

Aug. 16, 1966

D. S. LERNER
POLARIZATION CONVERTER

91,133
3,267,480

Filed Feb. 23, 1961

3 Sheets-Sheet 1

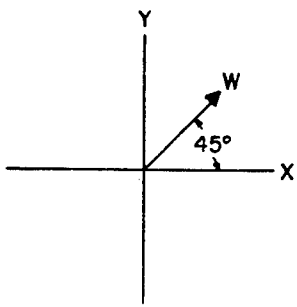


FIG. 1a

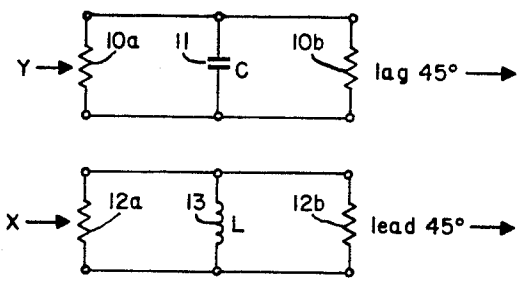


FIG. 1b

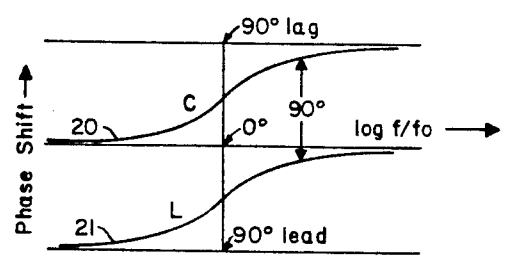


FIG. 2

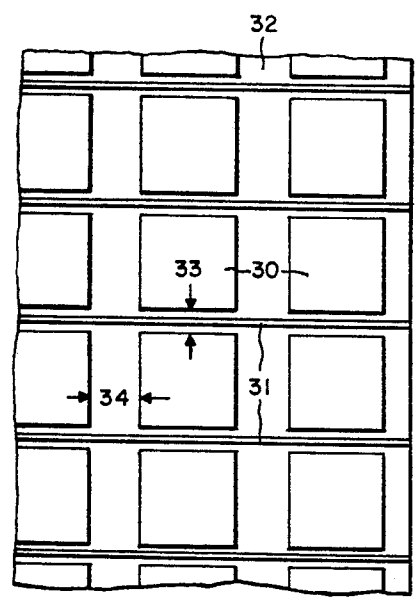


FIG. 3

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3 Sheets-Sheet 2

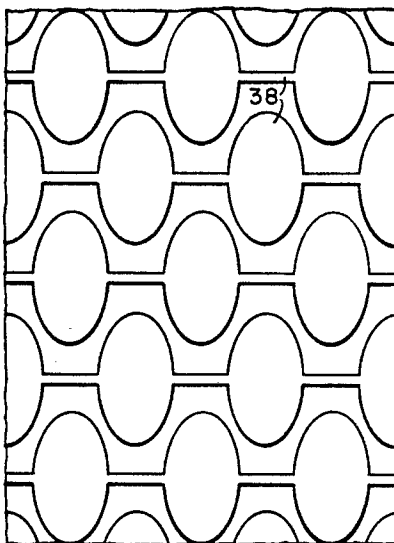


FIG. 4

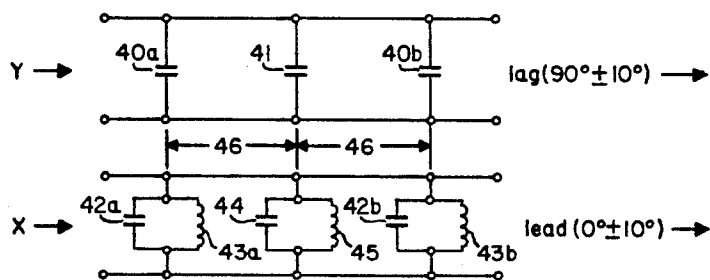


FIG. 5

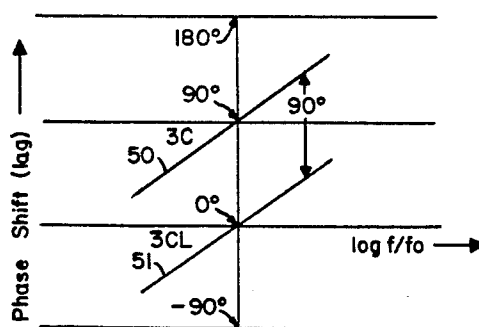


FIG. 6

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3 Sheets-Sheet 3

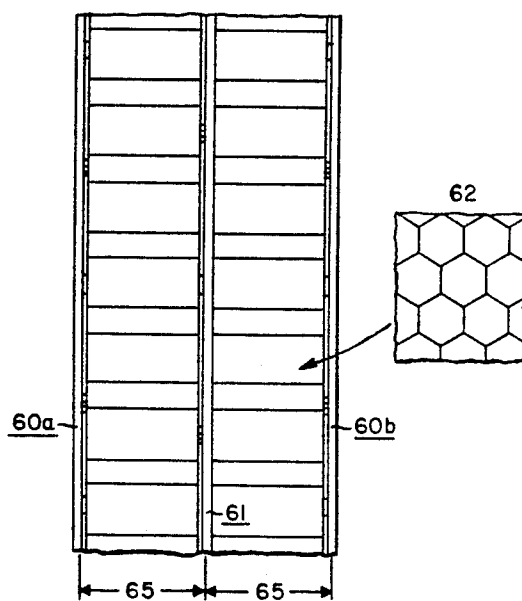


FIG. 7a

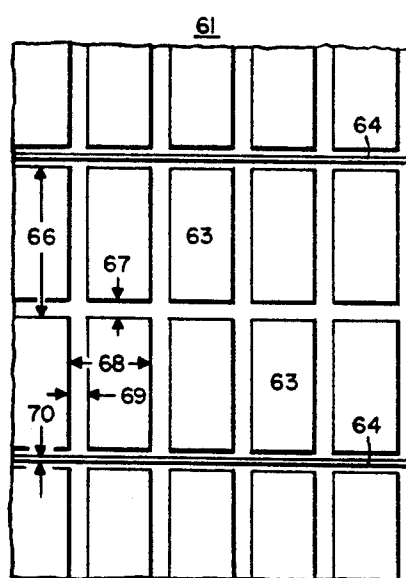


FIG. 7b

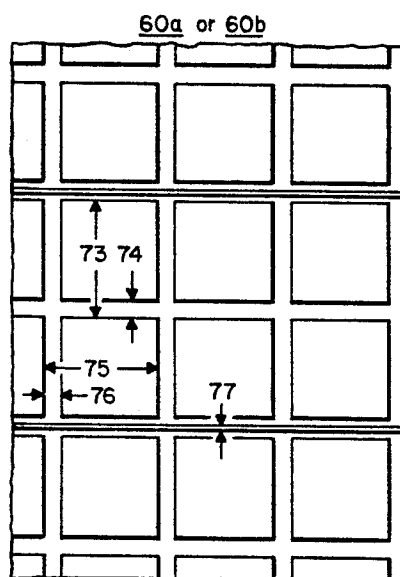


FIG. 7c

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POLARIZATION CONVERTER

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8 Claims. (Cl. 343-911)

This invention relates to transmission-type polarization converters and allows the conversion of any given polarization to any desired polarization. The invention will be described with particular reference to a polarization converter adapted to allow an antenna designed to operate with linear polarization to transmit and receive with circular polarization.

Polarization conversion is important in many areas to which the present invention is applicable. For example, circular polarization is required for various radar and communication applications; these include rain drop discrimination, propagation through the ionosphere (which may rotate the polarization) and communication with a missile or satellite of unknown or variable attitude. A transmission-type (as distinguished from reflection-type) polarizer may be used to convert a linearly polarized antenna to one with circular polarization and is applicable in this regard to existing antennas as well as to antenna systems intended for circular polarization applications, but which can be designed more conveniently and economically for linear polarization.

Many prior art antennas have utilized a lens in the form of an artificial dielectric. In applying this approach, an artificial dielectric is built up substituting discrete metal particles in place of the microscopic molecular particles existing in natural dielectrics. By the very nature of this approach a fairly substantial thickness of the artificial dielectric media is required to achieve useful results. This thickness is generally required to be several wave lengths at the design frequency (in the absence of special techniques such as zoning which are not applicable to the present problem). There have also been attempts to adapt this artificial dielectric idea to the design of polarization converters. One particular example suggested the use of twelve parallel sheets of conductive elements for operation as a quarter wave plate at a frequency in the vicinity of resonance of the elements. In this arrangement all the elements had a principal dimension of substantially one-half of the operating wave length and the complete arrangement was approximately three operating wave lengths thick (i.e., in the direction of wave transmission).

The present invention utilizes a lumped element approach. The thickness of a useful polarization converter constructed in accordance with the present invention can be made to depend only on the thickness required for structural support. Thus, a quarter wave plate might, in practice, be a few thousandths of a wave length thick rather than several wave lengths thick as in the prior art. The type of polarization converter presently considered to be the best mode of using the invention includes three sheet arrays of elements to achieve extremely broad band operation. In one specific converter of this three sheet type, the thickness was approximately one-third of a wave length in the design frequency range. While the comparison of a few thousandths of a wave length in thickness to several wave lengths in thickness very dramatically points out the advantages of the present invention, the difference between one-third a wave length and three or more wave lengths is still a very important advantage in the construction of a practical antenna system. It is obvious that great savings of space, weight, material, etc., result from the small size allowed.

The preceding discussion has completely ignored the

fact that prior art arrangements did not teach broad band impedance matching. Such matching is a very important additional advantage of the present invention.

It is an object of this invention, therefore, to provide new and improved polarization converters.

It is a further object of this invention to provide polarization converters which avoid one or more disadvantages of the prior art and which are adapted to relatively wide frequency band-width operation.

It is an additional object of the invention to provide polarization converters which are physically simple, relatively inexpensive, and the major components of which may be constructed using well known printed circuit methods.

In accordance with the invention a polarization converter for electromagnetic energy comprises a plurality of transmissive birefringent repetitive sheet array of conductive elements including elements which are discontinuous in all directions in combination with elements which are continuous in one direction, and means for supporting the sheet arrays; the converter including sheet arrays of at least two different configurations.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawing:

FIGS. 1a and 1b comprise two schematic representations useful in describing the invention;

FIG. 2 is a graph illustrating certain characteristics of the circuits of FIG. 1b;

FIGS. 3 and 4 illustrate polarization converter sheets in accordance with the present invention;

FIG. 5 is a schematic representation of a further embodiment of the invention;

FIG. 6 is a graph illustrating certain characteristics of the circuits of FIG. 5, and

FIGS. 7a, 7b and 7c comprise three views of a multiple sheet polarization converter in accordance with the invention.

To facilitate explanation of the invention, the discussion will be limited for the moment to the special case of conversion of a linearly polarized electromagnetic wave to a circularly polarized wave.

FIG. 1a illustrates arbitrary coordinates parallel to the wavefront of a wave. A wave of any polarization may be analyzed in terms of components along these coordinates. For example, a wave having a linear polarization W, as shown in FIG. 1a, may be considered to comprise equal amplitude X and Y components. In this discussion, the X and Y components, into which a wave may be broken down, will be referred to as the components of this wave. The polarization of a wave may be converted by shifting the phase of a particular component of the wave with respect to the remaining component. Thus referring to FIG. 1b, in such a polarization conversion we may regard the X and Y components of the wave as being transmitted through separate channels represented by transmission lines as shown. In one line the input and output wave impedances are represented by resistances 10a and 10b, respectively, and in the other line by resistances 12a and 12b, respectively. In one transmission line the input wave component (the Y component in this example) would be given a 45° phase lag by capacitance 11 of proper magnitude and supplied to resistor 10b. Simultaneously, the X component of the input wave would be given a 45° phase lead by inductance 13 of proper magnitude and supplied to resistor 12b. In this case, if the two original X and Y components were components of a wave of polarization W, as shown in

FIG. 1a, the signals appearing at resistors 10b and 12b could be recombined to produce a signal having circular polarization.

The results so produced are indicated in FIG. 2, wherein the vertical axis appears at the frequency for which the circuits of FIG. 1b were designed and at which these circuits produce leads and lags of exactly 45°. It will be seen that as the frequency of the electromagnetic wave is varied, the phase shifts produced by capacitance 11 and inductance 13, represented by the Curves 20 and 21, respectively, in FIG. 2, change in a manner such that the relative phase shift produced in the two wave components remains substantially equal to 90°, as indicated by the double-headed arrow labeled "90°" in FIG. 2. A properly designed system, as illustrated in FIG. 1b, would be effective to convert a linearly polarized wave at the design frequency and of proper aspect (i.e., linearly polarized at 45° to the X and Y axes) to a circularly polarized wave.

A circularly polarized wave may be represented as the sum of two equal amplitude linearly polarized waves separated in phase by 90°. If either or both of these conditions i.e., equal amplitude and 90° phase difference, are not present, the wave under consideration is elliptically polarized or in the special case of no phase difference, linearly polarized. If a wave of polarization W, as shown in FIG. 1a, is processed as described above by the circuits of FIG. 1b, a circularly polarized wave will result only at the design frequency. At any other frequency, the proper 90° phase shift will result, but these circuits do not have the same impedance magnitude except at the design frequency, and therefore, the components appearing at the resistances 10b and 12b will not be of equal amplitude and an elliptically polarized wave will be produced at other frequencies. Thus, these particular circuits exhibit wide frequency band width characteristics as far as phase shift is concerned, but very narrow frequency band width characteristics as far as amplitude equality is concerned.

Before referring to a specific embodiment of the invention, it will be helpful to have certain definitions in mind. For the purposes of this specification, "transmissive" indicates that polarization conversion takes place as a result of transmission rather than reflection of a wave; "birefringent" is defined substantially as in optics, where it means having differing indices of refraction along different axes; "repetitive" refers to the characteristic of a repeating pattern; "discontinuous" refers to a dimension of an element which is smaller than any operating frequency wave length; and "continuous" refers to an element which has a dimension in a plane perpendicular to the wave transmission axis which is comparable to an over-all dimension of the complete polarization converter in this plane.

The fact that particular elements are physically continuous or discontinuous is of no real importance by itself. However, certain electrical characteristics are inherent in elements with certain physical characteristics and this physical manner of description is relied upon because of the ease it allows in describing particular embodiments of the invention. This correlation between physical and electrical characteristics will be further brought out in the following description.

Referring now to FIG. 3, there is shown a polarization converter for electromagnetic energy which comprises a single transmissive birefringent repetitive sheet array of conductive elements including elements 30, which are discontinuous in all directions, in combination with elements 31, which are continuous in one direction and means for supporting these elements shown as a thin dielectric sheet 32. The complete sheet, as illustrated, is in the form of a printed circuit, a copper layer having been etched so as to leave the rectangular patches 30 and the narrow strips 31 on the surface of the thin supporting dielectric sheet 32. In operation, an electromagnetic wave passed through the

polarization converter is acted upon much in the way it would be if the X and Y components were actually separated and coupled to the circuits of FIG. 1b. Thus, if the wavefront strikes the sheet with a polarization W, as shown in FIG. 1a, the Y component (vertical) will be affected by shunt capacitances caused by the narrow vertical separation 33 between adjacent rectangular elements 30. The Y component will be substantially unaffected by the parallel elements 31. The X component (horizontal) will be affected by the shunt inductances caused by the parallel element 31. If the rectangular elements 30 have a horizontal separation 34 between adjacent elements which is large, the capacitive effect of the elements 30 will be negligible with respect to the X component. Thus, the sheet shown in FIG. 3 accomplishes the result of the circuits of FIG. 1b as shown in FIG. 2. As discussed with reference to FIG. 1b, this arrangement has wide frequency band width characteristics with regard to phase shift but rather poor impedance matching characteristics, with the result that energy of proper linear polarization and frequency transmitted through this sheet will receive the desired polarization transformation. However, the efficiency of this transmission will be rather poor and any input wave of 45° linear polarization but incorrect frequency will result in an elliptically polarized output wave.

All sheet arrays of conductive elements, as illustrated in FIG. 3, will be resonant at some particular frequency. However, the operating frequency range of such polarization converters, in accordance with this invention, is substantially below the resonant frequency so as not to rely on any of the effects directly resulting from resonance. "Substantially below" is intended to indicate that converters do not rely upon resonant effects as did certain prior art arrangements. Practical arrangements will, in fact, generally have an operating frequency range which lies below three-quarters of the resonant frequency of the sheet arrays. That is to say, for example, if a particular sheet array is designed with an operating range in the vicinity of 2500 megacycles per second, any resonance of this sheet array will occur above approximately 3300 megacycles per second in most designs in accordance with the invention.

With reference now to FIG. 4, there is illustrated a transmissive birefringent repetitive sheet array in which conductive elements which are discontinuous in all dimensions (i.e. elliptical patches which correspond to the rectangular patches 30 of FIG. 3) have been physically combined with conductive elements which are continuous in one dimension (i.e. thin strips corresponding to the thin strips 31 of FIG. 3) to form the illustrated pattern of elements 38. This arrangement may be designed to perform in the same manner as the FIG. 3 arrangement and is included to illustrate two points. First, that elements which are discontinuous in all directions should not be considered as limited merely to the rectangular patches 30 of FIG. 3 but may, in fact, be of any desired shape. And second, that the term "in combination with" refers to a combination of two distinct unattached types of elements, as in FIG. 3, as well as to physical combinations of the distinct types of elements into a single element, such as the elements 38 in FIG. 4.

In accordance with the invention it is possible to construct polarization converters utilizing a plurality of sheet arrays of conductive elements. One way of doing this would be to provide one type of sheet with only inductive elements and a second type of sheet bearing only capacitive elements. Using such sheets, it is possible to construct a polarization converter which is symmetrical along the axis of propagation and which includes four sheets—two with capacitive elements and two with inductive elements. This separation of the inductive elements from the capacitive elements allows the inductances and capacitances to be placed at proper separations along the propagation path, since in a converter using two inductive sheet arrays and two capacitive sheet arrays the optimum separation of

the capacitive sheets will be less than a quarter wave length and the optimum separation of the inductive sheets will be greater than a quarter wave length. This arrangement will allow a relatively wide band polarization conversion with a somewhat reduced reflection coefficient over this band width but with the disadvantage of requiring four separate sheet arrays.

It is desired that a number of criteria be optimized in the design of a polarization converter, including: accurate polarization conversion with respect to phase over a wide frequency band width; accurate impedance matching over a wide frequency band width; symmetry along the direction of energy propagation; and the economical requirement of the smallest possible number of individual sheet arrays. Referring now to FIG. 5 there is shown schematically an arrangement which effectively meets these criteria. In this arrangement the Y components are arranged to be coupled to the tandem combination of three capacitances and the X components are arranged to be coupled to three individual shunt circuits, each comprising the parallel combination of an inductance and a capacitance. Symmetry is desired to simplify design computation and to provide economy by reducing the number of different types of sheet arrays required in a converter. To obtain symmetry along the direction of propagation, it is necessary that capacitance 40a be identical to capacitance 40b; and that capacitance 42a and inductance 43a be identical to capacitance 42b and inductance 43b, respectively. Thus, in the design of the circuits of FIG. 5 seven variables must be accounted for; the magnitudes of each of capacitances 40, 41, 42 and 44; the magnitudes of each of inductances 43 and 45; and the separation 46 between the components. For a symmetrical structure, seven variables are more than actually required, four being required to match for two polarizations at each of two frequencies in the desired pass band and two being required to provide 90° phase shift at the two frequencies, thus leaving one variable for optimization of relative frequency response over the pass band at the two polarizations. The design process is rather complicated but can be carried out using known techniques by those skilled in the art once the present concepts are understood.

Referring to FIG. 6, there are shown curves representative of the operation of a polarization converter effectively similar to the circuits of FIG. 5. This design is such that the effect of the three shunt capacitances is to produce 90° phase lag in the Y components of an input wave of predetermined frequency as shown by Curve 50 of FIG. 6; and the three shunt arranged parallel inductance-capacitance combinations produce zero phase shift in the X components as shown by Curve 51. When the frequency of the input wave varies from the predetermined frequency, the characteristics of both circuits of FIG. 4 change in essentially identical manner and the relative phase shift can be caused to remain substantially constant at a desired value—90° in this case, as indicated by the double headed arrow labeled "90°".

With reference now to FIG. 7, there are shown three views of an actual polarization converter constructed in accordance with the invention, and having characteristics substantially as indicated in FIG. 6. FIG. 7a is a side view of a complete polarization converter including a plurality of transmissive birefringent repetitive sheet arrays of conductive elements separated by a dielectric medium. Thus, the converter of FIG. 7a includes a sheet 60a, an identical sheet 60b, a third sheet 61 and a separating dielectric in the form of a thin walled insulating material in the configuration of a honeycomb including relatively large volumes of air. This is shown by inset 62, which is an end view of a section of the honeycomb material shown in side view in the main part in FIG. 7a. As shown in FIG. 7b, sheet 61 includes conductive elements substantially similar to those utilized in the FIG. 3 arrangement, the principal difference being that there

are relatively small separations between adjacent elements 63 thereby providing sizable capacitive effects for both X and Y wave components. One of the sheets 60 is illustrated in FIG. 7c. The configuration of this sheet is very similar to that of sheet 61 except that the different capacitive and inductive effects desired require elements, which are discontinuous in all directions, of a different shape. Referring again to FIG. 7a, it will be appreciated that the separation 65 between individual sheets corresponds to separation 46 in FIG. 5.

The views of FIG. 7 are essentially scale drawings of a polarization converter which was actually constructed, except that certain dimensions have been distorted in the interest of clarity in the drawing. The actual dimensions in inches were as follows (the patterns are symmetrical and these values are typical):

65	-----	.711
66	-----	1.000
67	-----	.145
68	-----	.500
69	-----	.160
70	-----	.020
73	-----	.750
74	-----	.189
75	-----	.750
76	-----	.196
77	-----	.027

Each of the sheets 60a, 60b and 61 took the form of a sheet of glass fiber laminate .012 inch thick with copper elements .003 inch thick formed thereon by printed circuit etching methods. The honeycomb-air separating dielectric had a dielectric constant of approximately 1.06. A foam or expanded insulative material can be substituted for this honeycomb material and in some instances it may be desirable to have the conductive elements supported directly by this low dielectric constant means, without the thin sheets of higher dielectric constant used in this example. This polarization converter was effective to bilaterally convert a linearly polarized incident wave of proper aspect to a circularly polarized wave, or a circularly polarized incident wave to a linearly polarized wave. The converter was effective over a band from 2420 megacycles to 2930 megacycles with theoretical values of relative phase shift between X and Y of $90^\circ \pm 1^\circ$ and reflection coefficient of less than .025 over this band. Actual measurements tended to confirm these theoretical values but were limited by the accuracy of available measuring techniques and equipment.

With the basic ideas of the invention now in mind, a number of facts which are self-evident, nevertheless seem worthy of mention. All arrangements may be flat or curved in form as required for particular applications; for example, a complete converter may be used as a protective covering for an antenna or horn much in the manner of well-known radomes. It will be appreciated that the broad-band characteristics, of converters in accordance with this invention, allow efficient operation even though the propagation direction of an incident wave is not strictly perpendicular to the individual sheet or sheets of a converter. Also it may be desirable to construct converters in accordance with the invention which use a plurality of arrays of either elements which are discontinuous in all directions or elements which are continuous in one direction, without including any elements of the other type. In these cases the elements of each sheet array may be aligned in one common direction so that each array produces its principal effect in a common direction.

Although the invention has been described with particular reference to a converter for changing linearly polarized energy to circularly polarized energy and vice versa, it should be appreciated that this is merely a specific application and that the invention may actually be employed to convert energy of any given polarization

to any other desired polarization. It is, therefore, intended, in the appended claims, to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive sheet arrays of conductive elements, including elements which are discontinuous in all directions in combination with elements which are continuous in one direction; and means for supporting said sheet arrays; said converter including sheet arrays of at least two different configurations.

2. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive sheet arrays of conductive elements, each sheet array including elements which are discontinuous in all directions and elements which are continuous in one direction; and means for supporting said sheet arrays; said converter including sheet arrays of at least two different configurations.

3. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive sheet arrays of conductive elements, each sheet array including elements which are discontinuous in all directions in combination with elements which are continuous in one direction; and means for supporting said sheet arrays; the converter having an operating frequency range which is below the resonant frequency of all of said sheet arrays; said converter including sheet arrays of at least two different configurations.

4. A polarization converter for electromagnetic energy comprising: a plurality of sheets of insulative material; a birefringent repetitive array of conductive elements, including elements which are discontinuous in all directions in combination with elements which are continuous in one direction, adhered to each of said sheets; and means for supporting said sheets; said converter including sheet arrays of at least two different configurations.

5. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive sheet arrays of conductive elements, including elements which are discontinuous in all directions in combination with elements which are continuous in one direction; and low dielectric constant means for support-

ing said sheet arrays; said converter including sheet arrays of at least two different configurations.

6. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive sheet arrays of conductive elements, including elements which are discontinuous in all directions in combination with elements which are continuous in one direction; and means for supporting said sheet arrays and for forming a protective covering for an antenna; said converter including sheet arrays of at least two different configurations.

7. A quarterwave plate for electromagnetic energy comprising: three sheets of insulative material; a transmissive birefringent repetitive sheet array of conductive elements including elements which are discontinuous in all directions in combination with elements which are continuous in one direction, adhered to each of said sheets; and low dielectric constant means for supporting said sheets; said converter including sheet arrays of at least two different configurations.

8. A polarization converter for electromagnetic energy comprising: a plurality of transmissive birefringent repetitive arrays of thin substantially two-dimensional conductive elements arranged in a plurality of sheets, including first conductive elements all of whose dimensions are smaller than the operating wavelength in combination with second conductive elements having a single dimension in the plane perpendicular to the wave transmission axis which is comparable to an over-all dimension of the complete polarization converter in said plane; and means for supporting said elements; said converter including arrays of at least two different configurations.

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