

- [72] Inventor **Edward Bellamy McMillan**
45 Renwick Avenue, Huntington, N.Y.
11743
- [21] Appl. No. **612,696**
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- [45] Patented **Jan. 4, 1972**

[54] **LATTICE APERTURE ANTENNA**
19 Claims, 19 Drawing Figs.

- [52] U.S. Cl. **343/754,**
343/770, 343/781, 343/872, 343/909
- [51] Int. Cl. **H01q 19/06**
- [50] Field of Search 343/753,
755, 909, 910, 911, 754, 770, 781, 872, 909

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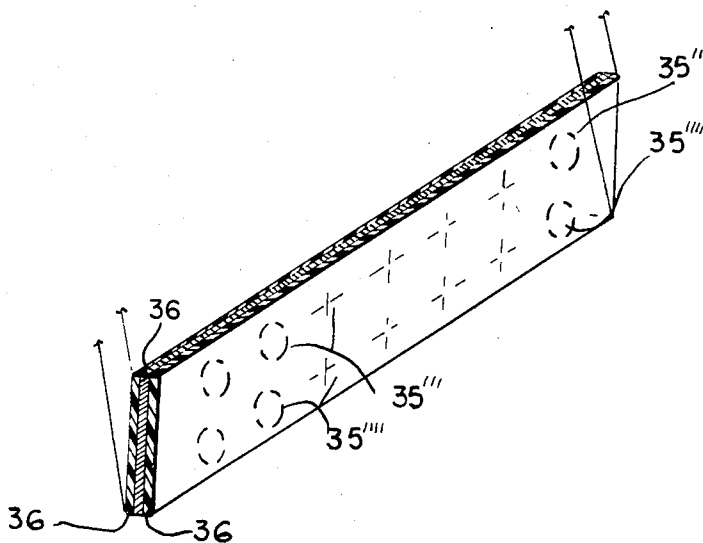
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Primary Examiner—Eli Lieberman
Attorney—John G. Mills, III

ABSTRACT: This invention is an antenna composed of an electromagnetic wave transmission line radiation aperture and a lattice wall sandwich facing across the wave path. The sandwich is spaced between the aperture and the outer region of the antenna. An equivalency circuit of the sandwich having at least one section of two capacitive layers shunted across codirectional through-conductors and disposed across opposite ends of a network with a series inductance in one of the through conductors and two inductances each shunted from an opposite end of the series inductance to the other of the through-conductors. The sandwich has an inductive lattice layer having nonconducting magnetic wall areas of thickness represented by the series inductance. Nonconducting magnetic areas are apertures in the conducting electrical wall areas. The inductive lattice layer has on each of its two sides capacitive layers and there is a predetermined distribution of antenna coupling reactance across the face of each layer of the lattice wall sandwich.



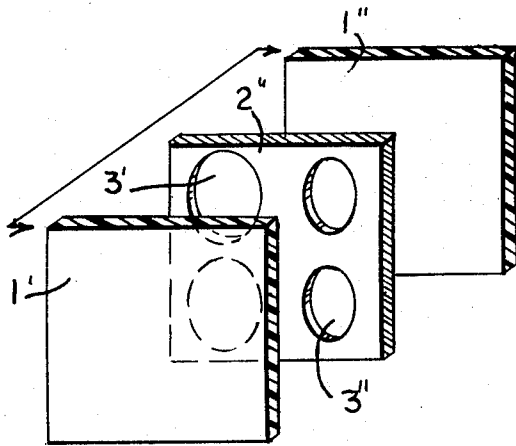


FIG. 1(A)

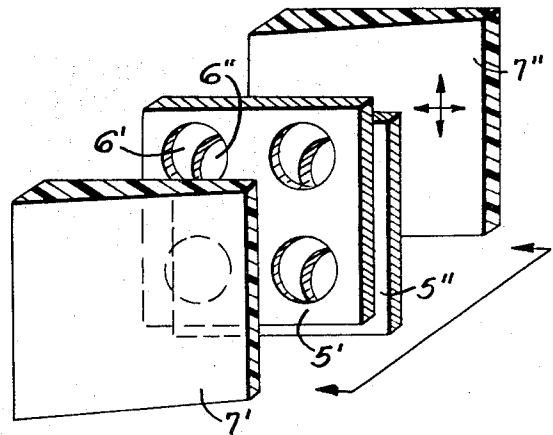


FIG. 1(B)

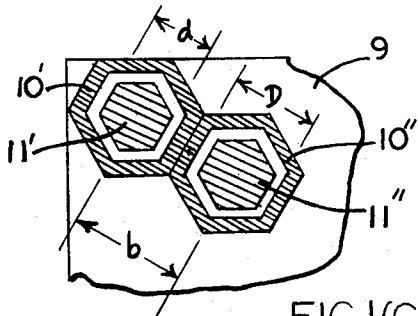


FIG. 1(C)

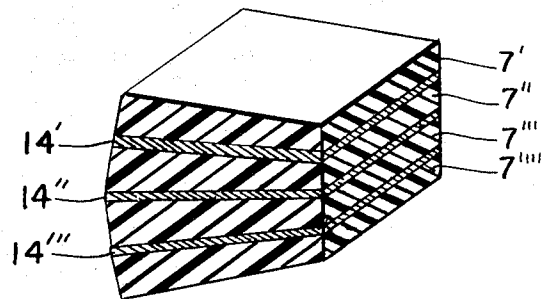


FIG. 1(F)

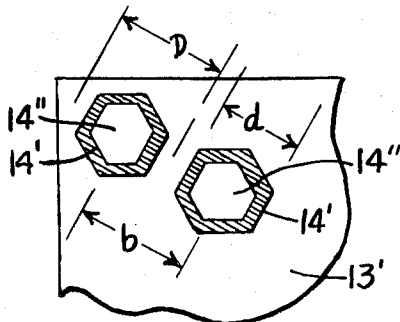


FIG. 1(D)

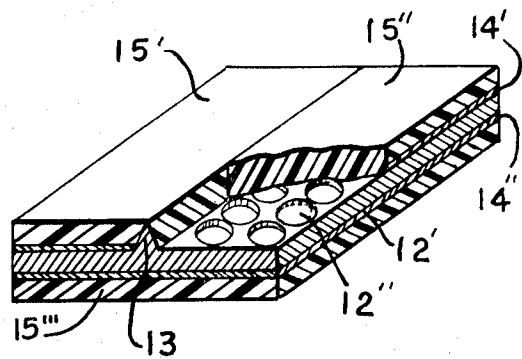


FIG. 1(E)

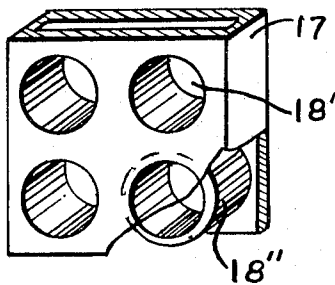
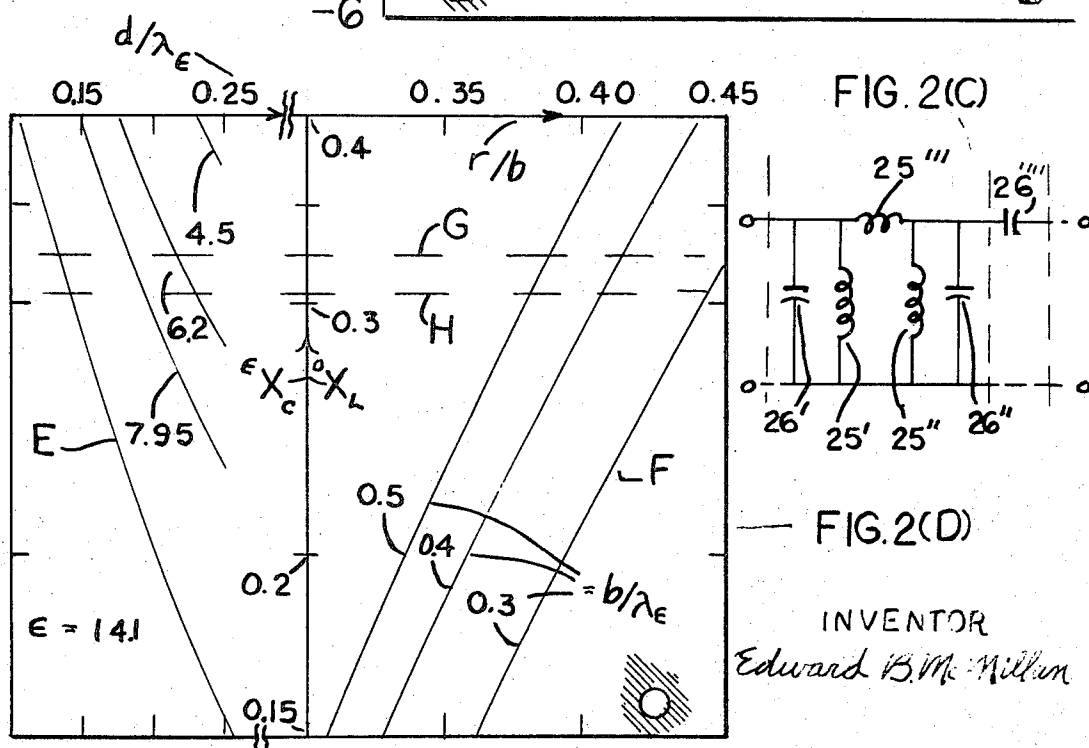
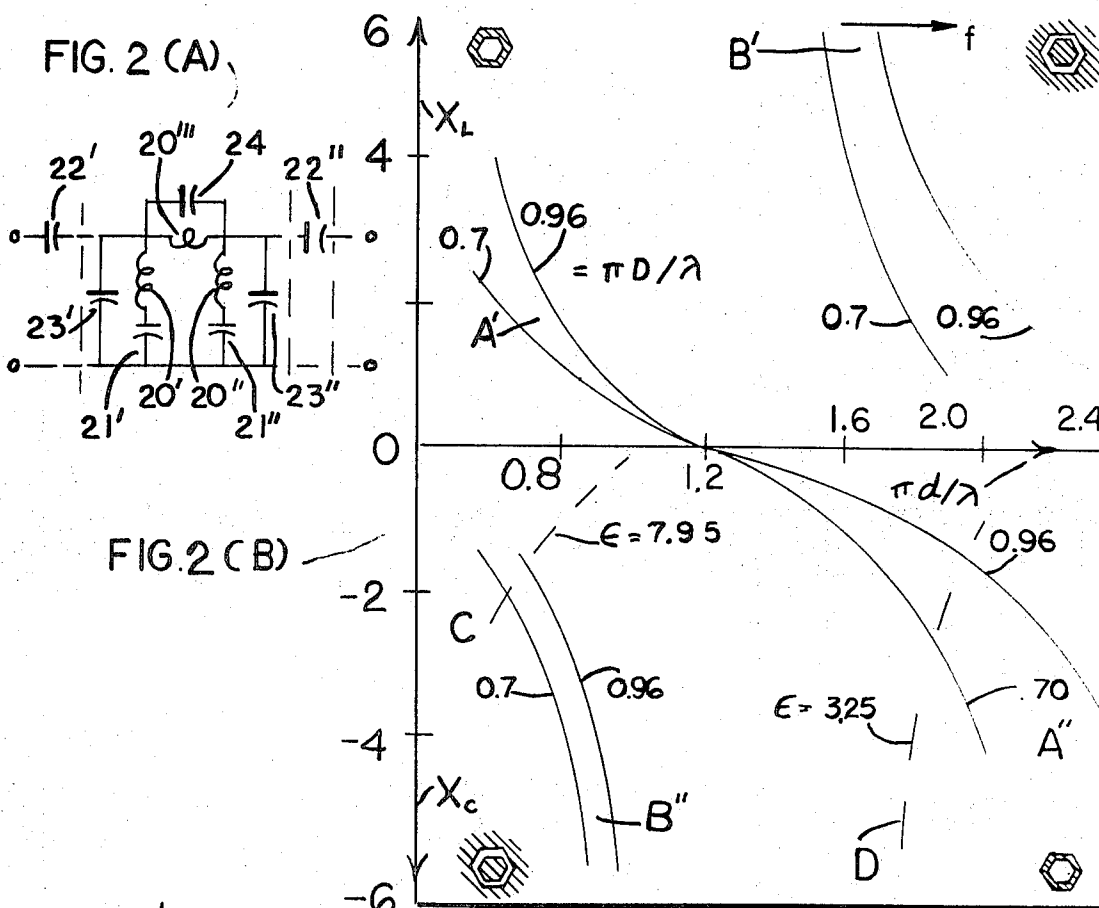


FIG. 1(G)

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Edward B. McMillan



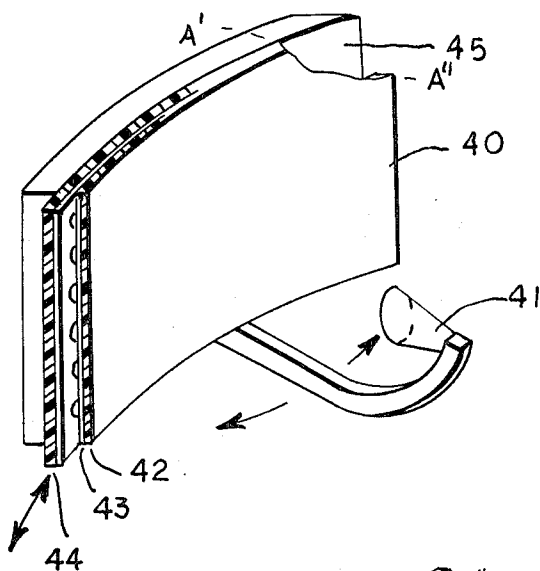


FIG. 4

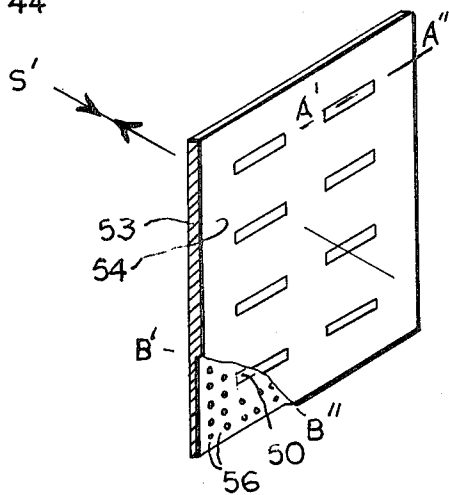


FIG. 5(A)

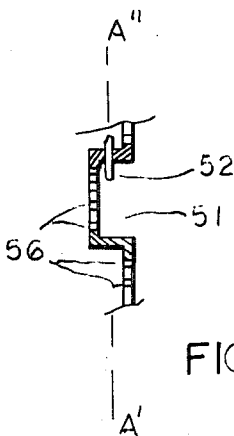


FIG. 5(B)

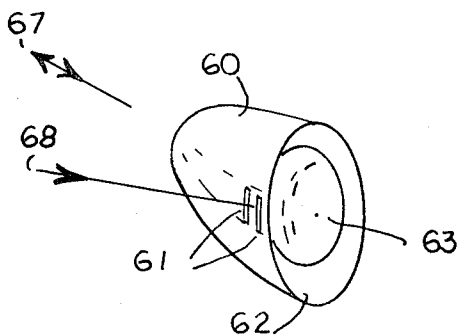


FIG. 6(A)

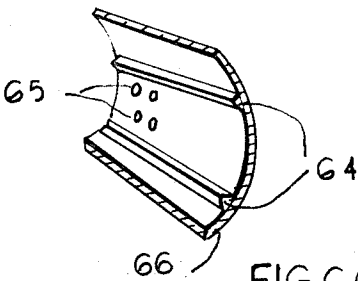


FIG. 6(B)

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Edward B. McMillan

LATTICE APERTURE ANTENNA

This invention relates to antennas for millimeter and microwave use and particularly to a new type of multimode antenna employing a lattice wall to achieve wave coupling.

The trend of aerospace and mobile microwave and millimeter antenna installations calls for the greatest versatility within a package of limited size and weight. A multiplicity of radiation sources of widely separated frequencies having a common aperture is a desired but hard to attain objective. Each source may have different scan, pattern, polarization and power requirements. Multipurpose components are the ideal objective.

In the most compact antenna installation the coupling device would lie across the common aperture of radiations of differing characteristics and be an integral part of each radiation subsystem. Satisfactory coupling between the radiation aperture of a transmission line and the outer antenna region is a problem for a single frequency, pattern, polarization and power level, let alone several. Thus a major requirement for the continued improvement of multimode antennas is that the coupling problem be overcome.

I have invented a new family of multimode antennas in which the foregoing difficulties are overcome. Each antenna comprises at least one transmission line electromagnetic radiation aperture in combination with at least one lattice wall sandwich spaced between the radiation aperture and the outer region of the antenna. I have provided for variable adjustment at will of electrical parameters of both the transmission line and the lattice wall. Through these parameters the relationship of the radiation in the antenna and outer regions are controlled, for example; frequencies, shape, gain, direction and polarizations of the patterns.

In the prior art antenna art the design and use of thin dipole slots is well known including inherent breakdown voltage, pattern and frequency limitations. In the prior waveguide art the principles for the design of single magnetic holes and electric obstacles, the use of either matched only by its spacing from a discontinuity of like reactive sign, and the use of rows of unmatched radiating holes of low transmissivity is well developed. Without attempting to reteach such techniques I teach new and nonobvious combinations of the old and the new.

In the prior microwave lens are thick, heavy lattices of phase delay and phase advance discontinuities have been used separately without provision for matching or scanning across the surface, limited by matching and beam-shaping difficulties. In the prior radome art, double and single layers of dielectric matched inductive aperture screens without gradients of reactance or provision for multifrequency use have been proposed lacking satisfactory matching over a range of incident angles and polarizations. The low shunt reactance required in the matching layers made them too thick and heavy and eliminated the dielectrics best suited for radome structures. Inherently lacking the low-frequency passband capability for beacon radiation as required by most radomes, practical application was further blocked.

In my present antenna invention I employ multiple and single layers of capacitive as well as inductive lattice patterns, each matched by a reactance of unlike sign, and I overcome the obstacles encountered in similar prior arts.

The objects of my invention comprise but are not limited to a new family of antennas with the following advantages:

1. Better coupling between the antenna and outer regions providing improved pattern control and a higher voltage rating;
2. Polarization selectivity, unwanted energy being removed by absorption;
3. Multiple frequency operation in the same source zone with improved reduction of back-lobing and shadowing;
4. Greater antenna survivability and environmental protection of a separate source;

Among the preferred embodiments of the antenna family of my invention are the following:

1. A transmission line coupled to free space by a capacitatively matched lattice wall;

2. A scanning antenna having a polarization and frequency match selective lattice wall as its reflector;

3. A multifrequency antenna in which the outer conductive surface of a lattice wall is a pole of a multipole feed;

4. Coplanar with a slot for a lower frequency, a capacitatively matched lattice wall providing a radiation path for additional sources spaced from it;

5. An antenna having a multifrequency coupler comprising a cascade of lattice wall sandwiches.

To assist in the understanding of the operation and construction of my multimode antenna, I have provided the following figures in which:

FIG. 1(A) is an exploded view in perspective of the lattice wall wave coupler of my invention in which the phase advance layers of the coupler are perforated with magnetic areas of varying size;

FIG. 1(B) is an exploded view in perspective of the lattice wall coupler of my invention in which the size and shape of the magnetic areas are adjustable and the phase delay layers are of tapered thickness;

FIG. 1(C) is a broadside view of a nonconductive sheet having a lattice of polygonal magnetic ring area containing conductive discs, as in a typical layer of the lattice wall coupler of my invention;

FIG. 1(D) is a broadside view of an insulating sheet supporting a lattice of conducting electric ring areas as in a typical layer of the lattice wall coupler of my invention;

FIG. 1(E) is an edge view in perspective of a ribbed lattice wall coupler of my invention;

FIG. 1(F) shows in perspective a stack of cascaded lattice wall sandwiches;

FIG. 1(G) is a broadside view in perspective, with the lower right front corner cut away, of a hollow conductive plate having tubes from face to face enclosing the conductive holes of a lattice wall coupler of my invention;

FIG. 2(A) is the equivalent circuit for a sandwich in which series reactive elements are in shunt with capacitive elements as in a lattice wall coupler of my invention;

FIG. 2(B) is a graph of shunt reactance versus transmitting area pattern dimensions in a shunt circuit lattice useful to establish high-reactance inductive layers and thin capacitive layers in the lattice wall sandwich of my invention;

FIG. 2(C) is the equivalent circuit for matching a lattice of simple inductive holes;

FIG. 2(D) is a graph of two families of curves showing the relationship of the vital parameters of a low-shunt reactance lattice wall sandwich;

FIG. 3(A) shows in perspective a special waveguide having an internal flap and a matching section as employed in a beam selective linear array embodiment of my antenna invention;

FIG. 3(B) shows in perspective the lattice wall which couples the waveguide to the outer region;

FIG. 3(C) shows in perspective a pair of my waveguide linear arrays serving as a multifrequency feed for a reflector;

FIG. 4 shows in perspective the antenna of my invention embodied as a scanning antenna having a special polarization and frequency selective reflector comprising my lattice wall;

FIG. 5(A) shows in perspective a multifrequency embodiment of my antenna invention, an array of slot arrays providing a radiation path for another source;

FIG. 5(B) shows a sectional view through A'—A'' of a low-frequency slot of the array of FIG. 5(A);

FIG. 6(A) shows in perspective a multifrequency radant of my invention in which one antenna is in the surface of a method lattice wall and a second antenna is behind it;

FIG. 6(B) shows in perspective a portion of a ribbed and perforated conductive layer suitable for use in the matched lattice wall of the radant of my invention.

In my new approach to antenna problems in combination with transmission lines and other essential antenna elements, in apertures I employ capacitatively matched lattices of magnetic and electric wall areas for more versatile and improved coupling.

A surface may be called an "electrical wall" or sheet or zero impedance when the magnetic field vanishes within the conductor, the boundary conditions being substantially that the tangential electric field and the normal magnetic field each becomes zero, while the tangential magnetic field equals the surface current density. When a complimentary set of boundary conditions are met, the normal electrical field and tangential magnetic fields being substantially equal to zero, a surface may be called a sheet of infinite impedance or a "magnetic wall."

The operation and construction of one lattice wall of my invention can be understood from examination of FIG. 1. In the exploded view of FIG. 1(A) dielectric plates 1' and 1'' are of uniform thickness and design to cover and be in contact each with one side of metal plate 2. A gradient of inductive holes through the metal plate and of progressively diminishing size from the left of the page to the right are shown in two rows 3' and 3''.

The holes may be elliptical, as shown, or of other shapes providing useful, for example, other elongations, circular and polygonal. They will not have the small breakdown voltage sensitive gaps of resonant slot dipoles. Equations and graphs for the susceptance and reactance of various types of magnetic and electric walls, single holes and obstacles, are available in the "Waveguide Handbook" edited by N. Marcuvitz, the McGraw-Hill Book Company, Inc., 1951.

The dielectric constant and thickness of plates 1' and 1'' and the open area of the holes is derived from the graph, equations and supporting procedures found in my description of FIG. 2. For odd multiples of a quarter-wavelength of thickness a gradient of increasing thickness of a dielectric layer increases the susceptance (reciprocal of the reactance) of a three-layer sandwich in a positive direction. The gradient in the area and spacing of the holes of rows 3' and 3'' increases the susceptance of the sandwich inductively as the holes or their spacing becomes smaller.

There is no insertion phase when the inductive reactance of the sandwich equals its capacitive reactance. In order to obtain phase delay as for beam-shaping purposes the susceptance of the sandwich must be positive (capacitive). For phase advance it must be negative (inductive). In either case there will be some reflection. The insertion phase can be varied over the face of the sandwich by tapering a capacitive layer or the dimensions or spacing of the holes, whichever is the most convenient.

In the exploded view of FIG. 1(B) the dielectric plates 7' and 7'' have a thickness variation decreasing from left to right to produce a prismatic effect for the radiation if one is desired. The metal core of the sandwich comprises perforated plates 5' and 5'' which are slid with respect to one another for the desired degree and angle of occlusion of the open area extending through both plates. Thus the effective open through area is diminished, one axis being shorter than the other unless a third perforated metal plate is employed to polarize the hole and to decrease its inductive shunt reactance. Radiation will be favored or discriminated against in keeping with its own polarization and the shunt impedance of the sandwich with respect to the medium from which the radiation enters the lattice of holes, as from dielectric layers sandwiching it.

In FIG. 1(C) is shown a dielectric supporting sheet 9 on which conductive boundaries enclose a lattice of wall patterns two of which are shown comprising conducting rings 10', 10'' and conducting discs 11', 11'', which may be polygonal as shown, circular or elongated, the shaded areas being conductive and the unshaded areas being nonconductive. Dependent upon the selection of the ring periphery πD and the disc periphery πd the lattice of patterns will be inductive or capacitive above and below the resonant frequency respectively, as shown in FIG. 2(B) by curves B' and B''. When sandwiched with layers having reactance of the opposite sign, the lattice may be designed to match a passband as shown in the circuit of FIG. 2(C), the mathematical procedures for such a circuit being well known. A broadbanded match for an induc-

tive lattice wall sheet can be obtained with a dielectric curve D in FIG. 2(B).

In FIG. 1(D) is shown a dielectric supporting sheet 13' on which conductive boundaries enclose a lattice of wall patterns comprising an outer electrical ring area 14' and inner magnetic area 14''. The lattice will be inductive or capacitive below and above the resonant frequency, respectively, as shown in FIG. 2(B) by curves A' and A''.

The circuit of FIG. 2(A) shows the design procedure to match a passband when layers of opposite sign alternate. A broadbanded match for FIG. 1(D) may be obtained with an insulating material of a low-dielectric constant such as 3.25, Curve D, FIG. 2(B).

In FIG. 1(E) is shown an aperture-coupling sandwich comprising conducting plate 12' perforated with an inductive lattice 12'' of through holes. The plate is strengthened by conductive ribs 13 and capacitatively matched by a thin high-dielectric constant material such as fused silica 15', 15'' and 15'''. A clear advantage of this construction is that silica has superior high-temperature properties and the inherently small areas in which it can be satisfactorily made are mechanically adequate in a ribbed structure. It is preferable that the dielectric constant of sublayers 14', 14'' should be at least as high as the square of the dielectric constant of layers 15, 15'' and that the sublayers are at least a little more reactive but of opposite sign from the inductive lattice plate. To support small dielectric plates by a metallic rib structure alone would be very unsatisfactorily electrically as the rib pattern would be so coarse grained in a diffractive sense as to deteriorate the wave pattern severely.

In FIG. 1(F) is shown a multifrequency multisandwich which can be designed as for the circuits of FIGS. 2(A) and 2(C), by cascading the network. As a preferred example of the selection of alternate layers, the prismatic dielectric layers of FIG. 1(B) may be located at 7', 7'', 7''', and 7'''. The lattice 14' of the wall patterns of FIG. 1(D) may be employed within their inductive range to match high-dielectric constant prisms. As a second preferred example, a gradient inductive plate such as 2'' of FIG. 1(A) can be matched by lattice 14 when the conductive boundaries of its areas are of a peripheral length for the lattice to be capacitive.

FIG. 1(G) shows an inductive lattice structure 17 designed to be hollow so as to be more rigid and to permit the passage of hot gas or hot liquid. Ground based antennas often must be anti-iced or subject to icing difficulties. Simple holes such as 18' may be employed. The cutaway shows the tubular nature of the hole walls 18''. In cross section, the tubes may be round, elongated or polygonal to meet the particular application requirements.

FIG. 2(A) is the equivalent transmission line circuit for an aperture-coupling sandwich comprising alternating layers of capacitive and inductive layers, such as those of FIGS. 1(C) and 1(D), in shunt across a wave front, matching a load at either end to a source at the opposite end. It is to be understood that while each face of the inductive layer is represented by a series circuit 20', 21' and 20'', 21'' in which the resultant shunt reactance is inductive, the shunt capacities 23' and 23'' might also be represented by a similar series circuit in which the resultant reactance is capacitive. The little shunt circuit 24, 20''' in series represents the thickness of the inductive layer. Capacitances 22', 22'' are equivalent to the series reactance between codirectional shunt layers having wall patterns defined by conductive boundaries. The circuit may be cascaded with similar sections to describe a sandwich comprising additional layers.

FIG. 2(B) is a graph of inductive reactance ($+X_L$) and capacitive reactance ($-X_C$) in the range of 0 to ± 6 versus the ratio of the periphery of an inner boundary $\pi d/\lambda$ in the range of 0.6 to 2.4. In each corner is sketched the transmitting area pattern characterizing that quadrant of the graph. Curves A'-A''-B''-C', D' represent the values of 0.7 and 0.96 for an outer boundary of periphery $\pi D/\lambda$ where λ is the wavelength. Curves A'-A'' show the trend of the reactance of

electric wall patterns from inductive to capacitive and curves B'-B'' the trend of magnetic wall patterns in the same direction. Curve C represents the capacitive reactance for a thickness range of $0.25 \lambda_e$ for an insulator of dielectric constant 7.95 and curve D for a dielectric constant of 3.25. It can be seen that curve D has the same trend but is of opposite sign from the median of the B' curves and that curve D nearly matches the median of the B' curves. This means that lattice wall layers can be matched for a broadbanded passband by being alternated with layers of suitable dielectric constant. Furthermore, layers designed as for B' may be matched by layers designed as for B'', while layers designed for A' may be matched by layers designed for A''. The patterned lattice layers have a principal advantage over the dielectric layers in that they can be thin. Thus I have provided wide latitude in planning an aperture-coupling sandwich.

FIG. 2(C) is a repetitive section of the equivalent transmission line circuit for a stack of capacitive layers alternating with shunt and inductive reactance across a wave front in which the inductive elements are "alternatively" a lattice of polygonal, circular and elongated inductive holes as shown in FIGS. 1(A), 1(B) and 1(G) or in which such holes enclose an electric wall area as in FIG. 1(C). As in FIG. 2(B) capacitive shunts may be elements proportioned as for curves B'', and A'' or dielectric materials as for curves C' and D'. The inductive depth of a hole is represented by 25''. The capacitance between shunt metallic layers is shown at 26''.

FIG. 2(D) is a graph of curves E representing capacitive reactance versus electrical thickness for a group of dielectric materials and curves F showing inductive reactance versus the ratio of hole radius r to center-to-center spacing b for circular holes, as well as polygonal holes of equivalent periphery, the three codirectional lines being for spacing (b/λ_e) values of 0.5, 0.4 and 0.3. A horizontal line G of constant reactance placed across all of the curves provides the parameters for an exact match. Two such lines G and H define the parameters for a desired difference in reactance as may be required to couple a transmission line aperture and antenna outer region of differing reactances. It can be seen that simple inductive holes will not match insulators of low dielectric constant, although such materials are among the most valuable of the low-loss dielectrics, but that this can be done with the lattice walls of my FIGS. 1(C) and 1(D).

For simplicity in drafting I have shown my holes as though they were open circles. However, they may contain additional elements as in FIGS. 1(C), (D), (F) or they may have comparable peripheries but other shapes.

Technical literature contains information on theory and measured data on the reactance of lattices of discs. There is considerable information on symmetrical single holes rather than lattices of holes. The measurement of hole lattices is inherently inaccurate because the reactance is so low as to make the reflection observed extremely high. Consequently my preferred approach is to construct a model array of discs at the angles of incidence and for the modes of interest, measure the reflection which will be lower than for holes of the same dimensions and then compute the lattice susceptance from:

$$R = \frac{-jB}{2+jB} \quad \text{Equation (1)}$$

where R is the reflection coefficient and B the susceptance. Then for the same angles and modes on the basis of Babinet's principle of optics I derive the reactance of a lattice of holes from

$$^0X = -4jB \quad \text{Equation (2)}$$

I have found that I can compute the reactance of a lattice of holes, utilizing information from single holes, but great care must be taken in determining the frame of reference for the starting data. Montgomery, Dicke and Purcell in their "Principles of Microwave Circuits," The McGraw-Hill Book Company, Inc., 1948, pages 176-178, provide useful values of the

polarizabilities of small symmetrical holes. The Lorentz static field theory for the interaction of arrays of conducting obstacles may be employed although it is approximate since its greatest validity is for obstacles with dimensions much smaller compared to their spacing than mine.

It is found that the magnetic and electric dipole moments of discs in a rectangular lattice are increased in a static interaction field by:

$$(1-\alpha_m C_m)^{-1} \text{ and } (1-\alpha_e C_e)^{-1} \text{ Equation (3)}$$

Then 0.65 jB is simply multiplied by these factors, for a convenient approximation. The polarizabilities in the case of one-half a circular disc are:

$$\alpha_e = \frac{16}{3} r^3 \left[1 + \frac{(K_o r)^2}{15} (8 - 1.5 \sin^2 \theta) \right] \quad \text{Equation (4)}$$

$$\alpha_m = (-) \frac{8}{3} r^3 \left[1 - \frac{(K_o r)^2}{10} (2 + \sin^2 \theta) \right] \quad \text{Equation (5)}$$

where r is the radius, θ is the angle of incidence and

$$K_o = \frac{9.139 \times 10^{-4}}{2\pi}$$

and

$$C_o = \frac{1.2}{\pi b^3} - \frac{8\pi}{b^3} K_o \left(\frac{2\pi a}{b} \right) \quad \text{Equation (6)}$$

$$C_m = (-) \frac{1.2}{\pi b^3} - \frac{1.2}{\pi a^3} + \frac{8\pi}{b^3} K_o \left(\frac{2\pi a}{b} \right) + \frac{8\pi}{a^3} K_o \left(\frac{2\pi b}{a} \right) \quad \text{Equation (7)}$$

where a is the center-to-center spacing of holes transverse to the electric field and b is the spacing in the direction of the electric field. When the lattice is not rectangular I change the moment in direct proportion to the decrease in the hole spacing in the direction of excitation. This amounts to a factor of 0.82 for a hexagonal lattice.

The effect of hole depth in a lattice can best be determined through reflection or transmission phase measurements of a model of thick obstacles, designed to a first approximation by applying interaction equations such as (3) to the equations of N. Marcuvitz for single deep holes found in the "Waveguide Handbook," the McGraw-Hill Book Company, Inc., 1951.

For lattices comprising individual transmission areas with axes and spacings that are a large fraction of a wavelength such as those of my FIGS. 1(C) and 1(D) the radiation field from each area becomes more important than the local induction field, varying as the inverse third power of the distance. Dynamic-field-interaction constants and polarizabilities for electric wall areas are available with instructions for their use in the "Field Theory of Guided Waves" by Robert E. Collin, McGraw-Hill Book Company, Inc. 1960, Chapter 12. This information is carried over to magnetic wall areas with my equation (2).

For a rectangular lattice of negligible thickness of circular holes or polygons of equivalent circumference, the reactance may be computed for $r < (b/2)$ and (b/λ_e) lies between 0.3 and 0.5 from:

$$\alpha_{XL} = \frac{9.6}{\cos \theta} \frac{b}{\lambda_e} \left(\frac{r}{b} \right)^3 \left[1 - 1.92 \left(\frac{r}{b} \right)^3 \right]^{-1} \quad \text{Equation (8)}$$

for the inductive component

$$\alpha_{Xe} = \frac{\sin^2 \theta}{2} (\alpha_{XL}) \quad \text{Equation (9)}$$

for the capacitive component

where:

0X_L and 0X_e - inductive and capacitive shunt reactances in the lattice;

b = the center-to-center spacing of the holes;

λ_e = wavelength in the capacitive medium surrounding the lattice sheet;

θ = the angle of incidence of the wave in the surrounding capacitive medium as it impinges upon the aperture sheet.

Reactances obtained by means of equations (8) and (9) generally fall between those measured without imaging and those measured with imaging.

The shunt reactance of my capacitive dielectric layer is obtained from the following equation:

$$\epsilon_{X_0} = \frac{(\epsilon+1) + (\epsilon-1) \cos \phi}{2\sqrt{\epsilon(\epsilon-1)} \sin \phi} \quad \text{Equation (10)}$$

where;

ϵ = the effective dielectric constant of the capacitive layer;
 ϕ = the electrical thickness in the dielectric.

In most practical cases I either taper the dielectric thickness along the surface of the lattice wall or provide a gradient of varying inductive lattice dimensions. Implicit to FIGS. 2(C) and 2(D) the susceptance (reciprocal of the reactance) to match an inductive lattice comprises the sum of the susceptances on both sides of the lattice.

The shunt reactance to match with a capacitive lattice wall such as shown in FIGS. 1(C) and 1(D) is obtained as for the negative portion of my FIG. 2(B).

At arbitrary incidence from the normal the angle of the wave as it impinges on the dielectric medium from air will be much greater in proportion to the index of refraction, than the angle incident on the inductive lattice sheet, thus the change of inductive reactance with external angle of incidence is conveniently small.

Materials typical of those which I employ are:

	ϵX_c for $\phi =$		
	ϵ	0.17 radian	1.57 radians
Alumina/nickel-aluminide cermet	14.1	2.14	.153
85% to 94T alumina	7.95	2.32	.228
Aluminum powder loaded polyester resin reinforced with E glass fibers	6.2	2.73	0.278
Polyester resin reinforced with E glass fibers	4.5	3.48	0.371
Fused silica	3.25	4.58	0.523
Polytetra fluoroethylene	2.02	8.00	1.03

In my lattice wall I seek high-inductive shunt reactances so that I can obtain high transmission with the thinnest shunt capacitances suitable. An increase in the $(r/b)^2$ portion of the $(r/b)^3$ term can be used to depict an increase in the proportion of open area. In the case of the slot dipole other than the requirement that the length of the slot be at or near resonance it is necessary to keep the open area as small as the breakdown voltage of the slot will permit. Thus while it is necessary for the dipole to be polarized, it is not essential for my magnetic areas.

To appreciate the distinction between my capacitively matched magnetic areas and holes which are not, at a wavelength of 1.26 inch holes whose diameter are 0.4 wavelengths have transmission losses in decibels of 4, 7 and 18 for hole depths of 0.006, 0.072, and 0.313 inches suitable to construct a so-called leaky waveguide antenna but not my antenna, since for my holes of the same dimensions the allowable transmission loss range must and can extend to less than a fraction of one decibel to achieve the degree of wave coupling that characterizes my invention.

In a cascade of my lattice wall sandwiches the collective admittance transformation ratio of all the layers at n different frequencies have a collective common ratio Y_o/Y_{in} for all n frequencies, Y_o/Y_{in} being equal to the product of the terms

$$T_1(\lambda) \cdot T_2(\lambda n) \cdot \dots \cdot T_n(\lambda n) \quad \text{Equation (11)}$$

where Y_o is the admittance of the medium in contact with the surface of the stack facing the radiation, Y_{in} is the admittance of the stack, Y_{in} is the wavelength in the medium for each of the n different frequencies and T in each instance represents the desired transformation ratio. The circuits of FIGS. 2(A) and 2(C) provide the transmission line models for detailed calculation. The preferred parameters are as follows:

a. that the passbands be spaced at constant increments of frequency above the lowest passband;

b. that the maximum electrical thickness of the sandwich cascade be less than π radians of free space wavelength in the lowest passband.

In the description of FIGS. 1 and 2, I developed my specifications for a lattice wall sandwich to make possible my family of multimode antennas for multifrequency, multipattern, multipolarization operation, in which the sandwich couples between a radiation aperture in a transmission line and an antenna outer region. My ranges of preferred and distinctive parameters may be summarized as being substantially as follows:

1. The reactance of the individual sandwich layers to be in the range of 0.010 to 6.0.

2. Major inductive lattice magnetic areas to be spaced:

a. By 1.05 to 1.6 their axial lengths in the direction in which their axes are 0.3 to 0.6 wavelengths;

b. By 1.05 to 2.08 their axial lengths in the direction in which their axes are 0.6 to 1.2 wavelengths;

3. For an inductive reactance in series with a smaller capacitive reactance, both shunted across the wave path, the ratio of axial lengths of conductive boundaries interior to the magnetic areas preferably are proportioned to the axis of the layer area in the same direction by:

a. A factor of 0.2-0.45 when the interior boundary contains a nonconducting magnetic area;

b. A factor of 0.45-0.8 when the interior boundary contains a conducting electric area;

4. The spacing of major capacitive lattice areas is as for (2);

5. For a capacitive reactance in series with a smaller inductive reactance, both shunted across the wave path, the axial lengths of conductive boundaries interior to the major capacitive lattice areas preferably are proportioned to the axial lengths of the latter in the same direction by:

a. A factor of 0.45 to 0.8 when the interior boundary contains a nonconducting magnetic area;

b. A factor of 0.2-0.45 when the interior boundary contains a conducting electric area;

6. The transmission level of a complete lattice wall sandwich preferably should not be more than 4 decibels below full transmission, except in the case of occluding holes as in FIG. 1(B), which may be adjusted for a range of transmission from less than 4 decibels down to a level of zero transmission;

7. Residual reactance is to be distributed across the lattice wall sandwich as required to match the reactance distributed across the radiation aperture and to provide path length changes as necessary to shape the beam;

8. A dielectric capacitive layer may be sublaminal, the layer adjacent to my inductive layer preferably having greater reactance than the inductive layer and a dielectric constant at least the square of that of the outer dielectric layer, the outer dielectric layer preferably being substantially 0.5 radians thick;

9. Lattice wall sandwiches cascaded for multiband and broadband use have at least three capacitive layers, at least two inductive layers and a total thickness preferably not in excess of π radians of free space wavelength;

10. Lattice wall sandwiches for use with radiation sources at frequencies outside the lattice walls transmission range are made coplanar as by providing slot dipoles for said radiation sources;

11. Ribs for lattice wall sandwiches are preferably sloped to reduce reactance changing imaging, except when it is wanted, and are located between transmitting area;

12. The conducting electric walls of lattices may be hollow for purposes such as anti-icing heat distribution and for weight reduction.

In a radome the requirement is that the dielectric wall be matched to free space on each side for complete transmission and that it not distort the wave front by introducing prismatic changes. The embedment of a metal plate perforated with inductive circular holes to match a dielectric radome wall has been investigated in the prior art. The conclusion drawn was that it is not possible for a radome to be thus matched to give

good transmission over a wide range of incident angles for both polarizations.

While my purpose is to provide a family of antennas achieving multimode performance by means of the antenna outer region being matched to a transmission line radiation aperture with a wave coupler comprising a sandwich of conductive boundaries in a lattice layer, I found some relevance in examining the foregoing prior radome art conclusion, since in my lattice there must be more degrees of matching and prismatic control than in a radome.

It can be seen that I have devised techniques for causing the capacitative and inductive reactances to have similar reactance trends for matching, and thus have accomplished what the prior art could not. For example:

1. when my conductive boundaries define a lattice of magnetic wall areas as for simple inductive holes, I prefer to select half-peripheries having a length in excess of 0.4 wavelengths in the direction of the spacing between holes.

2. When I wish to utilize the divergence between E and H mode reactance with increasing angle of incidence for matching transmission line apertures which require such a divergence, I employ the 0.3π - 0.4π wavelength range for the half-peripheries of simple holes;

3. When I wish the inductive reactances for the H and E modes to track together, I employ the dielectric sublayer illustrated in FIG. 1(E).

4. By using insulating layers of high dielectric constant to match simple holes in inductive magnetic wall lattices, I move Brewster's critical angle out to grazing angles of incidence thus lessening any diverging trend of dielectric and lattice wall reactances;

5. I employ the alternative of avoiding dielectric problems by employing lattice walls to match lattice walls to the degree necessary to couple my transmission line apertures.

In the embodiments of my multimode antenna invention which I will now describe, my lattice wall sandwich comprises the following additional distinctive features:

a. A predetermined distribution of combined antenna coupling reactance across the face of my lattice wall sandwich;

b. A cascade of at least three capacitative layers and at least two inductive layers in a multifrequency lattice wall sandwich of less than π radians thickness;

c. For adjustable polarization, reactance and insertion phase at least one electrically conductive aperture wall subdivided into at least two codirectional conductive layers in sliding contact with each other, for registration at successive positions and orientations of occlusion, partial occlusion and no occlusion;

d. Elongated, elliptical and unsymmetrical holes to maintain inductive matching of the dielectric in the arbitrary incidence region;

e. Alternatively: (1) dielectric capacitative layers, (2) capacitative layers comprising at least one conductive layer perforated with at least one lattice of nonconductive holes and coated with electrical insulation;

f. Thin capacitative layers. In contrast dielectric layers substantially in the range of 1.57 to 3.14 radians of uniform thicknesses are already known for providing reactance in the very limited range of 0.200 to 0.370 for matching at a single frequency of operation.

My family of multimode antennas comprise the following additional broad distinctive features as is demonstrated in the embodiments of my invention as follows:

1. The lattice wall sandwich comprises the electromagnetic wave radiation aperture of a waveguide as in FIG. 3;

2. Such a waveguide comprises at least one pole of a multipole feed of a second antenna as in FIG. 3(C);

3. A lattice wall sandwich such as that of FIG. 1(B) comprises the reflector for at least one feed as in FIG. 4;

4. The lattice wall sandwich of FIG. 1(B) is backed by an electromagnetic wave absorber as in FIG. 4;

5. The lattice wall sandwich is substantially coplanar with at least one slot dipole as in FIGS. 5 and 6;

6. The coplanar lattice wall sandwich and at least one slot dipole are a radant, that is mounted as a radome and cover at least one additional antenna as in FIG. 6(A);

7. The radant is ribbed between the holes of the lattice wall as in FIGS. 1(E) and 6(B).

8. The electrically conductive perforated lattice wall is hollow as in FIG. 1(D), an alternate construction for FIG. 6.

To illustrate the embodiment of my invention as a waveguide linear array, I have prepared FIG. 3(A). Rectangular waveguide 30 comprises an opening from 31' to 31'' along the right hand narrow side closed by my lattice sandwich. It is closed at end 32'' and the interior of the waveguide 30 is fed by generator G connected to probe P and said guide at end 32'. Its other narrow side 33' contains an inner surface plate 33'' which is hinged at 33''' so that 33'' can swing toward the right-hand open side. The swinging end of plate 33'' swings in sliding contact with iris 34', a metal plate slotted so as to be open between lines 34'' and 34'''. Thus when plate 33'' is swung toward side 31'-31'' the proportion of reflective surface of the iris is changed to keep the reflection constant. Holes 35' and 35'' remove energy entering the space between iris 34' and end 32''.

Electromagnetic wave energy which can be propagated in waveguide 30 can pass through opening 31'-31'' as though the guide were a special type of horn antenna. Swinging plate 33'' maintains electrical contact with the guide inner surfaces and the iris by fingers, alternatively by a choke channel along its edge, and reflects radiation in and out with respect to opening 31'-31''. I enclose opening 31'-31'' with my lattice wall sandwich to control the coupling between free space, the antenna outer region, and the waveguide. Since my lattice wall sandwich contains a conductive inner layer, the horn becomes a waveguide and the individual apertures contain nonresonant more or less matched dipole moments when the guide is excited.

The guide wavelength increases and the angle of incidence of the wave in the guide against side 31'-31'' decreases as plate 33'' swings toward narrow side 33'. The coupling of energy in amount through my lattice wall is increased as the match between guide wavelength and angle of incidence on the screen is improved. Furthermore, since the outer region radiation pattern of my apparatus is dependent upon the coupling, it is controlled by the design of my lattice wall.

For the design of my lattice wall I have the option of tapering the inductive susceptance of my hole arrays 25''', 35'''' or the capacitative susceptance of the dielectric layers to further shape the outer region pattern. This pattern will be what is known as end-fire, though its angle away from broadside can be varied. To produce a broadside pattern, I feed my waveguide from side 33' rather than end 32', as a special form of a so-called box horn. In this case I omit swinging plate 33'', iris 34', and extend my opening 31'-31'' and my hole array along the full length of their side.

In a design of an end-fire array for 15.7 gc. employing RG-91/U rectangular waveguide (0.622 by 0.311 inches inside) I place two lengthwise rows of 0.12 inch diameter dielectric filled holes along the lattice wall, having a square lattice spacing between the rows and between hole centers of 0.156 inches, the distance of the lengthwise edge being 0.078 inches. As in the case of conventional arrays, the length derived may be selected for the array factor desired. The innermost side of swinging wall 33'' when parallel to fixed wall 33' is 0.100 inches inwards from it. The inward swing of wall 33'' to a depth of 0.250 inches is provided by any convenient mechanical apparatus which may be placed behind it.

In FIG. 3(B) is shown the conductive aperture layer in perspective and cross section, 32 gauge metal 36' covered with alumina plates 36'' and 36'''. These have a dielectric constant of 7.95. The inner plate is thicker than the outer, the former being matched to the waveguide and the outer to free space. The initial design thicknesses are 0.074 and 0.068 inches respectively. During a prototype construction and test period common to antenna engineering, these parameters are adjusted to tailor the antenna for detailed shaping, phasing and

impedance match. By substituting dielectric plates of other dielectric constant values, also substantially greater than 4.5, the array can be employed at other frequencies in the 12.4–18.0 gc. range.

Installed as a flush mounted array in the skin of an aerospace vehicle my antenna, optionally fixed or rotatable, provides the advantages of elevation control of the pattern without a tilting of the waveguide itself, a superior and controlled coupling of energy between free space and the transmission line, the compactness vital to such vehicles, plus the environmental and structural survivability of the alumina-coated metal aperture screen.

My array may also be employed as a feed in a reflector antenna in which the reflector 37 further modifies the pattern and scanning as in FIG. 3(C). The aperture screen may be split into two half-sandwiches as in FIG. 1(B) for polarization and matching control. Also, my high-frequency arrays 38' and 38'' may be excited at 39', 39'' on their outer surfaces to serve an additional function as lower frequency dipoles in a multifrequency antenna system.

FIG. 4 shows in perspective a multipolarization scanning antenna having a special composite selective reflector 40 and at least one circularly polarized horn feed 41. Reflector 40 comprises an alumina/nickel aluminide cermet dielectric layer 42 adhering to a perforated aluminum sheet 43, the half-sandwich designed with the aid of the curves of FIG. 2 behind which moves coaxially with it 40 a second such half-sandwich 44 shown in the cutaway view afforded by A'-A''.

In a preferred design the capacitive layers have a uniform thickness of 0.10 wavelengths (0.628 radians) in the dielectric providing a reactance of 0.435. The holes are circular, have a center-to-center spacing of 0.5 wavelengths in a rectangular lattice and a half-periphery to spacing ratio of 0.44π .

By relative motion the registration of the holes in the plates as in FIG. 1 can provide positions for (1) electrically effective occlusion, (2) through transmission into the absorber at circular polarization, (3) through transmission into the absorber for one plane of polarization and rejection for a second plane, (4) tuning to other frequencies by change in the hole area. Thus feed 41 receives and transmits in conjunction with the composite selective reflector only desired polarizations and frequencies.

The embodiment of my invention shown in FIG. 4 not only is polarization selective but also removes unwanted energy by absorption rather than creating interference with other systems. A multiplicity of feeds may be employed to obtain overlapping lobes. There may simultaneously be feeds operating at other frequencies.

FIG. 5 illustrates in perspective a multifrequency embodiment of my antenna invention. Arrays of slot arrays are built into a metal surface 50 as shown in FIG. 5(A). FIG. 5(B) shows in cross section a half-wave narrow rectangular slot 51 whose backwards pattern is cutoff by quarter-wave deep metal box 51. The slot is fed at 52 by conventional means. The sheet 50 of which the array and the boxes are built is a sandwiched perforated plate designed as shown in the description of FIG. 2 in order to permit the passage of higher frequency radiation along the axis S'-S''.

The capacitive surfaces 53, 54 are of a dielectric composition comprising parallel layers of resin filled and bonded fabric woven from E glass fibers. The resin is loaded with powdered aluminum. Less than 10 percent of the latter by weight of the resin is added until the dielectric constant of the mixture when solidified by curing is a little greater than that of the E glass, which is 6.2. The excess is to compensate for the residual air which will be entrapped, so that the final product will have a dielectric constant of 6.2.

On examination of FIG. 2 it will be seen that when weight limits permit the dielectric layers to total as much as 1.44 radians (0.23 wavelengths) thick, the capacitive reactance available for matching is 0.31. A square lattice of holes shown by cutaway B'-B'' as at 56 spaced center-to-center 0.5 wavelengths apart and having each a radius of 0.2 wavelengths

is designed to match the equal dielectric layers on each face and permit maximum transmission. Test results and the special conditions attendant to imaging by the dipole slots and practical structural elements may require an increase in the hole radius.

A very rugged construction for the lattice wall employs a thick-walled (14 ga.) aluminum hexagonal honeycomb core. The depth t of the holes is 0.064 wavelengths, their spacing is 0.50 wavelengths and their periphery is that of a circle of 0.4 wavelengths diameter. The core is sandwiched by aluminum powder loaded plastic matching layers having a dielectric constant of 6.2. The total thickness of the dielectric layers is 1.57 radians in the dielectric. When the lattice is employed to transmit at a wavelength of 4 inches, the core is 0.25-inches thick, and the periphery of the hexagonal holes is 2.0 inches. The dielectric layers are each 0.20 inches thick. When the dipole slots are for a wavelength of 12 inches, they are 6 inches long, 3 inches deep and as narrow as structurally feasible.

A similar construction is appropriate for the lattice wall employed in FIG. 6 with a deliberate gradient of reactance matched at arbitrary incidence away from the center of the wall as customary for carefully designed radomes. For the heavy gauge core may be substituted an easily formable honeycomb in the individual cells of which has been placed coaxially an aluminum tube. The choice of gradient techniques shown in FIGS. 1(A) and 1(B) is available. For multiband use at shorter wavelengths the multiple sandwich of my FIG. 1(F) may be employed with honeycomb inductive lattices and capacitive conductive lattice sheets as illustrated by FIGS. 1(C) and 1(D), coated with dielectric insulation and laminated with a dielectric binder.

Another embodiment of my invention a bottom view of which is shown in perspective FIG. 6(A) which I entitle "a radiant" 60, is a multifrequency antenna incorporating some of the functions of a radome. As in the case of the multifrequency embodiment of FIG. 5, narrow slots 61 substantially resonant for at least one frequency are coplanar with an aperture screen 62 matched at couple at least one other frequency, at least one antenna system 63 for which is directed toward the screen but is spaced away from it. In the illustration my radiant is of ogival shape to shield antenna system 63 from destruction by the outer environment and masks it electrically at frequencies at which radiant 60 is highly reflective. It may be of any other serviceable shape as to conform to the outline of an aircraft or the familiar spherical domes of ground based radar. In the latter case the hollow conductive lattice wall construction of FIG. 1(G) may be advantageous to channel heat for anti-icing.

The slots 61 may comprise a nonscanning beacon antenna such as is employed by aircraft to ride a beam down to a landing field and in that case need only occupy a selected and limited surface area such as at the bottom rear position of the radiant as shown in FIG. 6(A). Antenna system 63 may comprise the scanner of a weather avoidance radar and radars as for navigation and collision avoidance. Typical radiation directions are shown at 67 and 68.

The matched lattice wall 62 of the radiant may be designed as a major source of structural strength especially if the radiant is large. Its lattice of holes in the conductive layer may be varied in size and spacing as in FIG. 1(A) to provide a gradient of wave coupling for radiation in different directions. The gradient may be achieved also by varying the thickness of the covering dielectric layers as in FIG. 1(B).

In the former case, I employ holes varying in diameter from 0.3 to 0.45 wavelengths and center-to-center spacings in the range of 0.3 to 0.5 wavelengths. In areas of maximum angle of incidence the holes are elliptical to project a circle in the direction of radiation. As in FIG. 1(A) conductive aperture layer containing holes 3', 3'' may be of an aircraft alloy such as aluminum and be designed to have a thickness of 0.1 wavelengths, which would be 22 gauge sheet at a frequency of 16 gc. when the holes are not filled and 31 gauge when they

are. The conductive layer is covered on each side by capacitive layers. Of available dielectric layers I prefer for adverse environment flame-sprayed alumina over a thin priming coat of a flame-sprayed cermet, such as alumina/nickel-aluminide, the dielectric constant and thickness of the thicker alumina layers being substantially 7.95 and 0.25 wavelengths respectively, in the path of the transmitted radiation.

FIG. 6(B) illustrates a section of the conductive portion of the lattice wall employed in FIG. 6(A). Heavy triangular metal ribs 64 which would have an extremely adverse effect on the pattern of an antenna system covered by a radome can run between the holes such as those at 65 in the conductive layer 66 of my lattice wall as in FIG. 1(E) requiring only a very secondary cut-and-try adjustment in hole spacing and size to optimize imaging of the dipole moments of my screen. As in my other illustrations of lattice walls, the entire area through which transmission is intended would contain a lattice of perforations. In fact, with such ribs 64 the conductive lattice layer 66 can be merely a patterned film of silver particle-loaded conductive paint.

The advantages of such a radant as compared with a radome are:

1. That surface antennas as for a beacon do not have to transmit through a radome wall which cannot be optimum for them;
2. The environment-protected antenna systems are also shielded from illumination at frequencies outside of their desired operating bands;
3. The ceramic surfaced metal radant is more environmentally resistant than a plastic radome. A ceramic wall for a radome must be very limited in size as it cannot have a metallic support which will not seriously degrade antenna performance.

For the purpose of describing my invention, certain specific embodiments and materials have been illustrated, but it is to be understood that the invention is not to be limited thereto, since it is evident that such other embodiments and materials are contemplated as are within the spirit and scope of the invention.

What I claim is:

1. An antenna comprising at least one electromagnetic wave transmission line radiation aperture and at least one lattice wall sandwich facing and across the wave path, said sandwich spaced between said aperture and the outer region of said antenna, the equivalent circuit of said sandwich having at least one section comprising two capacitive members shunted across codirectional through-conductors and disposed across opposite ends of a network, said network comprising a series inductance in one of said through conductors and two inductances each shunted from an opposite end of said series inductance to the other of said through conductors, said sandwich having at least one inductive lattice layer having nonconducting magnetic wall areas of thickness represented by said series inductance, said nonconducting magnetic areas being apertures in the conducting electrical wall areas, the inductive lattice layer having on each of its two sides capacitive layers, there being a predetermined distribution of antenna coupling reactance across the face of each layer of said lattice wall sandwich.

2. The antenna of claim 1 wherein said inductive lattice layer is perforated through from face-to-face with magnetic areas having depth providing series inductance and insertion advance in a wave front direction through said areas, at least two of said areas sharing a magnetic interaction field, said areas being separated by a center-to-center distance of the order of a whole multiple of 0.6 wavelength to provide shunt inductance across each face of said lattice layer and the decrease the insertion advance of said wave front and spaced closer to increase said insertion advance, said capacitive covering layers dimensioned to provide insertion delay on each side of said two magnetic areas, the net insertion through said magnetic areas and capacitive layers representing a predetermine coupling across said aperture.

3. In the antenna of claim 2, the capacitive covering layer comprising a ringlike magnetic wall area having an outer planar periphery enclosing an axis of 0.6 to 1.2 wavelengths and an inner planar periphery whose axis is 0.2 to 0.45 of said outer axis, the lattice spacing between magnetic area centers being selected to approach a whole multiple of 0.6 wavelength and to separate nearby outer peripheries with an electric wall.

4. In the antenna of claim 2, the capacitive covering layer comprising a ringlike electric wall area having an outer planar periphery enclosing an axis of 0.6 to 1.2 wavelengths and an inner periphery whose axis is 0.45 to 0.48 of said outer axis, the lattice spacing between electric area centers being selected to approach a whole multiple of 0.6 wavelength and to separate nearby outer peripheries with a magnetic wall.

5. The antenna of claim 1 wherein at least one capacitive layer is of varying thickness.

6. The antenna of claim 1 wherein the capacitive layers are of substantially equal insertion phase along at least one wavepath.

7. In the antenna of claim 2, the lattice layer comprising a ringlike magnetic wall area having an outer planar periphery enclosing an axis of 0.6 to 1.2 wavelengths and an inner planar periphery whose axis is 0.45 to 0.8 of said outer axis, the lattice spacing between magnetic area centers being selected to approach a whole multiple of 0.6 wavelength and to separate nearby outer peripheries with an electric wall.

8. In the antenna of claim 2, the lattice layer comprising magnetic areas defining the boundaries of a ringlike electric wall area having an outer planar periphery enclosing an axis of 0.6 to 1.2 wavelengths and an inner planar periphery whose axis is 0.2 to 0.45 of said outer axis, the lattice spacing between electric area centers being selected to approach a whole multiple of 0.6 wavelength and to separate nearby outer peripheries with a magnetic wall.

9. The antenna of claim 1 wherein the distribution of insertion advance is varied across said lattice.

10. The antenna of claim 1 wherein said inductive lattice layer is perforated through from face-to-face with magnetic areas having depth providing series inductance and insertion advance in a wave front direction through said areas, at least two of said areas sharing a magnetic interaction field, said areas being separated by a center-to-center distance of the order of a whole multiple of 0.6 wavelength to provide shunt inductance across each face of said lattice layer and to decrease the insertion advance of said wave front and spaced closer to increase said insertion advance, said capacitive covering layers dimensioned to provide insertion delay on each side of said two magnetic areas, the net insertion through said magnetic areas and capacitive layers representing a predetermined coupling across said aperture, said lattice wall being subdivided into at least two codirectional conductive layers in sliding contact with each other, the individual perforations in said layers being in registration at successive positions and orientations of occlusion, partial occlusion and no occlusion.

11. The antenna of claim 1 wherein said inductive lattice layer is perforated through from face-to-face with magnetic areas having depth providing series inductance and insertion advance in a wave front direction through said areas, at least two of said areas sharing a magnetic interaction field, said areas being separated by a center-to-center distance of the order of a whole multiple of 0.6 wavelength to provide shunt inductance across each face of said lattice layer and to decrease the insertion advance of said wave front and spaced closer to increase said insertion advance, said capacitive covering layers dimensioned to provide insertion delay on each side of said two magnetic areas, the net insertion through said magnetic areas and capacitive layers representing a predetermined coupling across said aperture, said sandwich being substantially coplanar with at least one slot dipole.

12. The antenna of claim 2 in which at least two inductive areas of a lattice comprise each a larger magnetic wall area enclosed by an exterior electric wall and containing an interior conducting boundary defining a smaller electric wall and in

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which said capacitive layers covering said inductive areas on each side comprise each a dielectric layer, and at each frequency within a broad band the inductive lattice being geometrically proportioned and the dielectric constants and electrical thicknesses of said dielectric layers being selected to provide inductive and capacitive reactances, respectively, of opposite sign, the differences between said reactances being of substantially constant magnitude.

13. The antenna of claim 2 in which said lattice wall sandwich comprises a wave coupling cascade of at least three capacitive layers and at least two inductive layers.

14. The antenna of claim 2, in which at least one capacitive layer of said lattice wall sandwich comprises a dielectric layer subdivided into an outer layer substantially 0.5 radians thick and an inner sublayer having a dielectric constant at

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least the square of that of the outer layer and a reactance less than that of the inductive lattice layer which it covers.

15. The antenna of claim 2 in which said lattice wall sandwich comprises the electromagnetic wave radiation aperture of a waveguide.

16. The antenna of claim 10, in which at least one lattice wall sandwich comprises the reflector for at least one feed.

17. The antenna of claim 11 in which at least a portion of said antenna is a combination antenna and radome.

18. The antenna of claim 1 in which said lattice wall sandwich is ribbed.

19. The antenna of claim 1 in which said lattice wall is hollow.

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