Fig. 7
The invention relates to a dielectric antenna provided with a circular dielectric wave guide to feed micro-wave electromagnetic energy along the walls of said wave guide to the antenna for radiation through the atmosphere. Further the invention relates to new and improved coupling means between a circular dielectric wave guide feed and a metallic guide either rectangular or circular in cross-section for the transmission of micro-wave energy to said metallic guide.

An object of the invention is to provide an antenna and wave guide feeding and/or coupling means constituted substantially entirely of dielectric materials except for the micro-wave focusing elements.

In accordance with the invention, the essential electrical components of the antenna, the coupling means and the wave guide feeding means are constituted by pipe shaped dielectric members, said pipe shaped members being substantially circular in cross-section at the micro-wave feeding portion of the tube and being ribbon-shaped or strip-shaped in the radiating terminal portions as well as in the connecting portions where a connection is made to the metal wave guide members. The metal wave guide members are conveniently either rectangular or circular in cross-section. The tube elements constituting the wave guide feed or coupling elements are formed with intermediate transition portions between the tubular feeding sections and the terminal strip radiating sections. These transition portions are formed by notchting the pipe along a generatrix to spread the tubular periphery of the pipe flat-wise to form the ribbon or strip at the radiating portions. The flat ribbon of dielectric formed by notchting the top is branched in accordance with a predetermined scheme to provide a series of identical forked strips arranged in a particular geometric relationship to constitute cophase primary radiators. These radiators may be arranged in a linear terminal array, in line, to lie along the focal line of a cylindrically shaped parabolic reflector which thereby forms an antenna which is designated hereinafter as an antenna of the first type.

In another arrangement, the ends of the strips may be connected at equidistant points and in the same cophased wave radiating relationship to an internal surface of a radiating wall of a hollow cylindrical dielectric antenna. The antenna having said radiating wall is an antenna of the second type; the ends of the strips therein are no longer the primary radiators but are rather connected to the cylindrical dielectric radiator.

Micro-wave radiant energy guided by the strip continues to be guided by the wall of said hollow cylindrical dielectric radiator if the curvature of the generatrix along said hollow cylindrical wall is greater than that which permits the radiation of the wave energy into free space. But if along the generatrix of this wall the curvature is less, the penetration of the waves into free space occurs and the micro-waves emerge from the wall of the guiding dielectric to be radiated into space.

According to the invention, the bifurcation of the incident feeding ribbon or strip creates two or four ribs identical to the incident ribbons which are termed the emergent strips. In an antenna of the second type possessing four radiating cylinders, the guiding or incident strip may be bifurcated three times into four emergent strips, which provide sixty-four final emergent strips, there being sixteen strips for each cylinder connected to the four radiating cylinders. Generalizing, if the antenna has 2n radiating cylinders, the guided strips are bifurcated (n+1) times into four emergent strips, which give 4n+2 final emergent strips connected to the 2n cylinders at the rate of 4×2n strips per cylinder.

The important advantage of this antenna of the second type is that it presents a lesser resistance to the wind while at the same time providing an efficient radiating surface.

A micro-wave which is guided along a circular tube of dielectric substance, travels partially in the wall of the tube and partially along said wall. In more precise terms, if the wall has a thickness a, the electrical field a value E on the surface of this wall and if sigma designates the distance perpendicularly to the wall at the end of which the field diminishes by a value of one neper, then an energy which is proportional to e-σ is distributed in the wall and an energy sigma E² is distributed along the surface of the wall, half of said latter energy being distributed along the exterior surface and half along the interior surface.

In the transmission which is preferred, the electric field is contained in the plane of the tube wall and the mode of vibration of the guided wave is the TEMO mode as in the case of the metallic circular wave guide. The electrical field is perpendicular at all points to the axis of the tube; it is a maximum in the dielectric material and decreases rapidly at distances away from the internal and external surfaces of the tube. Propagation takes places only if the diameter of the tube is greater than 2 sigma. The propagated waves in the antenna and coupling structures which are described below are in the TEMO mode as in the case of the metallic circular wave guide.

Other and further objects of the present invention will appear from the more detailed description set forth below, it being understood that such more detailed description is given by way of illustration and explanation only and not by way of limitation, since various changes therein may be made by those skilled in the art without departing from the scope and spirit of the present invention.

In connection with that more detailed description, there is shown in the drawings, in

Fig. 1, a unit plate of dielectric material which is oriented with respect to rectangular coordinates; in

Fig. 2, curves illustrating the variation of the guided wave-length in the dielectric substance as a function of the thickness of the tube wall of the dielectric tube; in

Fig. 3, a perspective view of a dielectric coupling means in accordance with the invention between a metallic rectangular wave guide and dielectric circular wave guide; in

Fig. 4, a perspective view of a dielectric coupling means between a metallic circular wave guide and dielectric circular wave guide; in

Fig. 5, a perspective view of a first type of dielectric antenna and dielectric wave guide feed; in

Fig. 6, a perspective view of a modification of the wave guide feed and of the antenna of Fig. 5; in

Fig. 7, a face view of an antenna assembly of the antenna of the second type; in

Fig. 8, a perspective view illustrating details of the quadruple bifurcation or branching of the dielectric strips in

Figs. 9, 10 and 11, sectional views showing the quadruple bifurcation or branching of the dielectric strips
taken along line 9—9, 10—10 and 11—11 respectively of Fig. 8; in
Fig. 12, a schematic arrangement partly in perspective illustrating the disposition of the strips relative to the dielectric radiating cylinders in an antenna of the second type; an in
Fig. 13, a cross-sectional view of the antenna of Fig. 7
taken along diagonal line 13—13 in Fig. 7.
Referring to Fig. 1, the unit plate of dielectric material is of undetermined length and width and consists of a material having dielectric constant \( \varepsilon \) and the point of origin \( O \) of the rectangle coordinate axes is shown in the figure. The thickness of the unit plate is \( a \). At the propagation of an electromagnetic wave in said plate, the electric field decreases exponentially from the exterior surface of the plate in the form of an evanescent wave. The phase velocity of the waves which are propagated in the dielectric plate is a function of both the thickness of the plate and the wave length of the electromagnetic wave travelling through the dielectric.

In more precise terms:

- \( \varepsilon \) = dielectric constant
- \( a \) = plate thickness
- \( \lambda \) = wavelength of the electromagnetic wave in free space
- \( \lambda_d \) = wavelength of the guided electromagnetic wave in the dielectric of the plate
- \( v \) = phase velocity of electromagnetic waves guided in said plate

\[
v = \frac{\lambda_d \varepsilon}{\lambda}
\]

If the electric field of the electromagnetic wave is parallel to the plate, the following relation exists:

\[
\tan \left[ \frac{\pi \sigma}{\lambda_d} \sqrt{\varepsilon - \left( \frac{\lambda}{\lambda_d} \right)^2} \right] = \sqrt{\left( \frac{\lambda}{\lambda_d} \right)^2 - 1}
\]  

or:

\[
\tan \left[ \frac{\pi \sigma}{\lambda_d} \sqrt{\varepsilon \sigma^2 - \sigma^2} \right] = \sqrt{\sigma^2 - \varepsilon \sigma^2}
\]  

If the electric field of the electromagnetic wave is perpendicular to the plate, the following equation is obtained:

\[
\tan \left[ \frac{\pi \sigma}{\lambda} \sqrt{\varepsilon - \left( \frac{\lambda}{\lambda_d} \right)^2} \right] = \frac{\sqrt{\left( \frac{\lambda}{\lambda_d} \right)^2 - 1}}{\varepsilon}
\]  

or:

\[
\tan \left[ \frac{\pi \sigma}{\lambda_d} \sqrt{\varepsilon \sigma^2 - \sigma^2} \right] = \frac{\sigma^2 - \varepsilon \sigma^2}{\varepsilon \sigma^2 - \sigma^2}
\]

From Formulæ 2 and 4 it is seen that the phase velocity \( v \) in the plate tends towards the velocity of light \( c \) as the thickness of the dielectric plate \( a \) falls toward 0. The phase velocity \( v \) approaches

\[
\frac{c}{\sqrt{\varepsilon}}
\]

which latter value is the velocity of the wave in the unbounded dielectric material, upon increasing the thickness of the plate.

In Fig. 2 curve C shows the value of \( \lambda_d/\lambda \) as a function of \( a/\lambda \) in accordance with the relationship of Formulæ 1. Curve C' is a graph of these same values as in graph C but under the conditions of the dielectric field being perpendicular to the plate as is shown in Formula 3.

In these two cases the dielectric field at the exterior surface of the plate decreases exponentially and in proportion to:

\[
\frac{\varepsilon}{\lambda_d} = \frac{2\pi}{\lambda} \sqrt{\left( \frac{\lambda}{\lambda_d} \right)^2 - 1}
\]

The distance \( \sigma \) is termed the penetration of the electromagnetic waves into air. At said distance \( \sigma \) from the plate of dielectric, the electric field is diminished by 1 neper with respect to the intensity of the field at the wall of the plate.

In the case where the thickness of the plate is much less than \( \lambda/4 \), the tangent is substantially equal to the arc in the above Formulæ 1 and 3. Further, the term

\[
\sqrt{\left( \frac{\lambda}{\lambda_d} \right)^2 - 1}
\]

may be eliminated in these formulæ and in view of the relationship in Formulæ 5 above, we obtain

\[
\frac{a}{\lambda} = \frac{2\varepsilon}{4\pi^2 (\varepsilon - 1) \sigma - \lambda \sigma}
\]

This is the case of polarization which is parallel to the plate. In the case of polarization of the field which is perpendicular to the plate, we have:

\[
\frac{a}{\lambda} = \frac{2\varepsilon}{4\pi^2 (\varepsilon - 1) \sigma - \lambda \sigma}
\]

The Formulæ 6 and 7 relate the thickness of the plates to the penetration of the waves into the air. When \( \sigma \) is small, \( \lambda_d/\lambda \) is substantially equal to 1 and \( \sigma \) is large (see Formulæ 5). The term \( \lambda/\sigma \) in the Formulæ 6 and 7 can be neglected in favor of the term

\[
4\pi^2 (\varepsilon - 1) \frac{\lambda_d}{\lambda}
\]

and these formulæ show that the product \( \lambda_d \sigma \) is substantially constant for a given wave length. The result therefore is that for a small thickness \( a \), \( a \) and \( \sigma \) are substantially inversely proportional to each other.

The Formulæ 6 and 7 show that for the same value of \( \sigma \), the plates in which the wave is propagated with an electric field perpendicular to the plate are to be \( \varepsilon \) times thicker than the plates in which the wave is propagated with its electric field parallel to the plate. Since in both cases the electric field exterior to the plate is carried without power loss and the losses are localized in the dielectric, the propagation in plates in which the field is parallel to the plate thus exhibits smaller losses in the dielectric.

Fig. 3 shows a coupling means between a rectangular metallic guide and a circular dielectric guide. The metallic rectangular guide 2 forms the terminus of a pyramidal horn 3. The circular dielectric guide 4, is notched at generatrix line 5 near its extremity and is developed into a flat strip 6.

Pyramidal horn 3 consists of two half portions joined by the upstanding flat edges 7 and 8 which are held together by screws 9. Strip 6 is pressed between edges 7 and 8, on opposite sides of the horn.

The Fig. 4 shows a coupling means between a circular metallic guide and a circular dielectric guide. The circular metallic guide 10, terminates at conical horn 11 which is provided with a cylindrical sleeve portion or rim 12, in the interior of which guide 10 is seated. The circular dielectric guide 13, is terminated on the other side of the metallic guide 10 at the same rim 12. Said circular dielectric guide 13 is notchted by three generatrices, 120° apart, 14, 15 and 16 respectively, to form three strips, which are tongue-shaped, 17, 18 and 19 respectively. The tongue-
shaped strips which are developed are substantially flat strips and these three strips are pressed between guide 10 and rim 12 to anchor them.

In Fig. 5 there is shown a first type of dielectric antenna fed by a circular dielectric wave guide 20. Said circular dielectric guide 20 is shown in a vertical arrangement and radiating flat strip 21 is obtained by cutting the circular guide along a generatrix as shown and by developing the cylindrical surface on a plane. This strip 21 is bifurcated into two other identical flat strips 22 and 23, arranged in the same vertical plane as strip 21 and also proportionately inclined towards the vertical direction. In the same manner strips 22 and 23 are themselves bifurcated respectively into further flat strips 23, 23a, 23b, and 23c, which are identical to each other arranged in the same plane as 21 and also proportionately inclined towards the vertical direction. Finally strips 23, 23a, 23b, and 23c are further bifurcated into two additional branches in order to obtain strips 24a, 24a, 24b, 24c, 24d, and 24e. These last strips have their ends arranged in the straight line which is the focal line of a mirror 26. Mirror 26 is a portion of a parabolic cylinder whose generatrices are horizontal.

The free ends of strips 24; to 24e are suspended as is convenient by means of fine strong supporting wires 27 which are fixed to support 28.

Thus, the electromagnetic wave energy guided by dielectric wave guide 20 is divided into two paths at each bifurcated point. The resulting wave in the horizontal plane is cylindrical as a first approximation. The wave surfaces form parallel cylinders about focal line 25 and the intensity of the radiated field in a plane passing through focal line 25, diminishes quite rapidly when the plane is tilted from the vertical direction, thus making it convenient for practical purposes that substantially all of the energy is directed on to mirror 26 at focal line 25. This mirror which lies close to the plane inclined at 45° to the vertical direction, converts the cylindrical wave into a plane horizontally polarized wave which is propagated in the horizontal direction. The dielectric antenna of Fig. 6 is similar to that of Fig. 5, with the exception that the flat strip 31 which is obtained by developing the dielectric circular guide 30 on a plane and the bifurcated strips 32 and 32a, 33a, 33; and 34a to 34e are located within vertical planes perpendicular to the focal line 25, whereas in Fig. 5 they were in a vertical plane passing through said focal line. Mirror 26 converts the cylindrical wave radiated by the ends of the dielectric strips into a horizontally polarized plane wave which is propagated in the horizontal direction.

In Fig. 7 there is shown an antenna of the second type which is viewed from the rear. Cylindrical radiating members of dielectric material 35, 36, 37 and 38 are shown in a rectangular array in said figure and the cross-section of these members is a rectangle having rounded sides. The rounding of the sides of the rectangle constitutes a feature of the invention which is explained in greater detail hereinafter. Metal shields 39, 40, 41, 42, 43 and 44 are placed at the rear of the antenna by conventional means as are shown in Fig. 13.

In Fig. 13 the dielectric strips which serve as the dielectric wave guide means of the invention are shown arranged within these metal shields which are disposed with an inclination of 45° with respect to the direction of the cylindrical radiating members. The cross-section of the metal shields is rectangular, the longer sides of the rectangle being parallel to the axis of the antenna. The strips are extended within the shields with the surface of the strip being disposed parallel to the smaller side of the shields so that the strips in effect are disposed in parallel to the plane of the antenna.

The flat plates at the rear of the cylindrical radiating members are closed by means of metal plates 54, these plates being provided with openings or holes which are coincident with holes 46. Rear and front plates 45 and 54 respectively are assembled and joined by means of screws 55 as shown in Fig. 13. The cylindrical radiating members are mechanically tightened in place between braces 63 and counter-plates 64 by means of screws 65.

Strip 47 which guides the wave energy is completely enclosed within shield 48. The strips which are branched into four strips are illustrated in Fig. 12, schematically which shows point 51, corresponding to strip 47 and then shows the bifurcation into strips 52; to 52a; and 52b. The four emergent strips from point 51 can be taken as representative of the emergent strips from the single feeding strip and as shown in Fig. 12 these four strips are each disposed at right angles to each other as the emergent strips from the incident strip.

In Fig. 8, a perspective view of the quadruple bifurcation is shown. Strip 47, to which reference has just been made in Fig. 12 at point 51, gives rise to four emergent strips 49a, 49b, 49c, and 49d. These four emergent strips 49a, 49b, 49c, and 49d respectively are glued or otherwise adhered about the incident strip 47 so that each emergent strip is perpendicular to the incident strip as just mentioned. As shown in Fig. 8 the opposite bars of the emergent strips are shown on opposite faces of the incident strip and two being on the one face and two being on the other face. The emergent strips have substantially the same size or dimensions as the incident strip. The two emergent strips which derive from one face of the incident strip are glued to the latter at a part of their surface and then glued to each other at another part of their surface as is shown in Fig. 8. The remaining two emergent strips are glued in substantially the same manner to thereby form a flange construction 50 which is perpendicular at its middle portion to the surface of the incident strip 47.

In order to better comprehend the details of the bifurcated structure of the incident strip and emergent strips, reference is made to Figs. 9, 10 and 11 which, respectively, are sections of Fig. 8 along lines 9—9, 10—10 and 11—11.

In Fig. 13 there is shown a sectional view along line 13—13 of Fig. 7. In this sectional view through metal shield 40, the cylindrical radiating members 35 to 38 are shown as also are bifurcations 51i, 52; and 52a, 53b, 53a, 53b, and 53c. At each bifurcation, the arrangement is such that there are but two emergent strips within the section taken and that the two other strips are perpendicular to the plane of the figure and therefore are seen on end. For example, in Figs. 12 and 13, 51 is the point of bifurcation and the four emergent strips are represented. Of the four emergent strips which are represented in Fig. 12, only three are shown in Fig. 13 that is to say 49a, 49b, and 49c.

The walls 55 of the cylindrical radiating members are formed of a dielectric material as already mentioned. The emergent strips which are the terminated strips 56 are disposed tangentially to the interior surface of the said walls 55 and are glued or otherwise adhered to these latter at points 59. The guided wave which is propagated by strip 56 is thereafter guided by the wall 55 and is radiating from point 57. In effect, at point 57 of wall 55 of the radiating cylinder, the wave is curved in such manner to the surface or face in advance of the wall 58 as is 53a, 53b, 53c, 53d and 53e. At each bifurcation, the arrangement is such that there are but two emergent strips within the section taken and that the two other strips are perpendicular to the plane of the figure and therefore are seen on end. The radius of curvature at point 57 is smaller than the penetration σ which is given by Formula 5 so that there results therefrom the radiation of the microwave energy, which had previously followed the dielectric wall into free space from the neighbourhood of point 57.

One, therefore, observes on the same cylindrical radiat-
ing member, 37 for example, that there are eight points such as 59 on one of the faces 55 of the member, the left-hand side for example and additionally, eight other points on the face to the right. These eight points on the one face (left) are aligned within the rectangle 60 as is shown in Fig. 12. Similarly the eight points on the right are disposed in rectangle 61 on said cylindrical radiating member.

Although the rounded forward face 58 of the cylindrical radiating members 35 to 38 does not play too important a role in the construction shown, they are quite essential to maintain the necessary mechanical tightness of the antenna, and for this reason they are of importance to the antenna construction.

Having thus disclosed the invention, what is claimed is:

1. A dielectric antenna with dielectric feed means to be fed with microwave electromagnetic energy from a metallic wave-guide comprising a tubular dielectric wave-guide, first transition means between said tubular dielectric wave-guide and said metallic wave-guide, a main flatwise wave-guide dielectric strip, second transition means between said tubular dielectric wave-guide and said main flatwise dielectric strip formed by cutting the tubular dielectric wave-guide along a generatrix to develop it flatwise, said flatwise strip being bifurcated, secondary flatwise wave-guide dielectric strips issued from said bifurcation means, and an array arrangement of a plurality of radiators located at the ends of said secondary flatwise dielectric strips at equal distances from said bifurcation means.

2. A dielectric antenna with dielectric feed means as in claim 1, wherein the radiators are the terminal cross-sections of the secondary flatwise wave-guide dielectric strips.

3. A dielectric antenna with dielectric feed means to be fed with microwave electromagnetic energy from a metallic wave-guide comprising a tubular dielectric wave-guide, first transition means between said tubular dielectric wave-guide and said metallic wave-guide, a main flatwise wave-guide dielectric strip, second transition means between said tubular dielectric wave-guide and said main flatwise dielectric strip formed by cutting the tubular dielectric wave-guide along a generatrix to develop it flatwise, said flatwise strip being bifurcated, secondary flatwise wave-guide dielectric strips issued from said bifurcation means and guiding the microwave electromagnetic energy partly inside themselves and partly within penetration zones of a given width adjacent to said secondary strips, and hollow cylindrical dielectric radiators, having in cross-section a curved portion the radius of curvature of which is smaller than the penetration zone given width, and connected to the ends of the secondary strips at equidistant points at the internal surface of the hollow cylindrical dielectric radiators, said secondary strip ends being located at equal distances from said bifurcation.

4. A dielectric antenna with dielectric feed means to be fed with microwave electromagnetic energy from a metallic wave-guide, rectangular in cross-section, comprising a pyramidal dielectricantenna horn means between said rectangular metallic wave-guide, a tubular dielectric wave-guide, a flatwise portion of the dielectric wave-guide formed by cutting said guide along a generatrix to develop it flatwise and extending into the plane of symmetry of said horn, a main flatwise wave-guide dielectric strip, transition means between said tubular dielectric wave-guide and said main flatwise dielectric strip formed by cutting the tubular dielectric wave-guide along a generatrix to develop it flatwise, said flatwise strip being bifurcated, secondary flatwise wave-guide dielectric strips issued from said bifurcation means, and a plurality of radiators located at the ends of said secondary flatwise dielectric strips at equal distances from said bifurcation.

5. A dielectric antenna with dielectric feed means to be fed with microwave electromagnetic energy from a metallic wave-guide, circular in cross section, comprising a conical electromagnetic horn connected with said circular metallic wave-guide, a tubular dielectric wave-guide, tongue-shaped portions of the dielectric wave-guide formed by cutting said guide along a plurality of generatrices to develop them substantially flatwise and secured to the conical surface of the horn, a main flatwise wave-guide dielectric strip, transition means between said tubular dielectric wave-guide and said main flatwise dielectric strip formed by cutting the tubular dielectric wave-guide along a generatrix to develop it flatwise, said flatwise strip being bifurcated, secondary flatwise wave-guide dielectric strips issuing from the bifurcation, and a plurality of radiators located at the ends of said secondary flatwise dielectric strips at equal distances from said bifurcation.

6. In a dielectric antenna with dielectric feed means as claimed in claim 1, wherein said main flatwise wave-guide dielectric strip having a given width and four secondary flatwise wave-guide dielectric strips of the same width is secured to the main strip, both on each side of said main strip, along half their width, the second halves of the secondary strips are secured to the main one at a given side being secured to one another and forming wing portions perpendicular to the main strip.

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