Dec. 30, 1952 M. G. BOUIX 2,624,002

DIELECTRIC ANTENNA ARRAY

Filed Aug. 18, 1950 2 SHEETS—SHEET 1

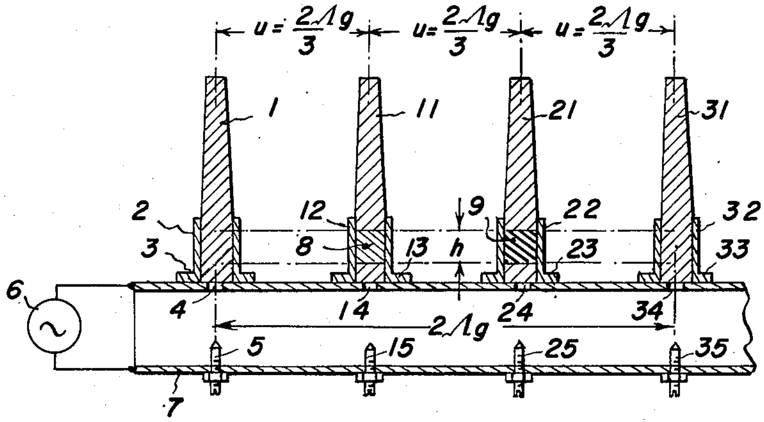

FIG. 1

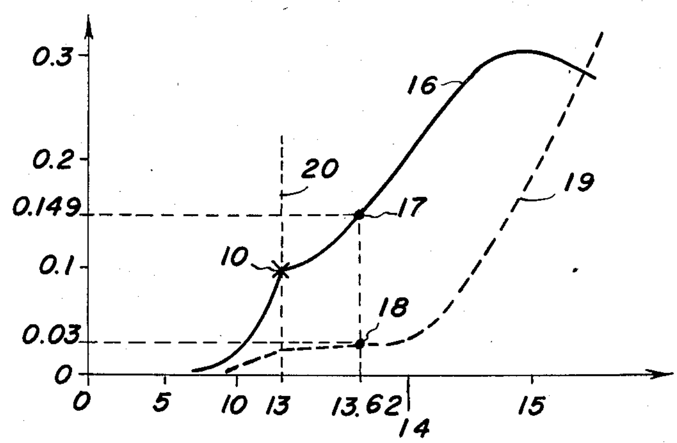

FIG. 2

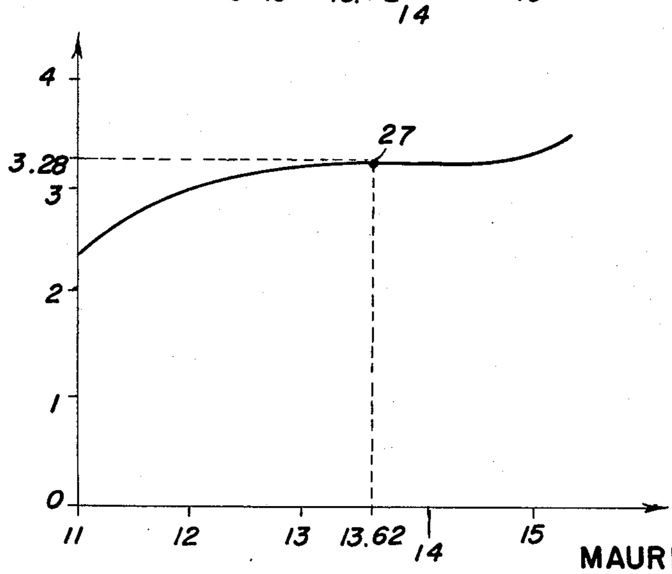

FIG. 3

INVENTOR
MAURICE G. BOUIX,

BY Wenderoth, Lind & Ponack
ATTORNEYS

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FIG. 4

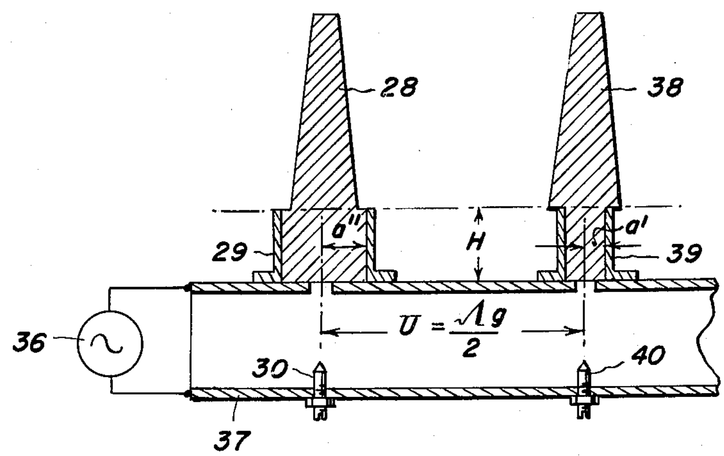
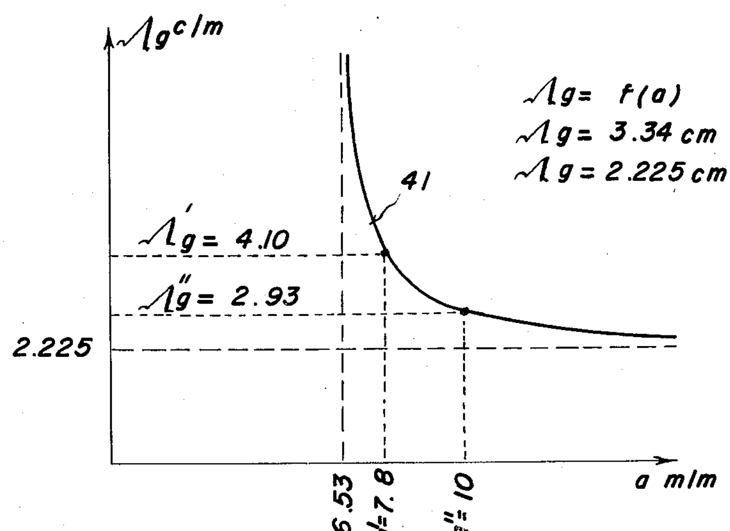


FIG. 5



INVENTOR
MAURICE G. BOUIX,

BY Wenderoth, Lind & Ponack
ATTORNEYS

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DIELECTRIC ANTENNA ARRAY

Maurice G. Bouix, Paris, France

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3 Claims. (Cl. 250—33.53)

The present invention relates to dielectric antennae arrays and more particularly compressed dielectric antennae arrays comprising a plurality of polyrods coupled to and fed cophasally by a single main guide along which they are spaced by distances smaller than the guide wavelength.

The dielectric rods are fitted into cylindrical wave-guide segments which are welded to the main guide and coupled to it by means of coupling holes. Cylindrical portions of dielectric material of the same height are inserted inside these segments and have characteristics so designed that they vary the phase-velocity of the wavelets travelling through the segments so that these wavelets, which enter the dielectric portions with differences of phase delay due to the spacing of the segments on the main guide, are in phase with one another at the points where they leave the inserted dielectric portions.

The dielectric portions may be said to act as transformers; for instance they act as half-wave transformers if their height is equal to half the wavelength in the guide segments in which they are inserted.

The invention will be better understood from the following detailed description, with reference to the accompanying drawings in which:

Figure 1 illustrates a first embodiment of a compressed array;

Figure 2 is a graph showing the relative resistance and reactance of a polyrod plotted against the diameter of a coupling hole by which the rod is coupled to the main guide;

Figure 3 is a graph of the length of the matching screw facing each coupling hole inside the main guide, plotted against the diameter of the coupling hole;

Figure 4 represents a second embodiment of a compressed array; and

Figure 5 represents a curve giving the wavelength in a circular guide of a H_{11} travelling wave, plotted against the diameter of the guide.

Figure 1 refers to a compressed array, in which all the rods radiate cophasal wavelets the polarisation of which is paralled to the array, and this in spite of their being coupled to the rectangular feed guide at mutual distances less than the guide wavelength Λg. In this example under consideration the spacing u between the rods is equal to

$$\frac{2\Lambda g}{3}$$

i. e. there are three polyrods within two guide wavelengths Λg. The numeral 7 denotes the rectangular feed guide, 6 denotes an ultra high frequency power source, 1, 11, 21. 31 are dielectric rods and 4, 14, 24, 34 are the coupling holes. 5, 15, 25, 35 are the matching screws and 2, 12, 22, 32 are segments of circular guides. 3, 13, 23, 33 are the flanges of said segments welded to the broad side of the guide 7.

In the circular guide 2 filled with a dielectric substance where the guide wavelength is λ_g, and the cut-off wavelength is λ_c, we have:

$$\lambda_g=\frac{\lambda\lambda_c}{\sqrt{\lambda_c^2-\lambda^2}}=\frac{\lambda_0\lambda_c}{\sqrt{\epsilon\mu\lambda_c^2-\lambda_0^2}} \qquad (1)$$

wherein λ_0 denotes the wavelength in free space, λ the wavelength in the dielectric medium, ϵ the electric inductive capacity of the medium (=2.25 for polythene), and μ denotes its magnetic inductive capacity (=1 for polythene).

The circular guide 12 is fed at its basis with a wave which has a phase retardation of

$$\frac{4\pi}{3}$$

due to its propagation over the distance u in the rectangular guide 7, with respect to the wave feeding the circular guide 2 at its basis.

In the circular guide 12 an h- high portion is introduced of a dielectric substance of inductive capacities ϵ_1 and μ_1 and of guide wave-length λ_{g_1}, determined in such a manner that the phase-shift delay introduced by the portion of the dielectric substance, added to the phase-shift delay

$$2\pi\frac{u}{\Lambda_g}=\frac{4\pi}{3}$$

due to the propagation, would give a total phase-shift of 2π, and that the height of the dielectric substance would act as a half-wave transformer. Then we shall have:

$$h=\frac{\lambda_{g_1}}{2}=\frac{1}{2}\frac{\lambda_0\lambda_c}{\sqrt{\epsilon_1\mu_1\lambda_c^2-\lambda_0^2}} \qquad (2)$$

and

$$2\pi\frac{h}{\lambda_g}=\frac{4\pi}{3}+\frac{2\pi h}{\lambda_{g_1}}-2\pi=-\frac{2\pi}{3}+\pi=\frac{\pi}{3}$$

$$\frac{h}{\lambda_g}=\frac{1}{6}$$

By substituting to h and to λ_g their respective expressions embodied in Equations 1 and 2, we shall have:

$$\frac{\sqrt{\epsilon\mu\lambda_c^2-\lambda_0^2}}{2.\sqrt{\epsilon_1\mu_1\lambda_c^2-\lambda_0^2}}=\frac{1}{6}$$

$$\epsilon_1\mu_1=\epsilon\mu-8\left(\frac{\lambda_0}{\lambda_c}\right)^2$$

Assuming $\mu_1=\mu=1$, we shall have:

$$\epsilon_1=9\epsilon-8\left(\frac{\lambda_0}{\lambda_c}\right)^2$$

By choosing a wavelength in free space:

$$\lambda_0=3.34 \text{ cm.}$$

and a circular guide of a radius of 1.6 cm., and therefore a cut-off wavelength of:

$$\lambda_c=1.6\times1.7=2.72 \text{ cm}$$

corresponding to a wave H_{11}, and by taking

$$\epsilon=2.25$$

we have:

$$\epsilon_1=9\times2.25-8\left(\frac{3.34}{2.72}\right)^2$$

$$\epsilon_1=8.15$$

In the same manner, in the circular guide **22** an h- high portion of a dielectric substance will be introduced having inductive capacities ϵ_2 and μ_2 and a guide wavelength λ_{g_2} determined in such a manner that the phase-shift delay introduced by this portion of dielectric substance, added to the phase-shift delay

$$2\pi\frac{2u}{\Lambda_g}=\frac{8\pi}{3}$$

due to the propagation, would give a total phase-shift of 4π, and that the height of the dielectric substance would act as a three-halves wave transformer. Then we shall have:

$$h=\frac{3\lambda_{g_2}}{2}=\frac{3}{2}\frac{\lambda_0\lambda_c}{\sqrt{\epsilon_2\mu_2\lambda_c^2-\lambda_0^2}} \quad (3)$$

and:

$$2\pi\frac{h}{\lambda_g}=\frac{8\pi}{3}+2\pi\frac{h}{\lambda_{g_2}}-4\pi=-\frac{4\pi}{3}+3\pi=\frac{5\pi}{3}$$

$$\frac{h}{\lambda_g}=\frac{5}{6}$$

By substituting to h and to λ_g their respective expressions embodied in Equations 1 and 3, we shall have:

$$\frac{3\ \sqrt{\epsilon\mu\lambda_c^2-\lambda_0^2}}{2.\sqrt{\epsilon_2\mu_2\lambda_c^2-\lambda_0^2}}=\frac{5}{6}$$

$$\epsilon_2\mu_2=\frac{81}{25}\epsilon\mu-\frac{56}{25}\left(\frac{\lambda_0}{\lambda_c}\right)^2$$

Assuming $\mu_2=\mu=1$, we shall have:

$$\epsilon_2=\frac{81}{25}\epsilon-\frac{56}{25}\left(\frac{\lambda_0}{\lambda_c}\right)^2$$

Adopting for λ_0, λ_c, and ϵ the same values as before, we shall have:

$$\epsilon_2=3.96$$

In order to obtain a given distribution of power, that is a uniform distribution in which equal electromagnetic energy is delivered to all the radiators, or a "gabled" distribution in which the energy delivered increases symmetrically from the end radiators of the array to the middle radiator, the following procedure is adopted:

In an article entitled "Slot guides and their application to antennae" published in the "Annales des Telecommunications," volume 4, No. 3, pages 75 to 86, the applicant has disclosed two tables giving the values of the product $G\times N$, wherein G is the relative conductance of a radiator (i. e. the real part of the relative admittance), and N is the number of radiators; this product is given for two cases, namely for a gabled distribution and for a uniform distribution. When the system comprises a great number of radiators, in order to avoid having a different coupling between each radiator and the main guide, a group of consecutive radiators are coupled to the main guide by like couplings calculated for the first radiator of the group, then a second group of radiators are coupled to the main guide by couplings calculated for the first radiator of the second group, and so on.

For a serial arrangement of the radiators, on the feed guide, like that of the polyrods of Figure 1, it will suffice to replace, in these tables, the value of G by the value of R, which is the relative resistance of the radiators **1**, **11**, **21**, **31**.

Assuming that the array of Figure 1 comprises 32 radiators grouped in pairs, the table reproduced hereafter gives, for the case of a uniform distribution of power, the relative resistance of each radiator, the radiator denoted in the table by the numeral 1 being the radiator marked **1** in Figure 1, the radiator denoted by 2 in the table being the radiator marked **11** in Figure 1 and so on.

Group	No. of radiator	R × N	R
1	1	1.01	0.0315
	2	1.01	0.0315
2	3	1.01	0.0315
	4	1.01	0.0315
3	5	1.15	0.0359
	6	1.15	0.0359
4	7	1.15	0.0359
	8	1.15	0 0359
5	9	1.35	0.0421
	10	1.35	0.0421
6	11	1.35	0.0421
	12	1.35	0.0421
7	13	1.63	0.0509
	14	1.63	0.0509
8	15	1.63	0.0509
	16	1.63	0.0509
9	17	2.04	0.0637
	18	2.04	0.0637
10	19	2.04	0.0637
	20	2.04	0.0637
11	21	2.53	0.0790
	22	2.53	0.0790
12	23	2.98	0.0931
	24	2.98	0.0931
13	25	3.68	0.115
	26	3.68	0.115
14	27	4.77	0.149
	28	4.77	0.149
15	29	6.83	0.213
	30	6.83	0.213
16	31	11.87	0.371
	32	11.87	0.371

The curve **16** of Figure 2 indicates thus the diameter of the coupling hole of each radiator as depending on the resistance of this latter. In this curve the portions on opposite sides of the line **20** corresponding to the point marked **10** are plotted with abscissae in difference scales. The part of the curve on the left hand side of the line **20** has been established according to the formula of Bethe giving the law of variation of the resistance as a sixth power D^6 of the diameter D of the coupling hole, see Bethe, "Theory of diffraction by small holes," Physical Review, 1944, 66, page 163. The portion of the curve to the right of the line **20** results from measurements carried out by the applicant.

These measurements have been carried out for a wavelength in free space of $\lambda_0=3.34$ cm., a rectangular guide of 22.86×1016 mm., and polythene dielectric radiators of 16 mm. diameter.

The curve 19 of the same Figure 2 gives the reactance of each radiator as plotted against the diameter of the coupling hole.

The curve 26 of Figure 3 gives the depth of advance of the screws 5, 15, 25, 35 (assumed to be of 3 mm. diameter) as plotted against the diameter of the coupling hole.

Considering, for instance, the 27th radiator, the reading for resistance is 0.149 to which corresponds the point 17 of the curve 16 giving a diameter 13.62 mm. of the coupling hole.

For this diameter the reactance is (point 18 of the curve 19) 0.03, and the advance of the screw (point 27 of the curve 26) is 3.28 mm.

But uniform or gabled distribution is not always obtainable by using standard size guides and ordinary radiating rods; in fact, for the last radiating rods the requisite diameter of Bethe holes may become greater than the broad side of the guide. In this case the narrow side of the rectangular guide 7 will be reduced, so reducing the characteristic impedance of the guide and thus the power transmitted through the coupling hole will increase.

If it is intended to radiate or receive a wave polarised perpendicularly to the array, i. e. perpendicularly to the longitudinal edges of the rectangular guide, the coupling holes are bored in the narrow side of the rectangular guide, and the segments of circular guides serving as sockets for dielectric rods are connected to this narrow side.

Figures 4 and 5 are relative to a compressed array in which the diameter of each circular guide 29, 39 . . . serving as socket to each polyrod 28, 38 . . . has been modified in order to modify the phase velocity in this circular guide. In this example the spacing U along the guide 37 fed by the source 36 between the rods is equal to

$$\frac{\Lambda_g}{2}$$

that is to say there are two polyrods within one wavelength of guide 37.

Let H be the common height of all the circular guide segments, λ'_g the wavelength in the guide segment 29, and λ''_g the wavelength in the guide segment 39.

The circular guide 29 causes a certain phase-shift

$$x=2\pi\frac{H}{\lambda'_g}$$

to the wavelet which it receives at its base input. In the same manner the circular guide 39 causes a phase-shift:

$$y=2\pi\frac{H}{\lambda''_g}$$

to the wavelet which it receives at its base input, and which is shifted by π with respect to the wave received at the base of the preceding guide. The condition that the waves feeding the two polyrods 29 and 39 be cophasal is:

$$H=\frac{x}{2\pi}\lambda'_g=\frac{y}{2\pi}\lambda''_g=\frac{\pi+x}{2\pi}\lambda''_g$$

whence:

$$\frac{\lambda''_g}{\lambda'_g}=\frac{x}{\pi+x} \qquad (4)$$

Figure 5 represents the wavelength λ_g in a circular guide as depending on the radius a of this

guide, for a wavelength in free space of $\lambda_0=3.34$ cm. and for a wavelength λ in the dielectic medium of:

$$\lambda=\frac{\lambda_0}{\sqrt{\epsilon\mu}}=\frac{3.34}{\sqrt{2.25}}=2.225 \text{ cm.}$$

To each value of λ_g of the curve 41 corresponds a radius a of the circular guide. It will be noted that the Equation 4 comprises a parameter x which may be chosen at will. For practical reasons, in the above example the value has been adopted:

$$x=7.85$$

that is to say:

$$\frac{\lambda''_g}{\lambda'_g}=\frac{5}{7}$$

If we take $\lambda''_g=2.93$ cm. to which corresponds, on the curve 41, a radius of 10 mm. of the circular guide, we shall have $\lambda'_g=4.10$ cm. to which corresponds, on the same curve, a radius of 7.8 mm.

Then a value of 51 mm. will be found for H.

The array of Figure 4 will thus comprise odd polyrods identical to 28 and even polyrods identical to 38, the odd ones having a widened root of 20 mm. of diameter fitted into the circular guide segments 29 having the same diameter and a height of 51 mm., and the even ones having a narrowed root of 15.6 mm. of diameter fitted into the circular guide segments 39 having the same diameter. In order to compensate for the cross-section variations between the portions of the radiators situated outside the guide segments and the portions of the same radiators situated inside of the guide segments, the reactance in each coupling point will be matched by actuating the screws 30, 40 . . . .

Although the invention has been described with reference to particular examples, its scope appears sufficiently from the foregoing description to enable a man skilled in the art to apply the same to any dielectric array having a desired distribution of power.

What I claim is:

1. A compressed dielectric antenna array comprising a single rectangular air filled main wave guide, means for introducing ultra high frequency waves into said main wave-guide, circular guide segments of the same height welded to said main guide, coupling and matching means comprising holes bored in one wall of the main guide and located on the axis of said guide segments and matching screws facing the holes located in the opposite wall of the main guide, the spacing of adjacent guide segments being smaller than one main-guide wave length and equal to some simple submultiple of said wave length, whereby a given number group of guide segments is coupled to the main guide along each wave length of said guide, radiating circular dielectric rods filled into said circular segments and the bases of which come into contact with the wall of the main guide in which the holes are bored, cylindrical portions of dielectric material of the same height, all terminating in the same plane, located inside all the guide segments except the first of each group and being a part of the bases of the rods, said dielectric portions being adapted to cause simultaneously such a phase shift delay that the wavelets radiated by all the rods be cophasal and such a wave length in the guide segments in which they are located that the height of the dielectric portions be an integral number of halves of said wave length.

2. A compressed dielectric antenna array comprising a single rectangular air filled main wave guide, means for introducing ultra high frequency waves into said main wave guide, circular guide segments of the same height welded to said main guide, coupling and matching means comprising holes bored in one wall of the main guide and located on the axis of said guide segments and matching screws facing the holes located in the opposite wall of the main guide, the spacing of adjacent guide segments being smaller than one main guide wave length and equal to some simple submultiple of said wave length, whereby a given number group of guide segments is coupled to the main guide along each wave length of said guide, radiating circular dielectric rods filled into said circular segments and the bases of which come into contact with the wall of the main guide in which the holes are bored, cylindrical portions of dielectric material of the same height, all terminating in the same plane, located inside all the guide segments except the first of each group and being a part of the bases of the rods, said dielectric portions having dielectric constants determined to cause simultaneously such a phase shift delay that the wavelets radiated by all the rods be cophasal and such a wave length in the guide segments in which they are located that the height of the dielectric portions be an integral number of halves of said wave length.

3. A compressed dielectric antenna array comprising a single rectangular air filled main wave guide, means for introducing ultra high frequency waves into said main wave guide, circular guide segments of the same height welded to said main guide, coupling and matching means comprising holes bored in one wall of the main guide and located on the axis of said guide segments and matching screws facing the holes located in the opposite wall of the main guide, the spacing of adjacent guide segments being smaller than one main guide wave length and equal to some simple submultiple of said wave length, whereby a given number group of guide segments is coupled to the main guide along each wave length of said guide, radiating circular dielectric rods filled into said circular segments and the bases of which come into contact with the wall of the main guide in which the holes are bored, cylindrical portions of dielectric material of the same height, all terminating in the same plane, located inside all the guide segments except the first of each group and being a part of the bases of the rods, said dielectric portions being constituted of the same dielectric material as the radiating rods and having diameters determined to cause simultaneously such a phase shift delay that the wavelets radiated by all the rods be cophasal and such a wave length in the guide segments in which they are located that the height of the dielectric portions be an integral number of halves of said wave length.

MAURICE G. BOUIX.

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