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G. C. SOUTHWORTH
TRANSMISSION OF GUIDED WAVES

2,106,769

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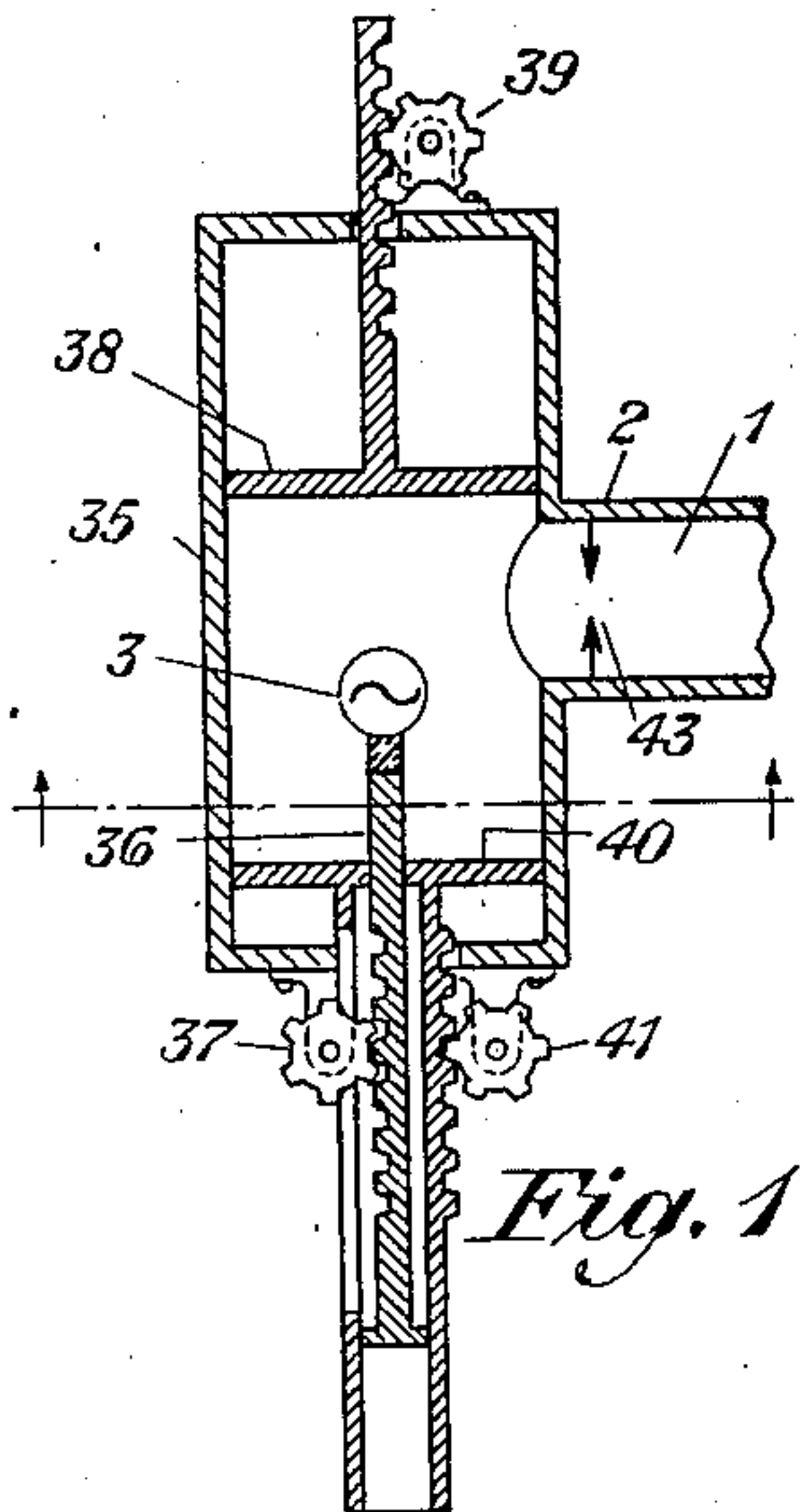


Fig. 1

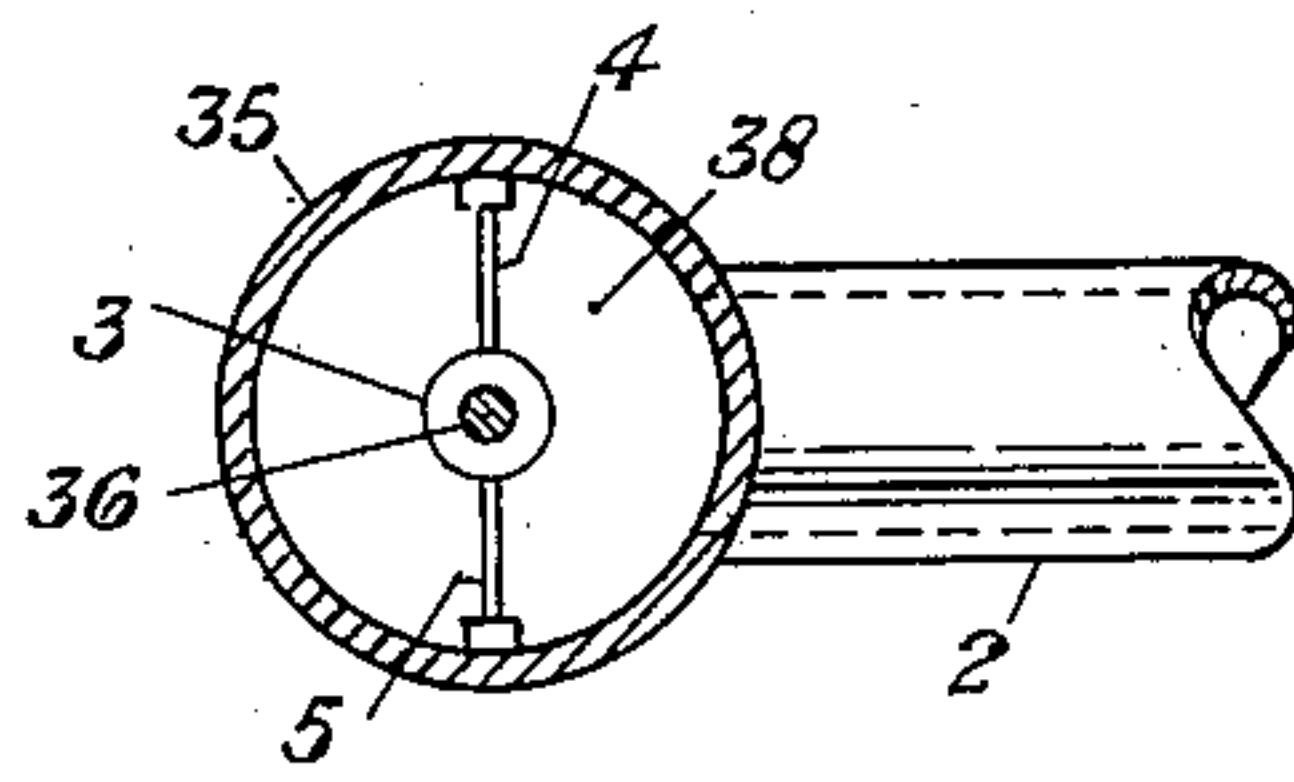


Fig. 1a

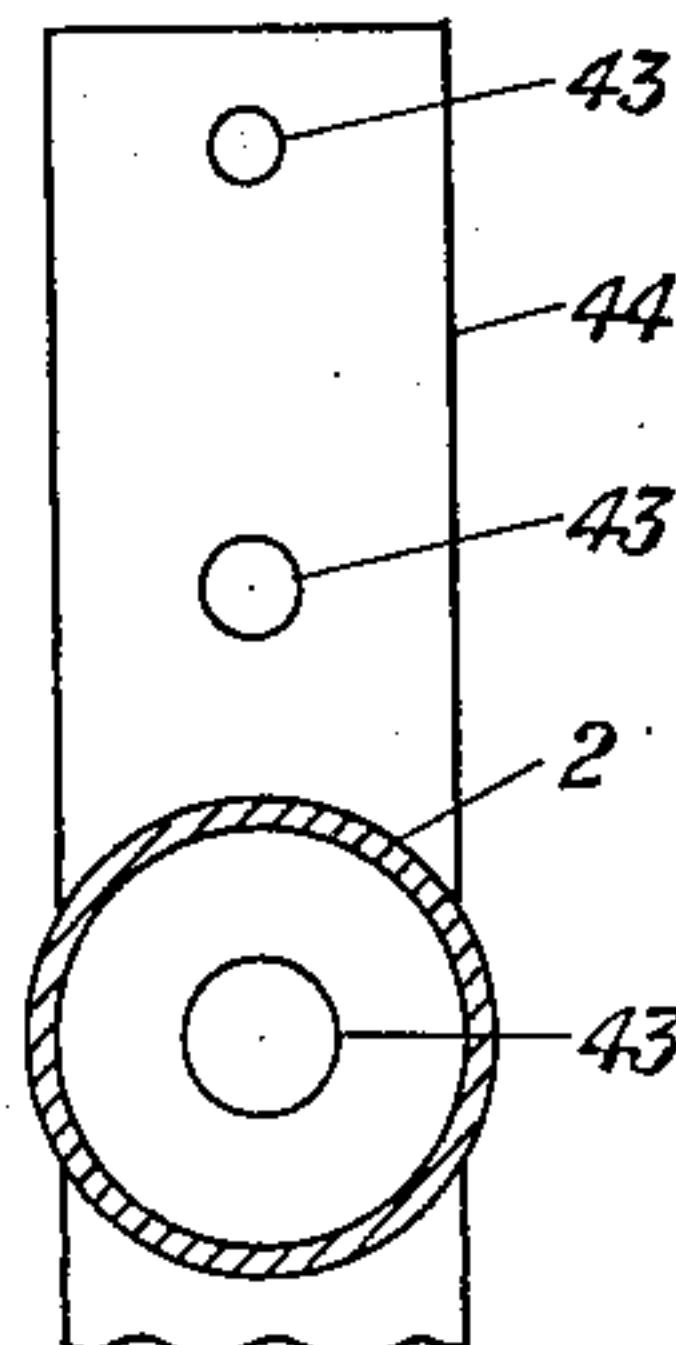


Fig. 2

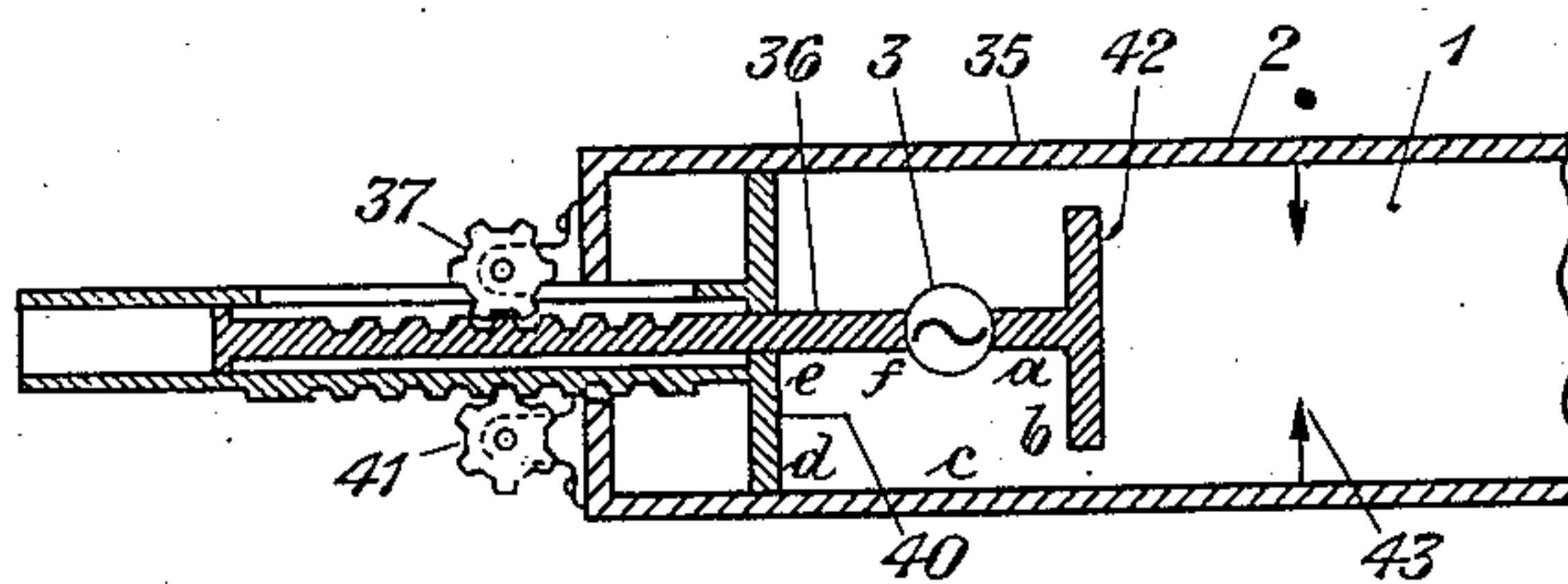


Fig. 3

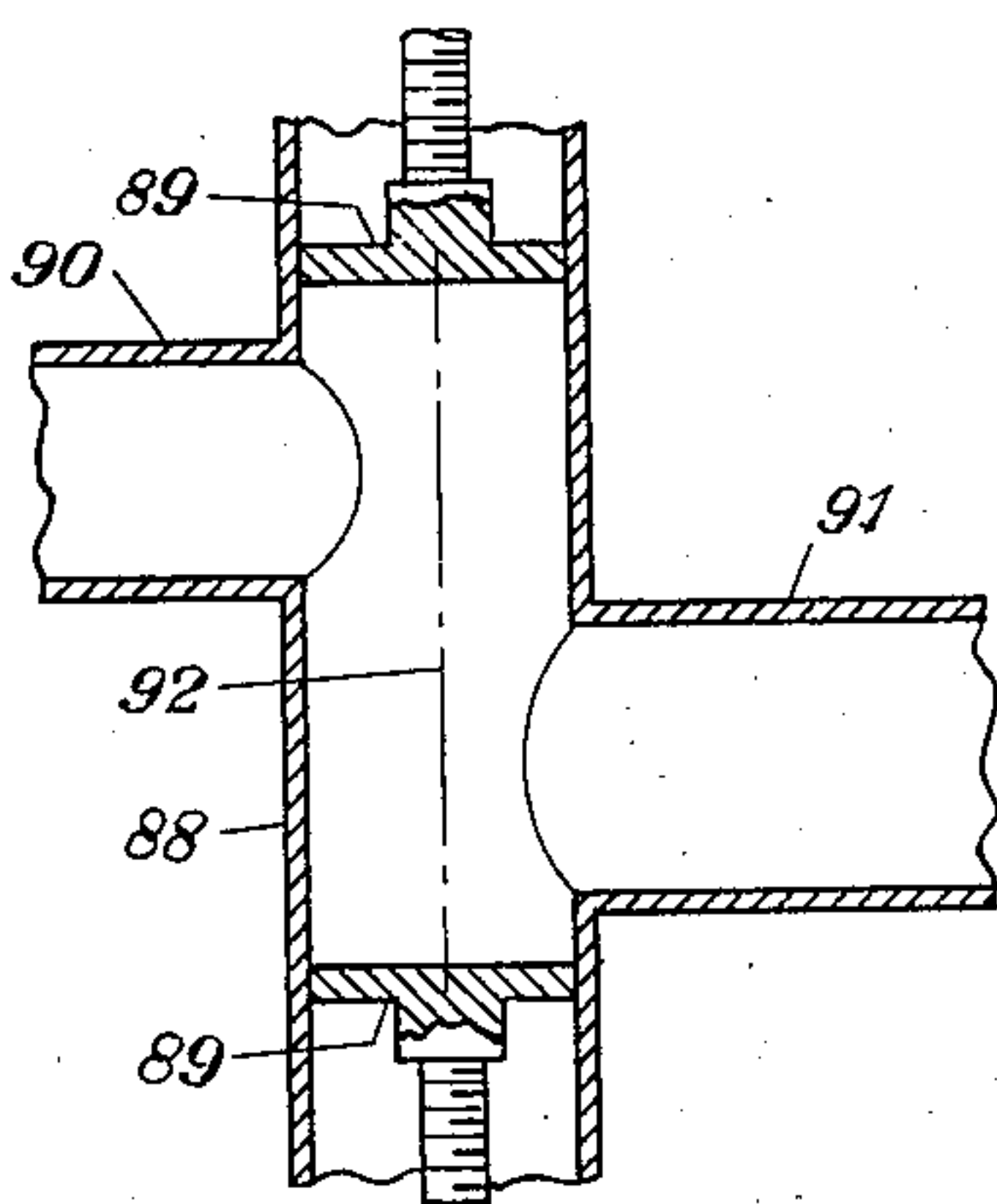


Fig. 4

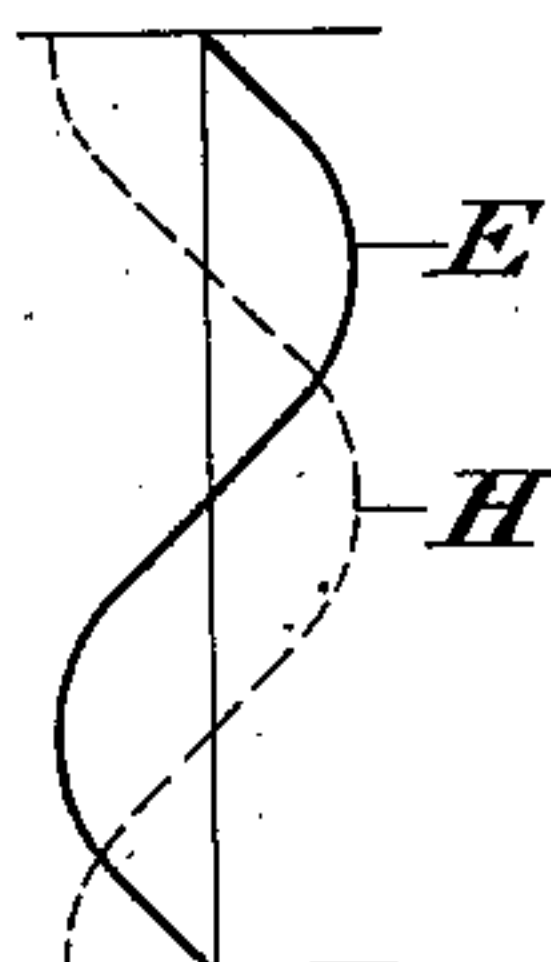


Fig. 5

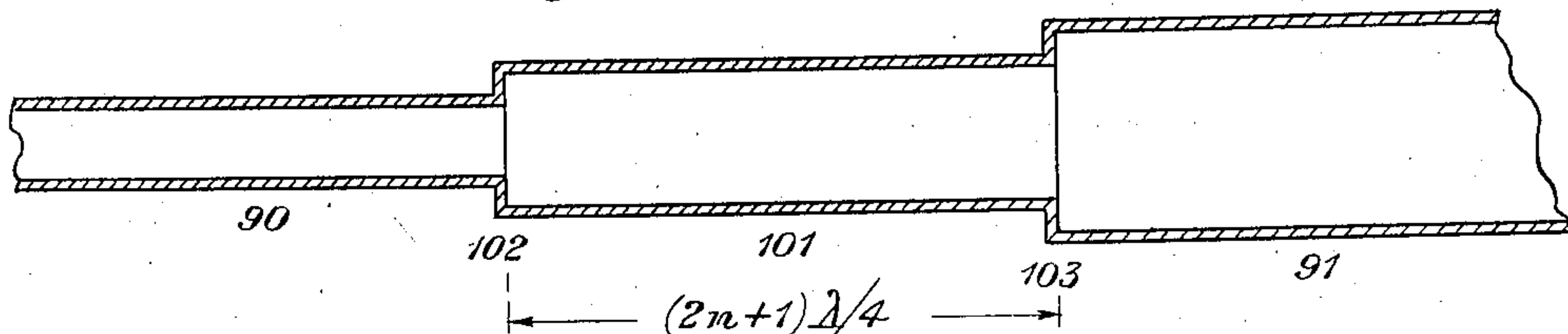


Fig. 6

INVENTOR
G. C. Southworth
BY *gr/fo*
ATTORNEY

UNITED STATES PATENT OFFICE

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TRANSMISSION OF GUIDED WAVES

George C. Southworth, Red Bank, N. J., assignor
to American Telephone and Telegraph Com-
pany, a corporation of New York

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21 Claims. (Cl. 178—44)

A principal object of my invention is to provide new and improved apparatus and a corresponding method for matching impedances in the operation of dielectric guides. Another object of my invention is to provide for transmitting electromagnetic waves over dielectric guides and associated apparatus with impedance match at transition places. Another object is to provide a chamber with an input and an output, the end walls of the chamber and the places of application of the input and output being relatively adjustable along the length of the chamber to secure an impedance match between the input and the output. All these objects and other objects and advantages of my invention will become apparent on consideration of a limited number of examples of practice in accordance with the invention which I have chosen for presentation in the following specification. It will be understood that this specification relates principally to these particular embodiments of the invention and that the scope of the invention will be indicated in the appended claims.

Referring to the accompanying drawing, Figure 1 is an axial section of impedance matching apparatus at the input end of a dielectric guide; Fig. 1a is a detailed cross-section on the corresponding line of Fig. 1; Fig. 2 is a sectional elevation of a structural detail which is indicated diagrammatically in Fig. 1; Fig. 3 is an axial section showing a modification as compared with Fig. 1; Fig. 4 is an axial section of impedance matching apparatus which may be interposed between two dielectric guides of different characteristics; Fig. 5 is a curve diagram corresponding to Fig. 4, which will be referred to in explaining the operation of Fig. 5; and Fig. 6 is a longitudinal section of a further modification.

This application is in part a continuation of my application, Serial No. 745,457, filed September 25, 1934, on a Filter system for high frequency electric waves.

In my pending application, supra, and also in my pending applications Serial No. 661,154 filed March 16, 1933 and Serial No. 701,711 filed December 9, 1933 are disclosed systems for the guided transmission of electromagnetic waves of unusual character. The wave guiding structure may take a variety of forms; typical is a guide consisting of a rod of dielectric material having a high dielectric coefficient relative to unity. Another typical guide comprises a metallic pipe, containing only a dielectric medium, such as air, for specific example. In these typical dielectric guides, as in all the others disclosed, there is a

dielectric medium and an enclosing boundary which defines a discontinuity in electromagnetic properties and within which electromagnetic waves may be propagated.

A specific dielectric guide which may be considered is a cylinder of ceramic material having rutile (titanium dioxide) as its principal constituent. This prepared material may be made to have a dielectric constant of about 70 to 90, and a low dielectric loss factor, and it has the favorable property that its loss factor decreases with increasing frequency. The specific gravity is about 4 and its bending strength and other physical properties are favorable for practical use in dielectric guides. For this purpose a cylinder of this ceramic material may or may not have a metallic sheath.

Aside from the structure of the guide, the systems disclosed in my pending applications, supra, are unique in respect of the character of the wave transmission. The field pattern of the waves transmitted through a dielectric guide may take a great variety of forms, but in each instance thus far observed all forms have certain characteristics in common. Thus, it has been shown that for each form the dielectric guide presents the attenuation characteristic of a high-pass filter. The critical or cut-off frequency is dependent on the transverse dimensions of the guide and the index of refraction of the dielectric medium comprising it, and it may be more or less distinct depending on the resistivity of the metallic portions of the guide and other factors that may influence energy dissipation along the guide. The phase velocity, too, is dependent on the transverse dimensions of the guide, and it is ordinarily either greater or less than that characteristic of light in the dielectric medium, depending on whether there is or there is not a metallic sheath around the dielectric medium. The absence of the go-and-return flow of conduction current is another characteristic common to many dielectric guide systems.

The expression "dielectrically guided waves", as used in this specification, denotes the unique waves discussed hereinbefore and all other guided electromagnetic waves of equivalent character. "Dielectric guide" denotes a wave guide adapted for the transmission of dielectrically guided waves.

Referring to Fig. 1, the metal pipe 2 which extends to the right and is shown broken off may be taken as the input end of a dielectric guide, the dielectric 1 consisting of empty space or its equivalent, air. This guide 1—2 may be thought

of as extending a considerable distance to the right from the input terminal apparatus shown in Fig. 1.

The input end of the dielectric guide 1—2 of Fig. 1 is connected to a side opening in a transverse cylindrical chamber 35. This chamber 35 and the associated apparatus constitute an adjustable impedance matching device for matching impedances between the alternating current generator 3 and the dielectric guide 1—2. The output connections for the source 3 are shown at 4 and 5 in Fig. 1a in the form of opposite terminal conductors from the generator 3, with sliding connections against the side walls of the chamber 35 so that the source 3 may be adjusted longitudinally in relation to the chamber 35. This chamber 35 is of conductive material and the source 3 is mounted on the insulated end of an axial carrier rod 36 which is adjustable along the axis of the chamber 35 by means of the pinion 37 engaging its corresponding rack. The opposite end wall 38 is adjustable by another pinion 39 engaging its rack; and the end wall 40 behind the source 3 is similarly adjustable by the pinion 41 engaging its rack. It will be seen that both end walls 38 and 40 and the source 3 are adjustable longitudinally in relation to the opening from the chamber 35 into the guide 1—2. Across this opening is an adjustable iris 43, which is indicated diagrammatically in Fig. 1. It may be constructed like a camera shutter, or a slide 44 may be provided as in Fig. 2, with different sized openings 43 along its length.

For any given frequency, a resonant adjustment may be established by shifting the end walls 38 and 40 and thereby determining the character of the reactance of the load presented to the source 3. On the other hand, the magnitude of the energy dissipation component will be determined by the size of the opening of the iris 43.

At sufficiently high frequencies the source 3 will generate lines of electric force within the cylinder lying in transverse planes and approximately parallel to the conductor system 4—5 of Fig. 1a. Waves of such lines will travel back and forth along the length of the cylinder 35, being reflected at its end walls 38 and 40, and on proper adjustment of these end walls, a system of standing waves will be established within the chamber 35. To some extent the wave energy will pass out through the adjustable iris 43 and be propagated along the interior of the dielectric guide 1—2. A wave of the type that has just been described, I call an asymmetric magnetic wave.

The modification shown in Fig. 3 is adapted to generate and propagate waves of the type which I call symmetric electric waves. These have their lines of magnetic force in circles centered on the axis and lying in planes perpendicular thereto. The dielectric guide 1—2 comprising the air core 1 and the metallic sheath 2 is terminated at the left by the end wall 40 which is adjustable by means of the pinion 41 and its corresponding rack. The rod 36 of conductive material carries the source 3 and the piston 42 of conductive material, both adjustable by the pinion 37 engaging the corresponding rack. The resonant chamber between the wall 40 and the piston 42 is adjusted in suitable relation to the frequency of the source 3. The two output conductors from the source 3 are respectively *a* and *fe*; and the complete circuit of the generator 3 is along the conductors *a*, *b*, then across the annular gap *bc*, and then along the conductive path *c*, *d*, *e*, *f*. The

energy in the form of symmetric type waves escapes through the annular opening *bc* between the edge of the piston 42 and the side wall 45. The volume of energy going into the guide 1—2 may be adjusted by varying the width of the annular opening around the piston 42 or by means of the iris 43.

Referring to Fig. 1 it will be seen that in relation to the guide chamber 35 with its end walls 38 and 40 there is an energy input at 3 and an output at the place of connection with the guide 1—2. The place of the input and the place of the output are relatively adjustable along the length of the chamber. The same general principle and the same general relation of parts are shown in Fig. 4, which represents two guides 90 and 91 of different diameters, between which it is desired to match their impedances. For example, the guide 90 may be of diameter 10.2 centimeters, and we may consider the transmission of asymmetric magnetic waves at a frequency of 2,000 megacycles per second. It is desired to pass these waves into the guide 91 whose diameter is assumed to be 12.7 centimeters, and to accomplish this transfer without substantial reflection loss. With these dimensions and at the frequency stated, the characteristic impedance in the output guide 91 will be about 1.84 times that in the input guide 90.

The transverse cylindrical chamber 88 is interposed with two adjustable ends 89. This cylindrical chamber 88 is made in the form of two half cylinders meeting along the diametrically opposite longitudinal lines 92. The chamber within the casing 88 between the pistons 89 can be adjusted to any desired length, and the place along the length where the input is connected and the place along the length where the output is connected are independently adjustable. The diameter of the chamber 88 is 12.7 centimeters, the same as that of the output guide 91, and the end plungers 89 are adjusted so that its length is 21.5 centimeters. In this way it is secured that the length of the chamber is such as to give about one standing wave length. This is diagrammed in Fig. 5 where the curve E represents the magnitude of the electric force vector of the wave and the curve H represents the magnitude of the magnetic force vector of the same wave. It will be understood that these vectors are at a right angle to each other and that for the asymmetric magnetic wave which is assumed to be involved in this case, the magnetic vector has a component along the axis of the chamber 88 and the electric vector is at a right angle with this axis.

The standing waves set up in the chamber 88 provide the impedances against which the impedances of the two guides 90 and 91 will be matched. Referring to the diagram in Fig. 5, this shows that the electric force component of the standing wave in the chamber 88 is at zero at each end and in the middle and is a maximum at the two quarter points. The magnetic component is a maximum at the ends and also at the midpoint, and zero at the two quarter points.

Looking into the chamber 88 at various points along its length, it appears as a low impedance at points where the magnetic field is a maximum and as a high impedance where the electric field is a maximum. Accordingly, to match the impedances of the two wave guides 90 and 91 we connect each of them at the particular point along the chamber 88 where the impedances are appropriate.

If the waves being propagated are of the sym-

metric electric or asymmetric electric types, the characteristic impedance of the guides 90 and 91 will be low, as compared with other wave types. In such case each guide should connect into the resonant chamber 88 near a voltage minimum as indicated by the curve E in Fig. 5. The exact locations may be determined by experiment. If symmetric magnetic waves are being propagated, then the guides 90 and 91 may have a high characteristic impedance and should be connected into the resonant chamber 88, each near a voltage maximum. After making these adjustments to a first degree of approximation, a further final adjustment for optimum conditions may be effected by again shifting the two movable plungers 89.

When it is desired to match two guides 90 and 91 of different diameters for a certain frequency and with certain other conditions established once for all, the system of Fig. 6 may be employed. The guide section 101 is interposed in coaxial alignment with the guides 90 and 91, having its length equal to an odd multiple of a quarter wave length, its diameter fixed at the proper intermediate value in relation to the diameters of the guides 90 and 91. Between the discontinuities at 102 and 103 a standing wave will be set up, which will afford the necessary impedance match at each end so that the energy flow from the one guide 90 or 91 to the other will be without reflection into the one whence such flow occurs. The proper diameter of the intermediate section 101 may be determined experimentally or by a computation based on general principles. The characteristic impedance of the intermediate part 101 should be a geometric mean between the characteristic impedances of the two guides 90 and 91.

Referring to Fig. 1 this shows the transmitting end for the dielectric guide 1—2. The high frequency generator 3 generates asymmetric magnetic waves which are propagated as such within the guide 1—2 from left to right. It is well known that, in general, the arrangement of apparatus which is appropriate at the sending end for dielectric wave energy may be reversibly appropriate at the receiving end. Accordingly, Fig. 1 correctly represents suitable receiving apparatus for connection to the distant end of the dielectric guide 1—2, provided that a suitable sensitive receiver is placed where the element 3 is represented. In the more general aspect of a source or a receiver, the device 3 may be called an electromagnetic energy translator.

Similarly, if the element 3 of Fig. 3 were taken to represent such a receiver, then this figure would represent the entire receiving end for reception along a dielectric guide whose transmitting end is that which is actually shown in Fig. 3.

Fig. 4 represents an intermediate assembly of parts by which an impedance match may be made for transmission from a dielectric guide of certain type into a dielectric guide of a different type. It will be seen that in principle, Figs. 1 and 4 are similar. In relation to the transverse cylindrical chamber there is an energy input at 3 in Fig. 1 and at 90 in Fig. 4 and there is an energy output at the iris 43 in Fig. 1 and at the branch guide connection 91 in Fig. 4. In both figures the relative spacing between the end walls and the places of application of the energy input and the energy output are adjustable.

In accordance with the principles which have been explained heretofore, Fig. 4 may be regarded as a generalized representation of my improved

impedance matching device in that 90 may be an input dielectric guide, or be replaced by a source, such as 3 of Fig. 1; and 91 may be an output dielectric guide or be replaced by a receiver or other energy absorbing device.

With regard to the combination disclosed in Fig. 3, a novel and useful adjustment and manner of operation of that combination is claimed in my copending application Serial No. 73,940, filed April 11, 1936.

I claim:

1. A metal sheathed wave guide, a source of electromagnetic waves, a metallic-walled chamber enclosing said source and connected with said guide to establish dielectrically guided waves therein, the impedance of said guide being matched with the impedance presented by said source.

2. A metal sheathed wave guide, a source of electromagnetic waves, a cylindrical chamber with an adjustable end wall enclosing said source, said chamber being connected with said guide for the generation of dielectrically guided waves therein, and said end wall being adjusted to a position for which said chamber is resonant at the frequency of said source.

3. A device for coupling two dielectric guides for the transfer of dielectrically guided waves consisting of a transverse metal sheathed guide section interposed between the two guides and connected therewith at different places along its length.

4. Two dielectric guides of different impedance and an adjustable impedance matching connection between them consisting of a hollow metal cylinder with transverse axis, and adjustable end walls therefor, said guides being connected to said cylinder at different places along its length.

5. The method of transferring electromagnetic wave energy from an input element to an output element, at least one of such elements being a dielectric guide carrying dielectrically guided waves, which consists in setting up a standing wave with the input element connected to sustain it and with the output element connected to draw energy from said wave, and adjusting the places of connection of said elements along the length of said standing wave to establish an impedance match between the said two elements.

6. The method of transferring electromagnetic wave energy from an input element to an output element, at least one of such elements being a dielectric guide in which said energy is in the form of dielectrically guided waves, which consists in setting up a standing wave with the input element connected to sustain it and with the output element connected to draw energy from said wave, adjusting the places of connection of said elements along the length of the wave so as to establish an impedance match between the said two elements, and adjusting the volume flow of wave energy at some place between the input and the output.

7. In combination, a cylindrical metallic pipe of limited length, respective reflectors across its ends, an electric wave translating means at an intermediate place along its length, and a dielectric guide opening into said pipe at an intermediate place along its length, said reflectors and said two places being relatively adjustable lengthwise and being adjusted so that said translating means operates at its optimum effectiveness.

8. The method of matching the impedances of two elements, one of which is a wave guide carrying dielectrically guided waves, which consists in

establishing a standing electromagnetic wave and connecting the said two elements into it at respective places positioned along its length so as to attain the desired proper impedance match.

5 9. A device for coupling two wave guides carrying dielectrically guided waves consisting of an intermediate metal sheathed guide section interposed between the two guides and connected therewith at different places along its length, said
10 intermediate guide section being proportioned to effect an impedance match between said two guides.

10. In combination, an input element for electromagnetic wave energy and a corresponding
15 output element, at least one of them being a dielectric guide consisting essentially of a metallic pipe, and an intermediate element adapted to have standing waves set up therein from the said input element, the said output element being connected to receive wave energy therefrom, said
20 input and output elements being so positioned along the length of the standing waves as to match their impedances.

11. A metal sheathed wave guide carrying dielectrically guided waves, an electromagnetic wave
25 energy translator, and a chamber enclosing said translator and connected with said guide, said chamber being so dimensioned and so related physically to said guide and said translator as to
30 effect an impedance match between said guide and translator.

12. In combination, two dielectric guides of different characteristic impedance values, and an interposed dielectric guide section of quarter
35 wave length and of geometric mean impedance value.

13. In combination, for the transmission of dielectrically guided waves of a certain mean wave length, two metal sheathed, air core dielectric
40 guides of different diameters and in axial alignment, an interposed metal sheathed, air core dielectric guide section in the same alignment and of quarter wave length, and having an intermediate diameter such that its characteristic impedance is the geometric mean of the impedances
45 of the two first mentioned guides.

14. In combination, two metal sheathed dielectric guides of different characteristic impedance values for dielectrically guided waves and an interposed tandem-connected section of dielectric
50 guide substantially an odd number of quarter-waves in length having a characteristic impedance intermediate the characteristic impedance values of said guides whereby said guides are coupled in efficient energy transfer relation.
55

15. In combination, two dielectric guides of unlike characteristic impedance and section of dielectric guide interconnecting them, the transverse dimensions of said section being such as to
60 minimize reflection in the transfer of dielectrically guided wave energy from one of said guides

to the other, said section of guide being substantially axially-resonant at an operating frequency of the combination.

16. In combination, two dielectric guides and means for conveying dielectrically guided wave energy from one of said guides to the other comprising a section of dielectric guide connected laterally to the ends thereof. 5

17. Two dielectric guides of unlike characteristic impedance and means coupling them for the transfer of dielectrically guided waves comprising a section of dielectric guide that is substantially resonant at the frequency of said waves, at least one of said guides being connected to a lateral point of said section of guide. 15

18. Means for interconnecting two metal sheathed dielectric guides the proximate ends of which are out of axial alignment comprising a metallic chamber connected to the ends of both of said guides, the length of said chamber and the points at which it is connected to said guides being such that dielectrically guided wave energy is efficiently transmitted from one of said guides to the other. 20

19. In combination, a metallically bounded chamber, two wave guides, each consisting essentially of a metallic pipe containing only a dielectric medium, connected to said chamber at respective points along an axis thereof, and means for transmitting dielectrically guided waves through said guides, the frequency of said waves, the length of said chamber along said axis and the points at which said guides are connected to said chamber being so correlated that wave energy is efficiently transmitted from one of said guides to the other. 25 30 35

20. A metal sheathed wave guide carrying dielectrically guided waves, an electromagnetic energy translator and a metallic-walled chamber enclosing said translator and connected with said guide for the interchange of electromagnetic energy, the dimensions of said chamber being such that said chamber is resonant at the frequency of said waves, and the impedance of said translator and its position within said chamber being so correlated that the impedance of said guide and the impedance of said translator are matched to each other. 40 45

21. In combination in a system for the transmission of dielectrically guided waves, an input element and an output element, a metallic-walled chamber enclosing one of said elements, the other of said elements being a metal sheathed wave guide opening into said chamber, said chamber being resonant at the frequency of said waves and the said element enclosed by said chamber being so positioned therein that its impedance is matched to the impedance of said guide, and an apertured barrier near the mouth of said guide for controlling the volume flow of wave energy. 50 55 60

GEORGE C. SOUTHWORTH.