **74** in center septum **50** which has a leg portion **75** normal to end wall **42** and a leg portion **76** parallel to end wall **42**. The leg portion **75** of slot **74** interrupts transverse currents, and the leg portion **76** interrupts longitudinal currents. The net effect is to generate a field having a phase that is the combination of both the leg portions **75, 76** with the relative lengths of both portions determining the relative phase of the horizontally polarized component of electric field at the radiating element (crossed slot or hole). A slot **62**, such as shown in FIG. **5**, can produce a field of the same phase by proper selection of the angle θ.

As an alternative to generating progressive phase shifts by propagation along the feed lines **28,29**, the dual polarized radiating elements may all be excited with fields of the same phase by means of corporate feeds **80,82** as shown in cross section in FIG. **10**. FIG. **10** shows a dual polarized radiating element in accordance with the invention, fed with strip line corporate feeds **80, 82**, thereby to energize each of the radiating elements in an array of which the portion **83** of FIG. **11** is shown with fields of the same phase. Referring to FIG. **10**, the stripline corporate feeds **80, 82** include outer conductive layers **85, 86** spaced from the center conductors **87** by air or other dielectric material **88**. The center conductors **87** as shown in plan view in FIG. **11** form a "tree," so that the electrical distance is the same from an input **90** to each output **91, 92, 93,** or **94**.

In the case of the stripline corporate feeds **80, 82**, the center conductors **87** enter the upper and lower cavities **52,54**, through the stepped-down portions **48, 47**, respectively, and extend parallel to the center septum **50** to probes **90,91**. The probes **90,91** are disposed opposite each other normal to the center septum **50** in the central portion of the respective upper and lower cavities **52,54**. Tuning screws **96,97** may be threaded through the outer board walls of waveguide section **40** opposite the tips of the probes **90,91**. In this case, the crossed slot **60**, alternate crossed slot **71**, or the circular hole **73** may be used in the end wall **42**. The upper and lower stripline corporate feeds **80,82** are either fed in phase or out of phase by means of an appropriate hybrid **98**.

Referring to FIGS. **12** and **13**, there is shown a perspective and cross-sectional view of a linear array **100** of dual polarized radiating elements with a parallel plate antenna feed **102** of the type referred to as a "folded pillbox" or other geodesic antenna. The array **100** includes dual polarized radiating elements **103–109**, each including the section of waveguide **40** having an end wall **42** and a symmetrically stepped-down extension **44** with steps **47, 48** but no end wall **46**. The center septum **50** extends through the combined cavity formed by waveguide section **40**, together with extension **44**. Although end wall **42** is illustrated with crossed slot **60**, the alternate crossed slot **71** or circular hole **73** may also be used. Center septum **50** includes slots of the type illustrated in FIGS. **5 – 9** and described in connection therewith.

The parallel plate antenna feed **102** includes a cylindrical parabola **112** of a height substantially equal to that of waveguide section **40** and extends across the entire linear array **100** around the back side relative to the radiating elements. The cylindrical parabola **112** is compartmented by conductive plates **113, 114,** and

115, plates 113 and 115 being in the plane of the top and bottom surfaces of the waveguide sections 40 of radiators 103–109 and plate 114 being in the plane of the center septum 50. Plate 114 extends from the cylindrical parabola 112 to the center septums 50 of the linear array 100. Plates 113 and 115, on the other hand, extend from the parabola 112 to respective edges which overlap the stepped-down extensions 44 and extend therefrom towards the cylindrical parabola 112 with a gap approximately equal to one-quarter the height of the waveguide sections 40 therebetween. Waveguide inputs 118, 119 along one or both sides of the steps 47, 48, respectively, to connect with feed horns 120, 121 which are located at the focal point of the cylindrical parabola 112. The input waveguides are fed in the same manner as the corporate feeds in the device of FIG. 10 by the use of appropriate hybrid junctions. Linear arrays 100 may be stacked in the same manner as in the device of FIG. 2.

What is claimed is:

1. A two-dimensional phased array comprising a plurality of rows of contiguous slot radiating elements in a common plane, each of said radiating elements including:

a. uniformly oriented sections of waveguide disposed normal to and commencing from said common plane in a common direction;

b. a stepped-down extension in the narrow dimension attached to each of said uniformly oriented sections of waveguide and extending away from said common plane;

c. a conductive end wall disposed across each of said uniformly oriented sections of waveguide in said common plane;

d. a center conductive septum disposed across the broad dimension of each of said uniformly oriented sections of waveguide and said stepped-down extension thereto, thereby to form first and second cavities in each of said sections of waveguide;

e. a radiating aperture disposed across said center septum in each of said end walls in said common plane;

f. a slot in each of said center septums commencing from each of said radiating apertures in said common plane, and

g. means for exciting said first and second cavities with energy of the type included in the group wherein said first and second cavities are energized in phase and wherein said first and second cavities are energized in anti-phase.

2. The two-dimensional phased array as defined in claim 1 wherein said radiating aperture disposed across said center septum in each of said end walls in said common plane is a longitudinal slot oriented normal to said center septum.

3. The two-dimensional phased array as defined in claim 2 including an additional longitudinal slot in each of said end walls disposed normal to and across said longitudinal slot oriented normal to said center septum.

4. The two-dimensional phased array as defined in claim 1 wherein said radiating aperture disposed across said center septum in each of said end walls in said common plane has a circular configuration.

5. The two-dimensional phased array as defined in claim 1 wherein said radiating aperture disposed across said center septum in each of said end walls in said common plane constitutes first and second crossed longitudinal slots disposed in said end wall with said center septum bisecting the angle therebetween, said crossed longitudinal slots being substantially the same length.

6. The two-dimensional phased array as defined in claim 1 wherein said slot in each of said center septums is at an angle with said end wall, thereby to control the phase of the horizontal polarization component of energy radiated from the concomitant radiating aperture.

7. The two-dimensional phased array as defined in claim 1 wherein said slot in each of said center septums is normal to said end wall and on one side of the centerline of said center septum along said uniformly oriented sections of waveguide, thereby to control the phase of the horizontal polarization component of energy radiated from the concomitant radiating aperture.

8. The two-dimensional phased array as defined in claim 1 wherein said slot in each of said center septums has segments that are normal and parallel to said end wall, thereby to control the phase of the horizontal polarization component of energy radiated from the concomitant radiating aperture.

9. The two-dimensional phased array as defined in claim 8 wherein said slot in each of said center septums has a plurality of spaced segments that are parallel to said end wall.

10. The two-dimensional phased array as defined in claim 8 wherein said segment of said slot in each of said center septums that is normal to said end wall is disposed to one side of the centerline of said center septum along said uniformly oriented sections of waveguide.

11. A two-dimensional phased array comprising a plurality of rows of contiguous slot radiating elements in a common plane, each of said radiating elements including:

a. uniformly oriented sections of waveguide disposed normal to and commencing from said common plane in a common direction;

b. a stepped-down extension in the narrow dimension attached to each of said uniformly oriented sections of waveguide and extending away from said common plane;

c. conductive end walls disposed across opposite extremities of each of said uniformly oriented sections of waveguide and said stepped-down extensions thereto, thereby to enclose each of said sections of waveguide;

d. a center conductive septum disposed across the broad dimension of each of said uniformly oriented sections of waveguide and said stepped-down extensions thereto thereby to form first and second cavities in each of said enclosed sections of waveguide;

e. a radiating aperture disposed across said center septum in each of said end walls in said common plane;

f. a slot in each of said center septums commencing from each of said radiating apertures in said common plane; and

g. means for exciting said first and second cavities with energy of the type included in the group wherein said first and second cavities are energized in phase and wherein said first and second cavities are energized in anti-phase.

12. The two-dimensional phased array as defined in claim 11 wherein said last-named means includes first and second strip line corporate feeds coupled to said first and second cavities, respectively, of said radiating elements along a common row.

13. The two-dimensional phased array as defined in claim 11 wherein said last-named means includes first and second lengths of reduced-height waveguide disposed normal to and on opposite sides of said stepped-down extensions of said radiating elements along a common row and coupled to said first and second cavities thereof, respectively.

14. A two-dimensional phased array comprising a plurality of rows of contiguous slot radiating elements in a common plane, each of said radiating elements including:

a. uniformly oriented sections of waveguide disposed normal to and commencing from said common plane in a common direction;

b. a stepped-down extension in the narrow dimension attached to each of said uniformly oriented sections of waveguide and extending away from said common plane;

c. a conductive end wall disposed across each of said uniformly oriented sections of waveguide in said common plane,

d. a center conductive septum disposed across the broad dimension of each of said uniformly oriented sections of waveguide and said stepped-down extension thereto, thereby to form first and second cavities in each of said sections of waveguide;

e. a radiating aperture disposed across said center septum in each of said end walls in said common plane;

f. a slot in each of said center septums commencing from each of said radiating apertures in said common plane, and

g. means including a parallel plate antenna feed for exciting said first and second cavities of a number of adjacent uniformly oriented sections of waveguide along a row with microwave energy through said respective stepped-down extensions thereto.

15. The two-dimensional phased array as defined in claim 14 wherein said parallel plate antenna feed constitutes an antenna feed of the folded pillbox type.

* * * * *