

Sept. 13, 1938.

G. C. SOUTHWORTH
TRANSMISSION OF ENERGY EFFECTS BY GUIDED
ELECTRIC WAVES IN A DIELECTRIC MEDIUM
Filed Dec. 9, 1933

2,129,712

5 Sheets-Sheet 1

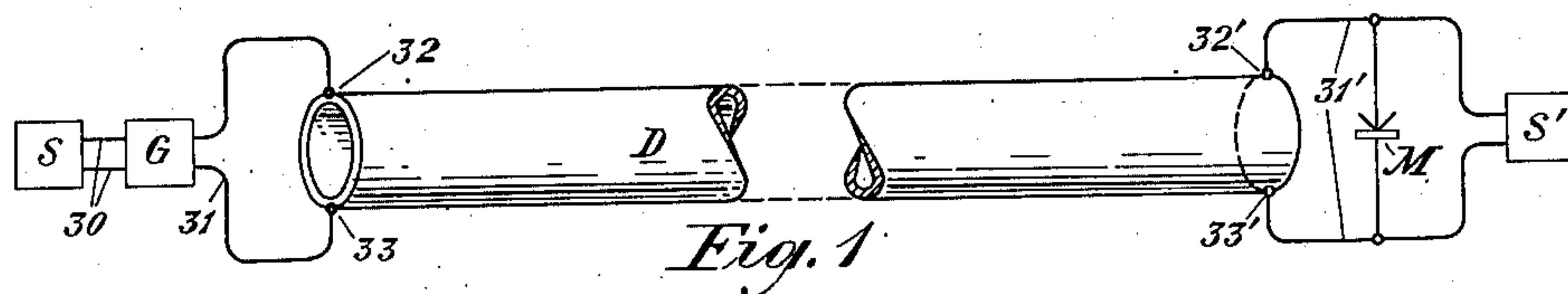


Fig. 1

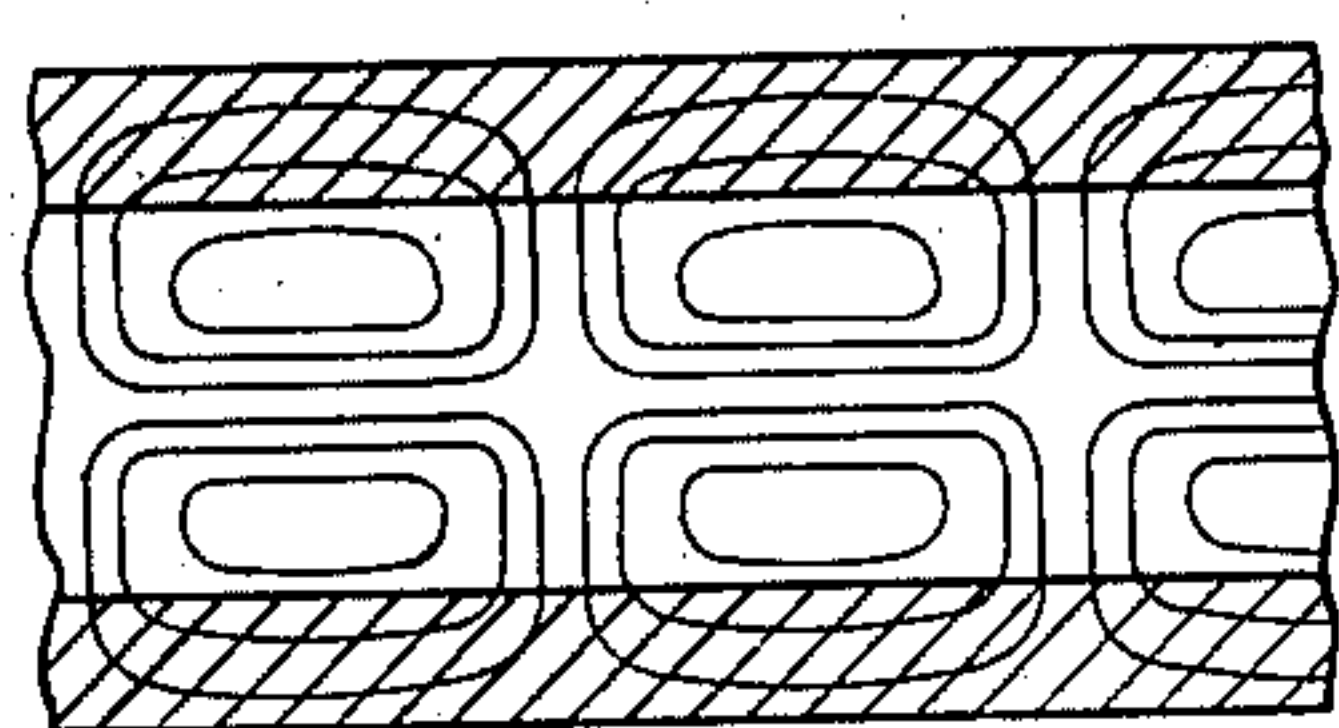


Fig. 6

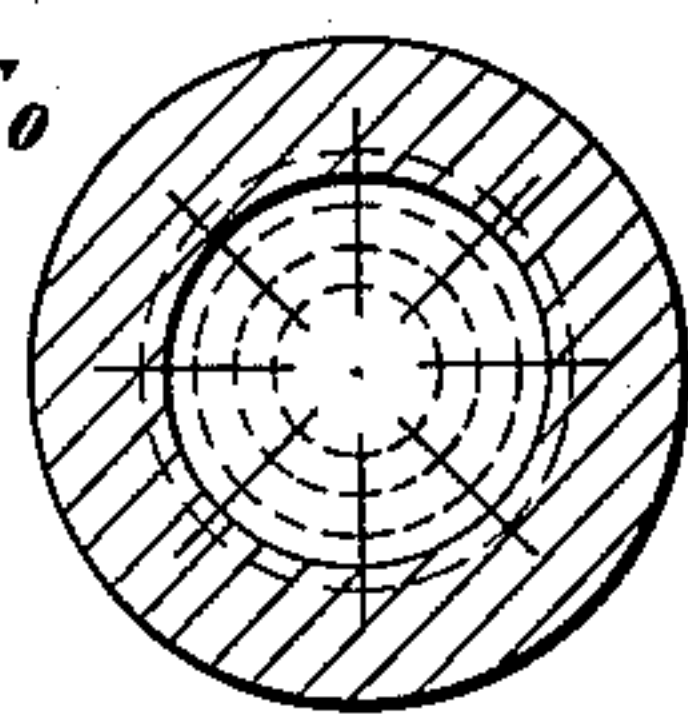


Fig. 6a

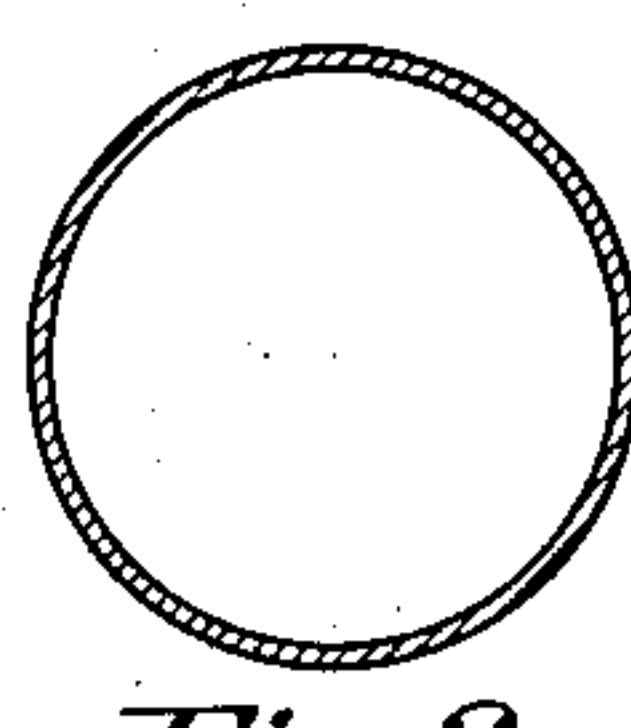


Fig. 2

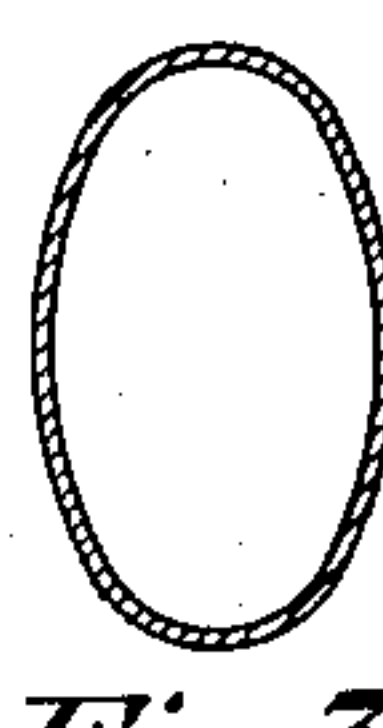


Fig. 3

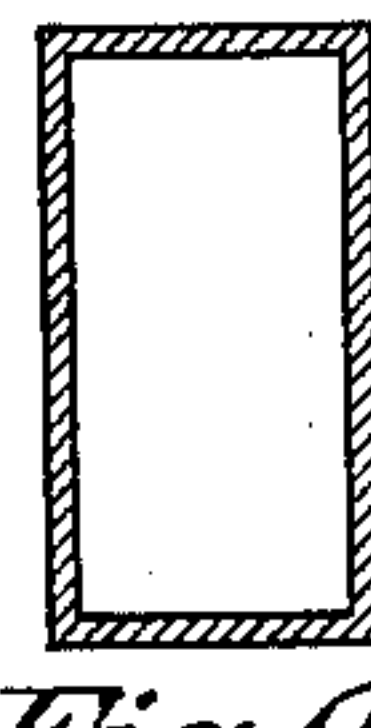


Fig. 4

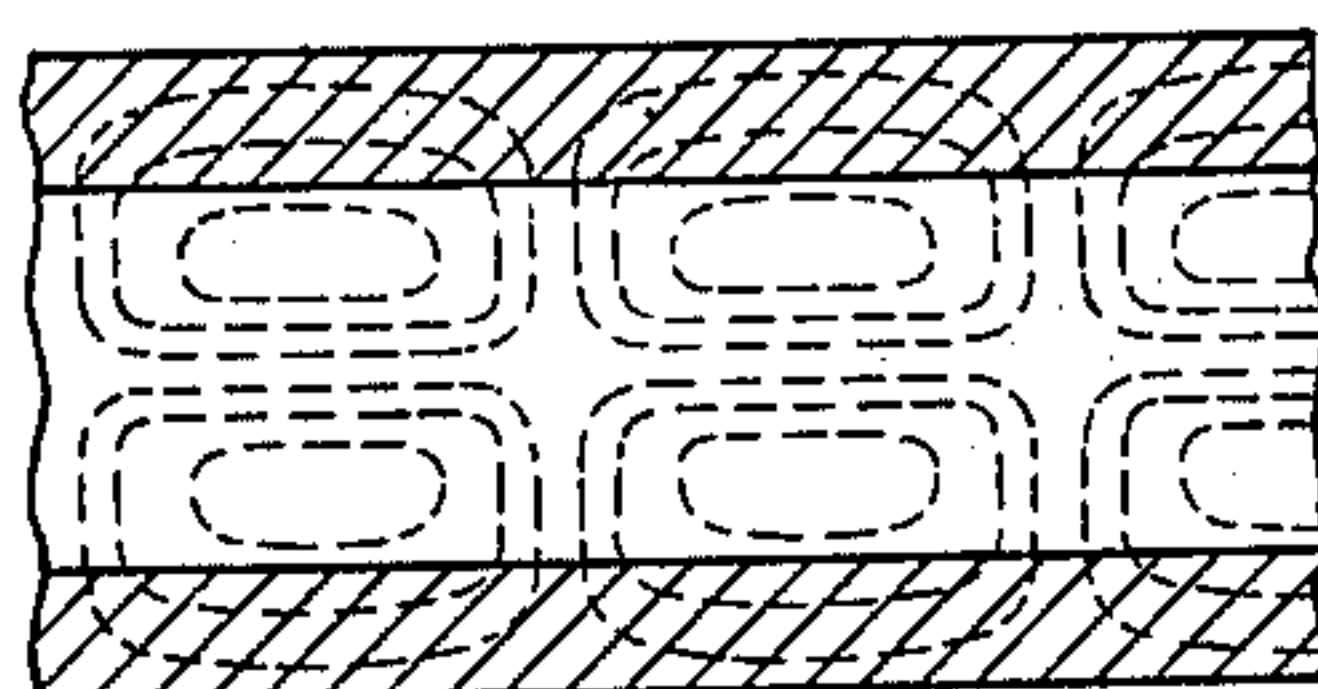


Fig. 7

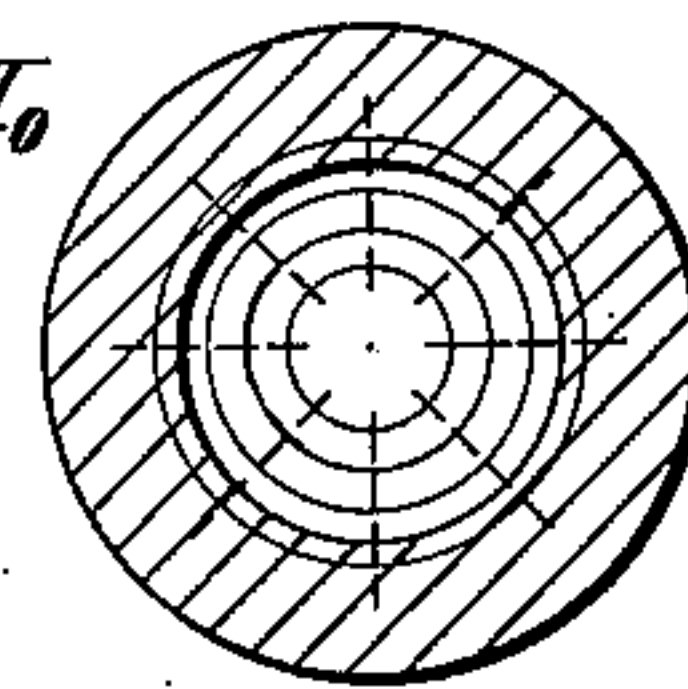


Fig. 7a

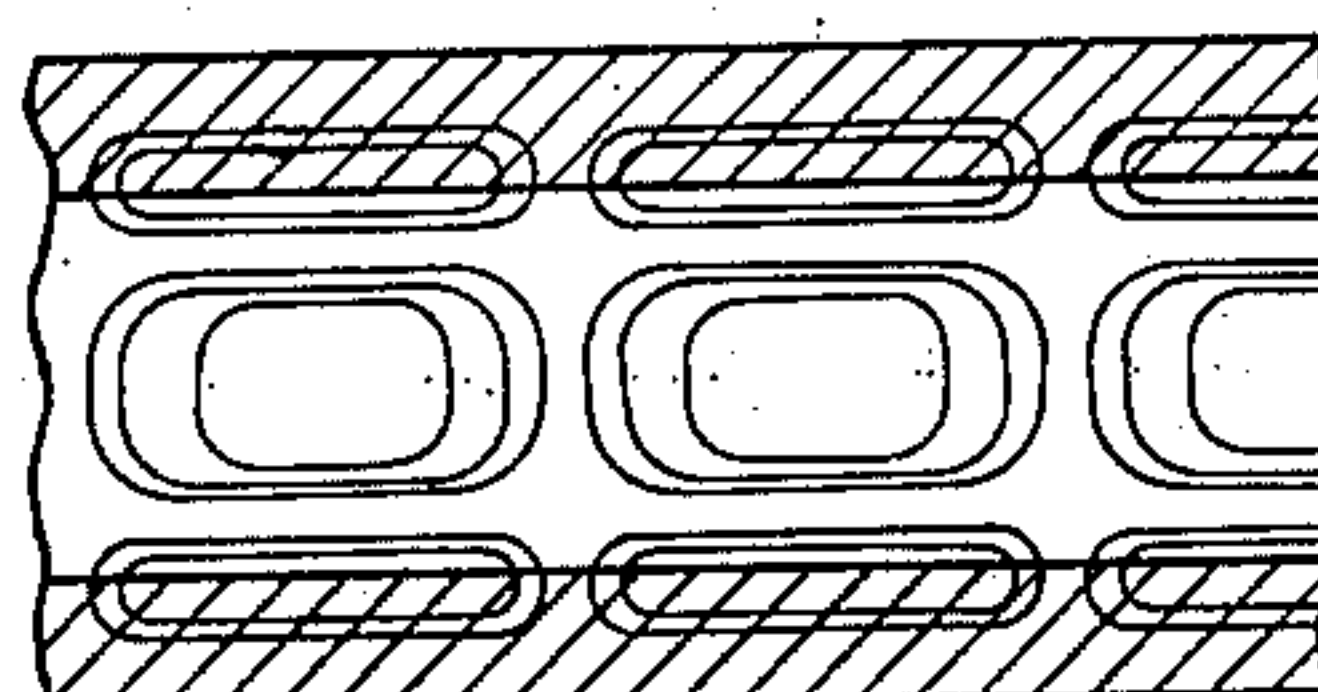


Fig. 8

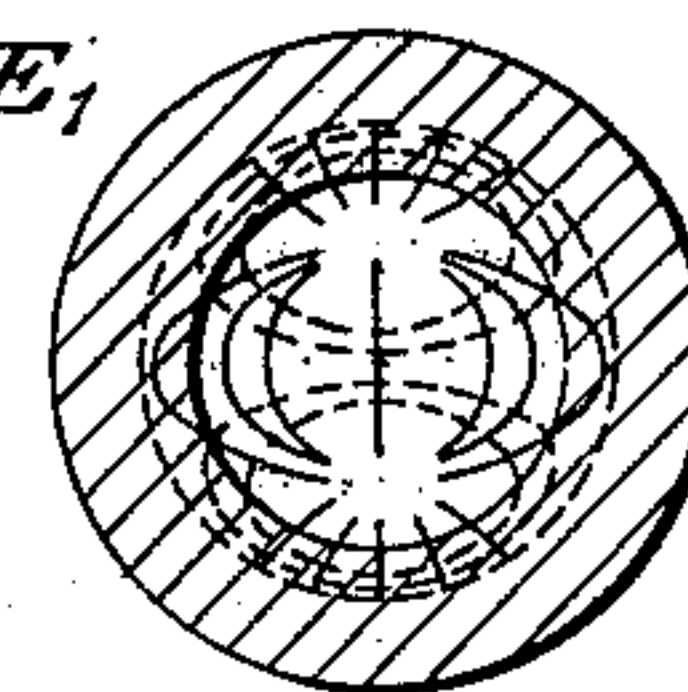


Fig. 8a

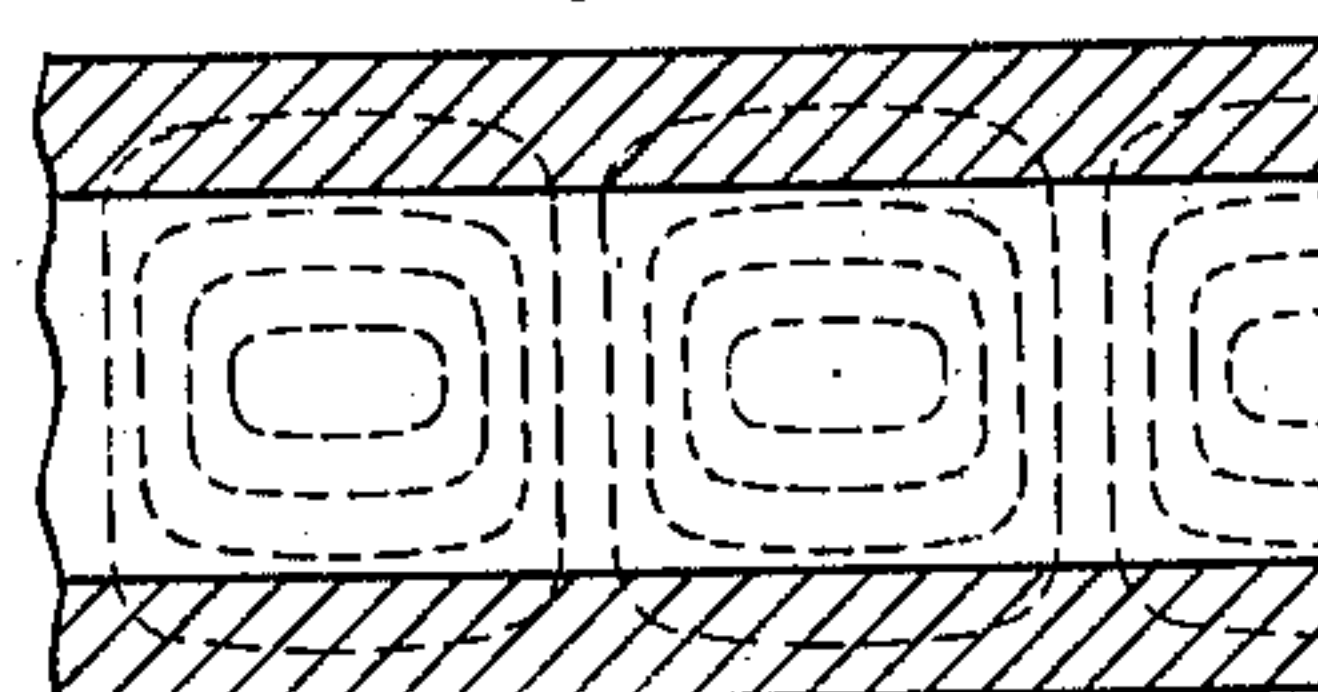


Fig. 9

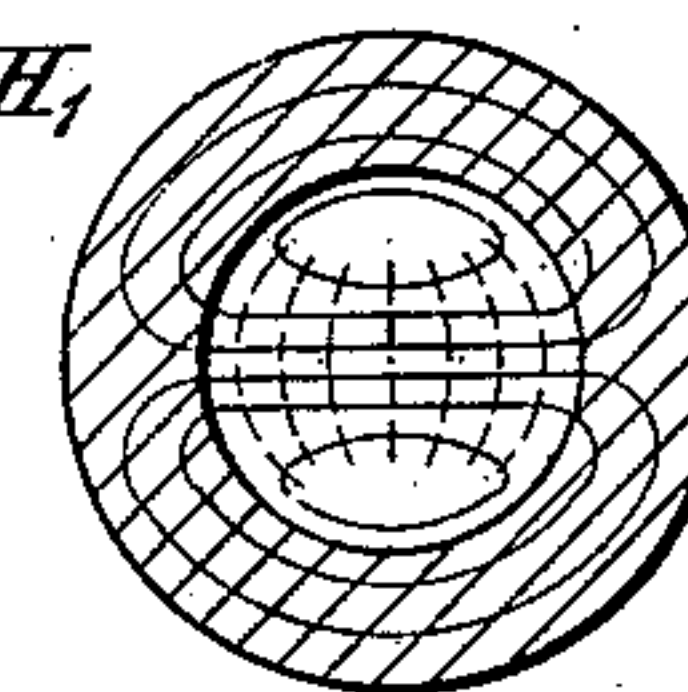


Fig. 9a

Fig. 9b

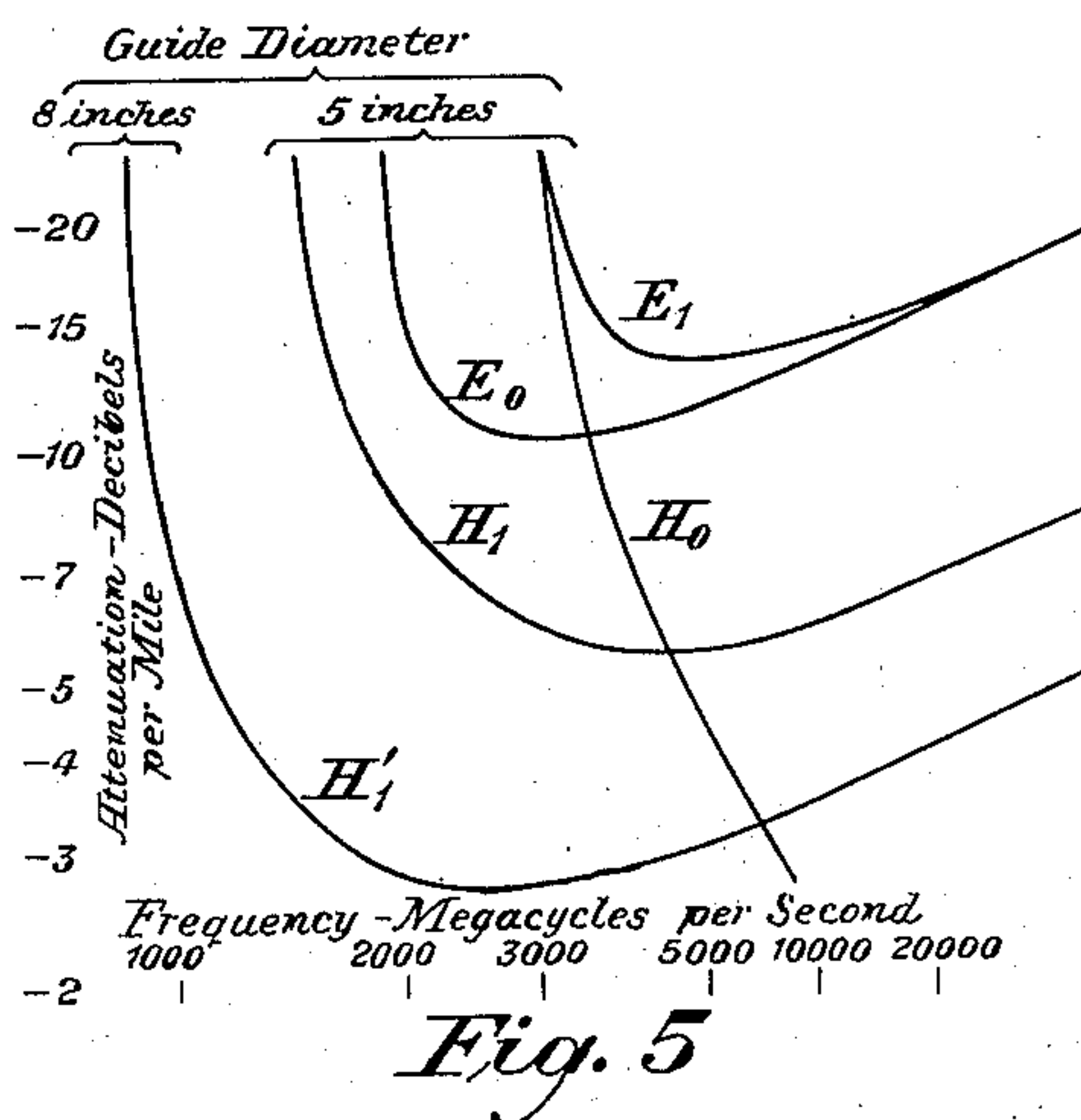
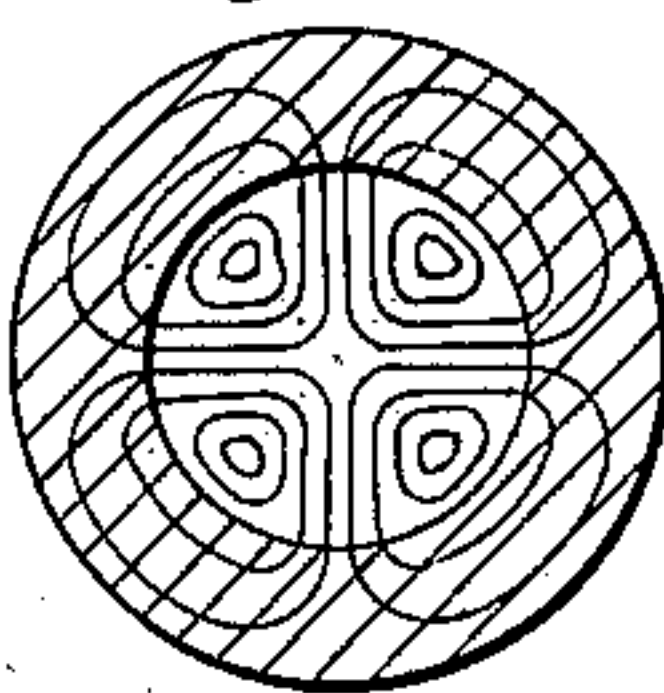


Fig. 5

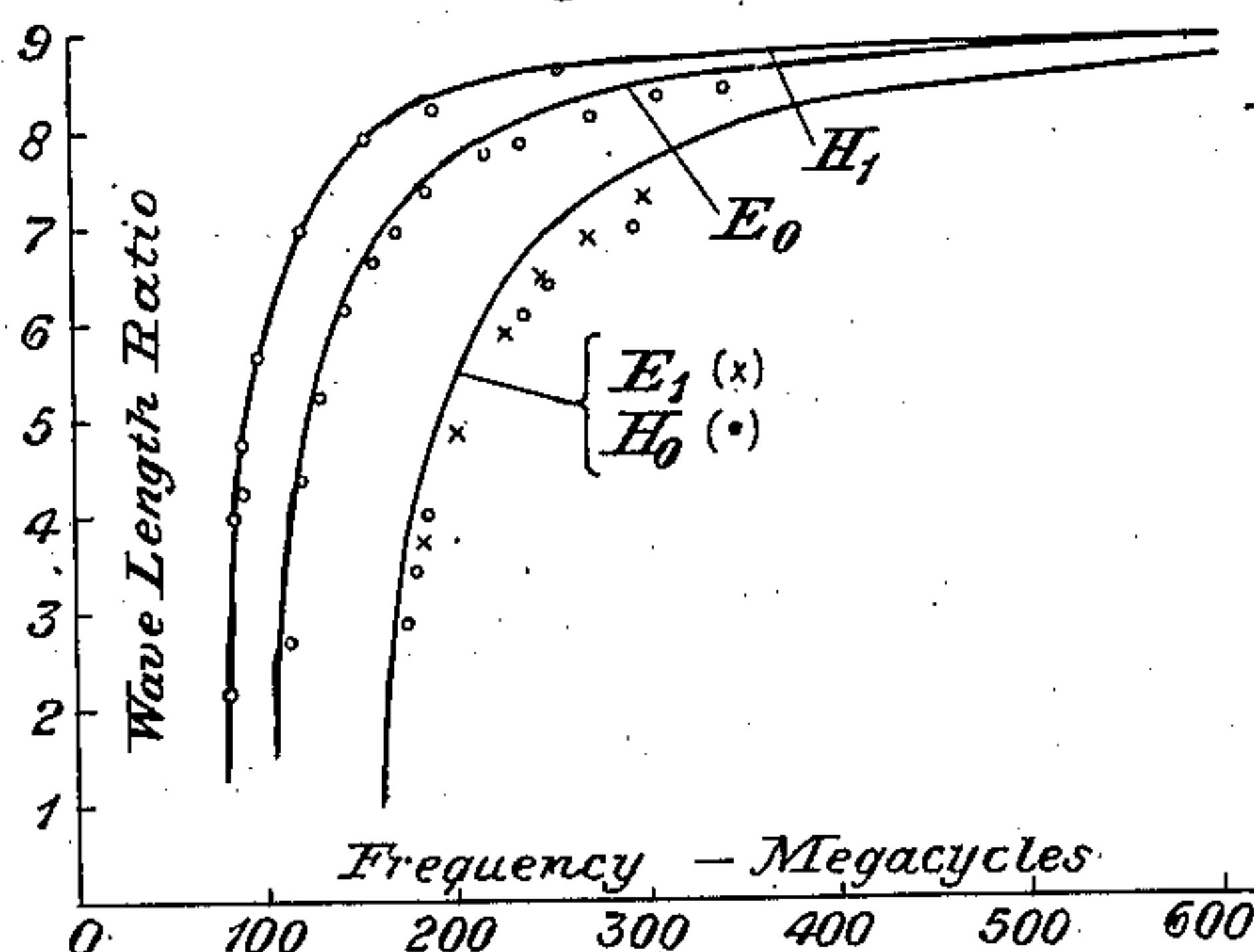


Fig. 5a

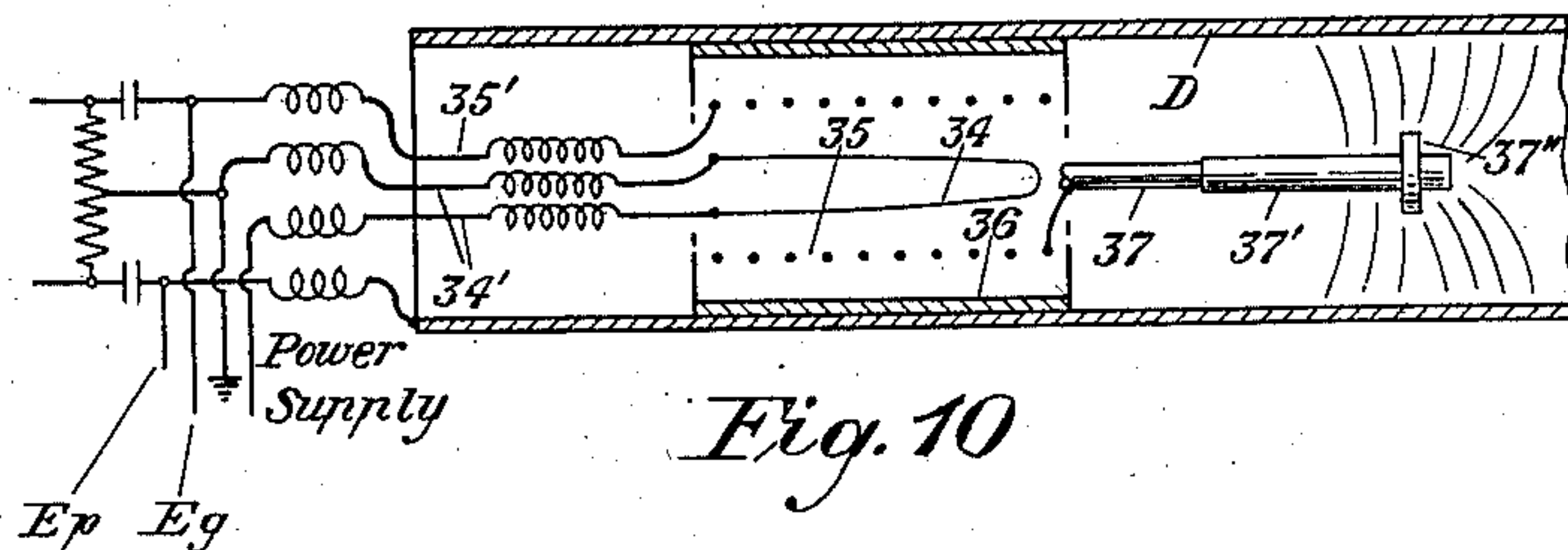


Fig. 10

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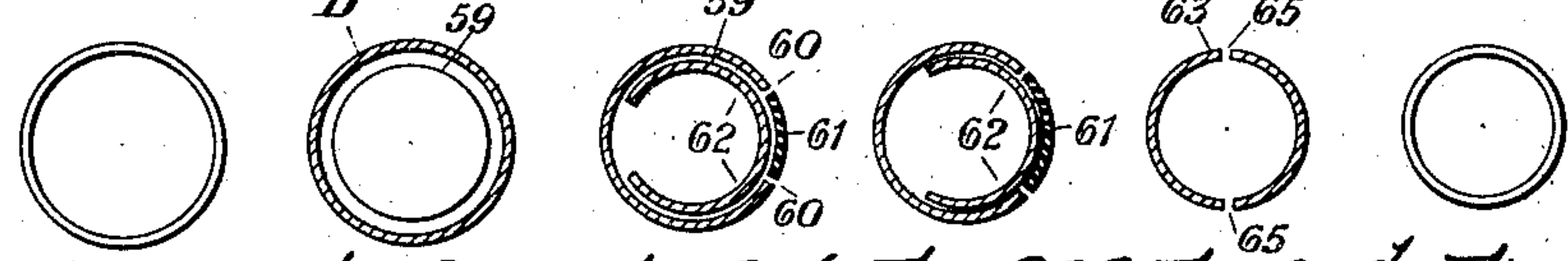
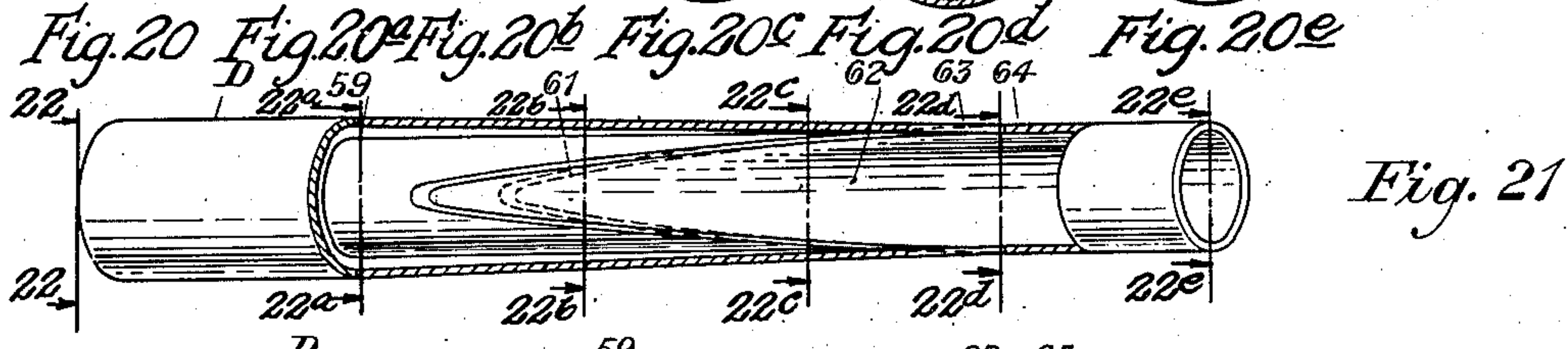
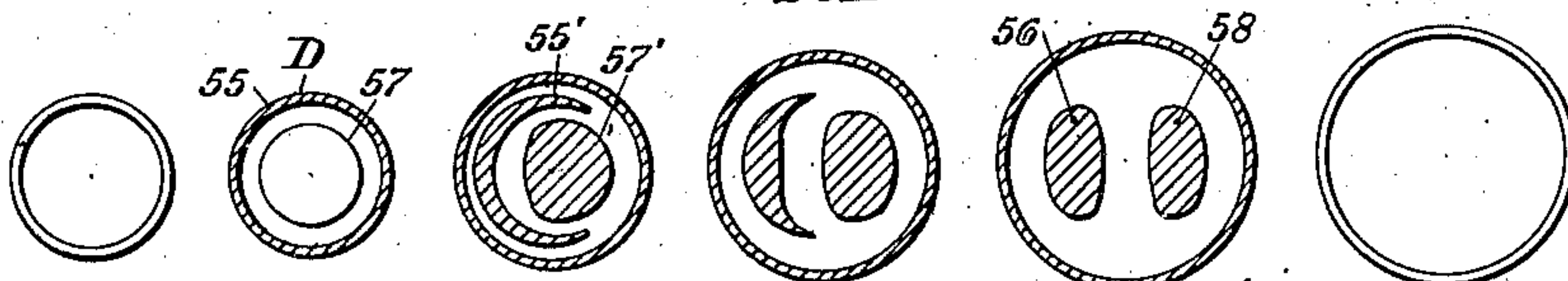
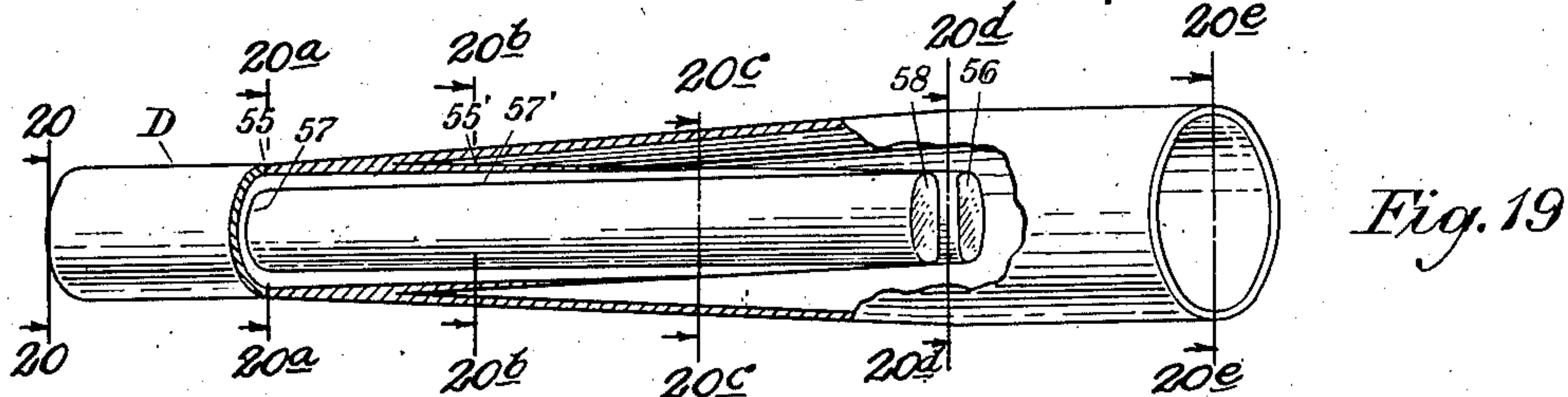
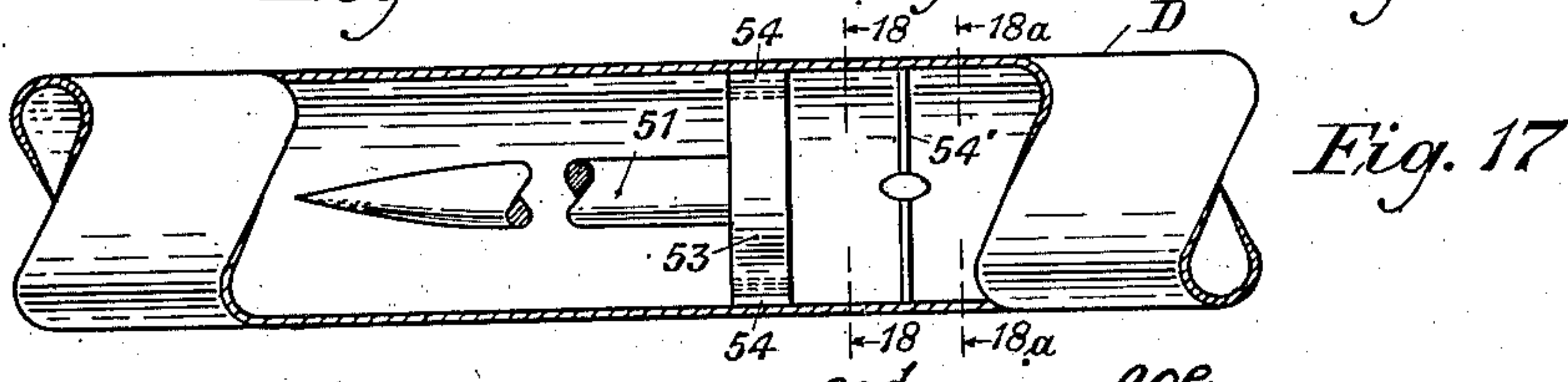
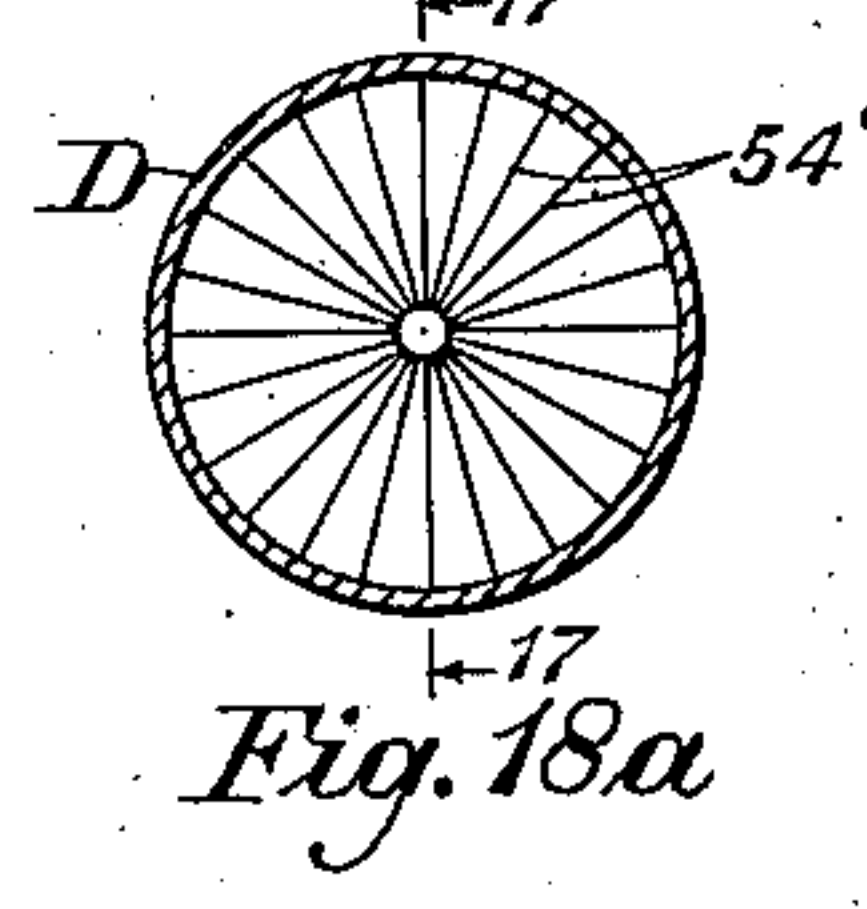
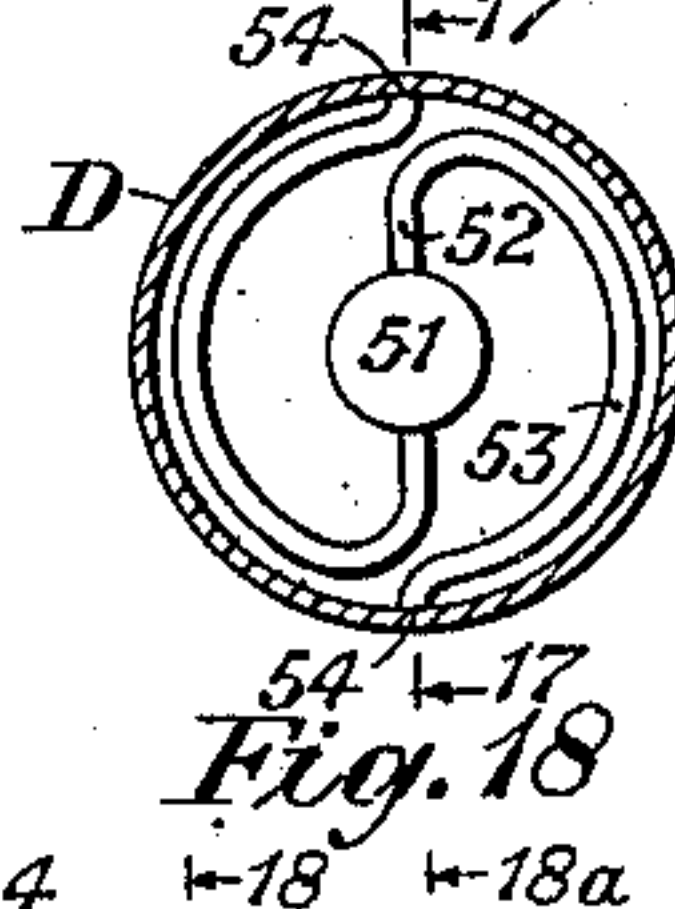
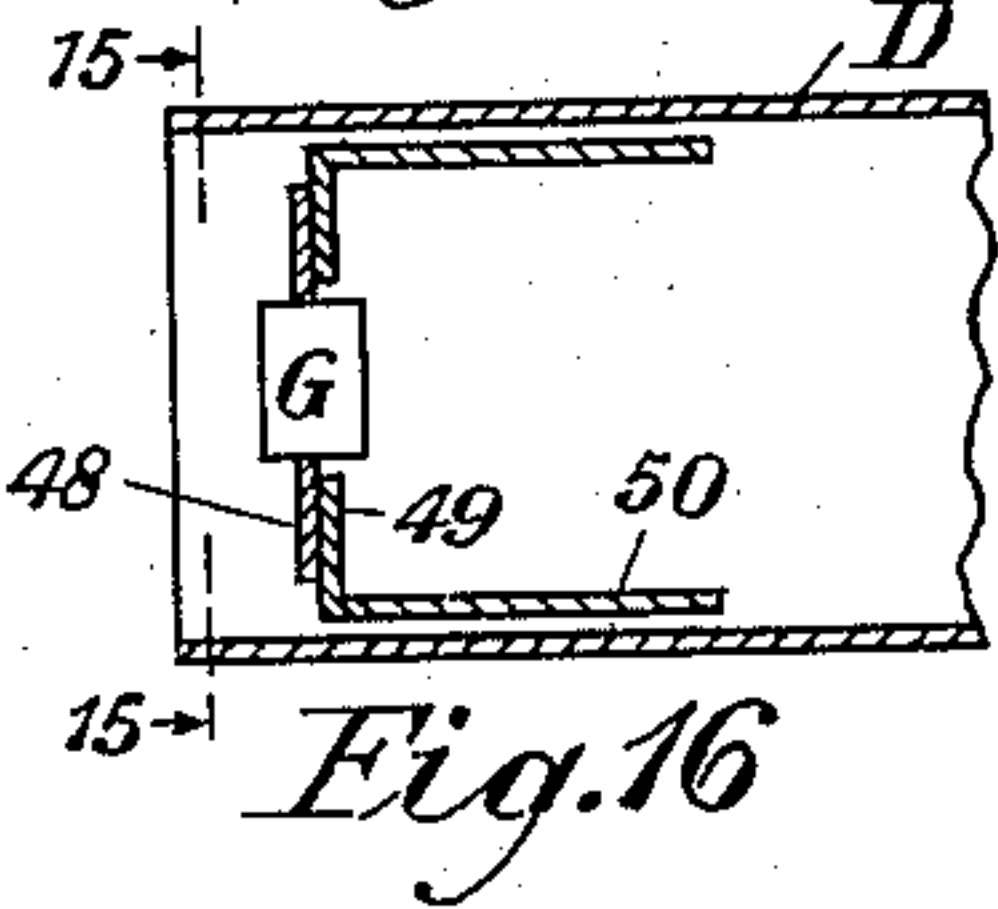
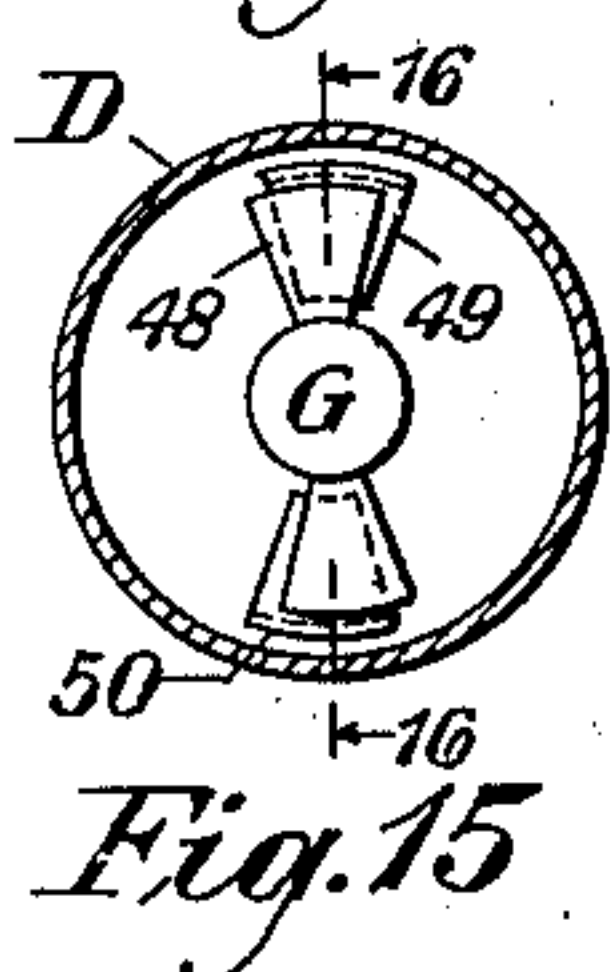
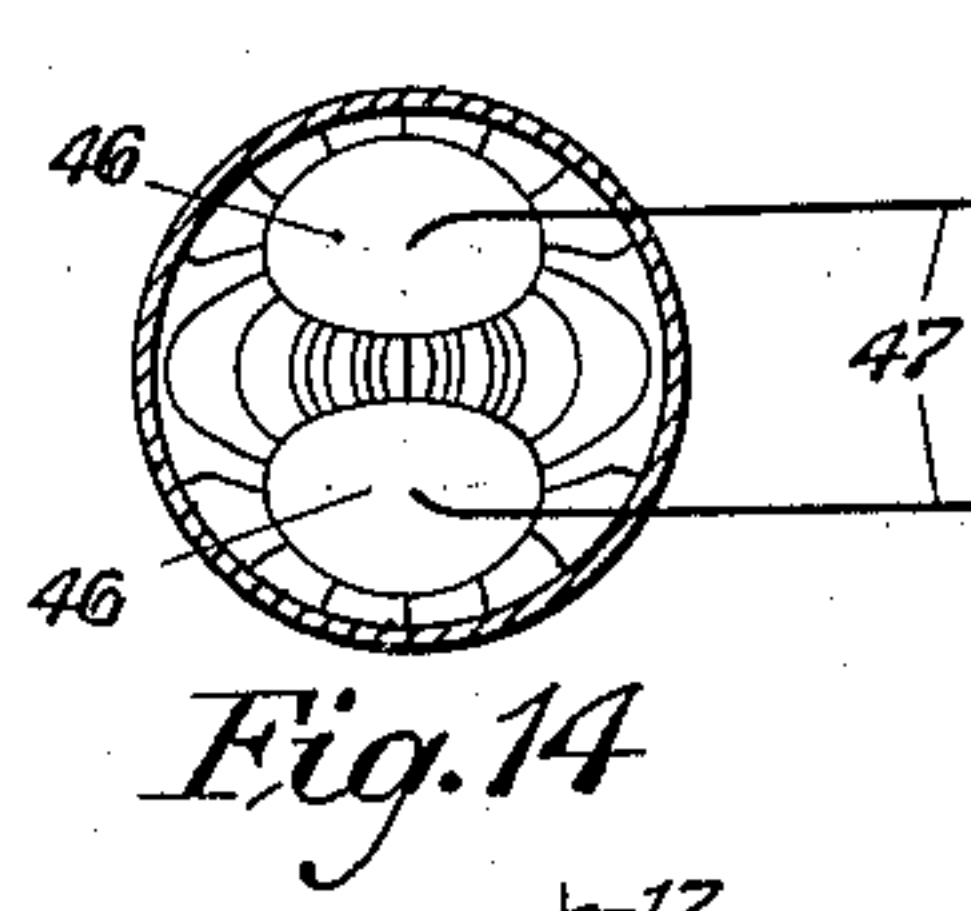
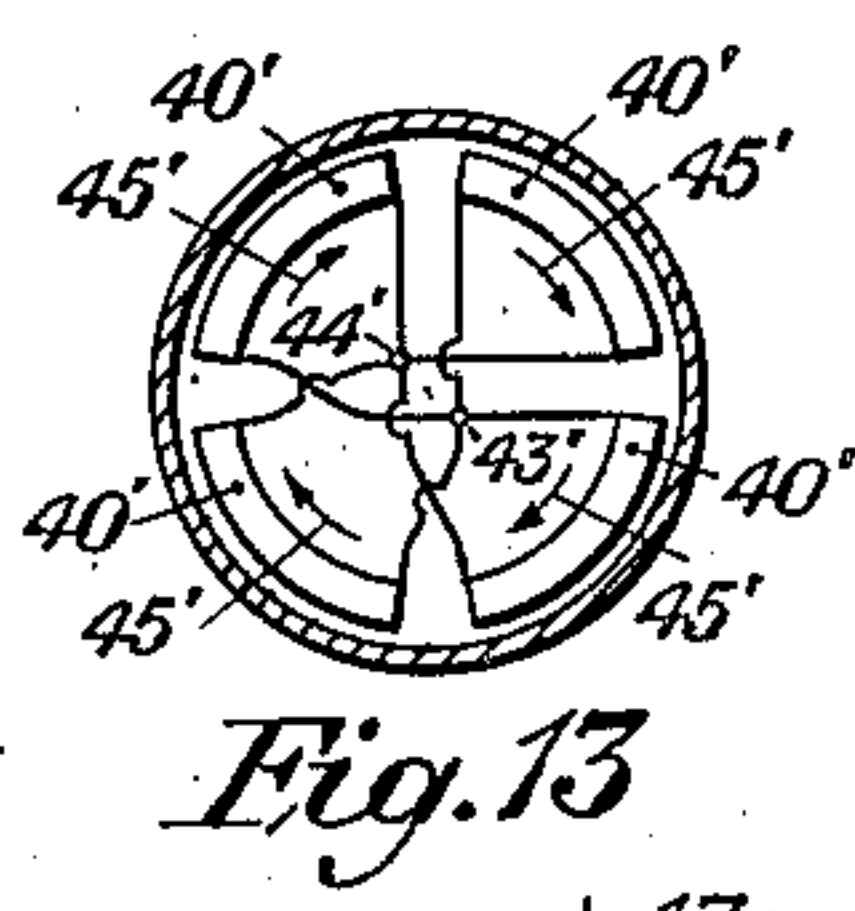
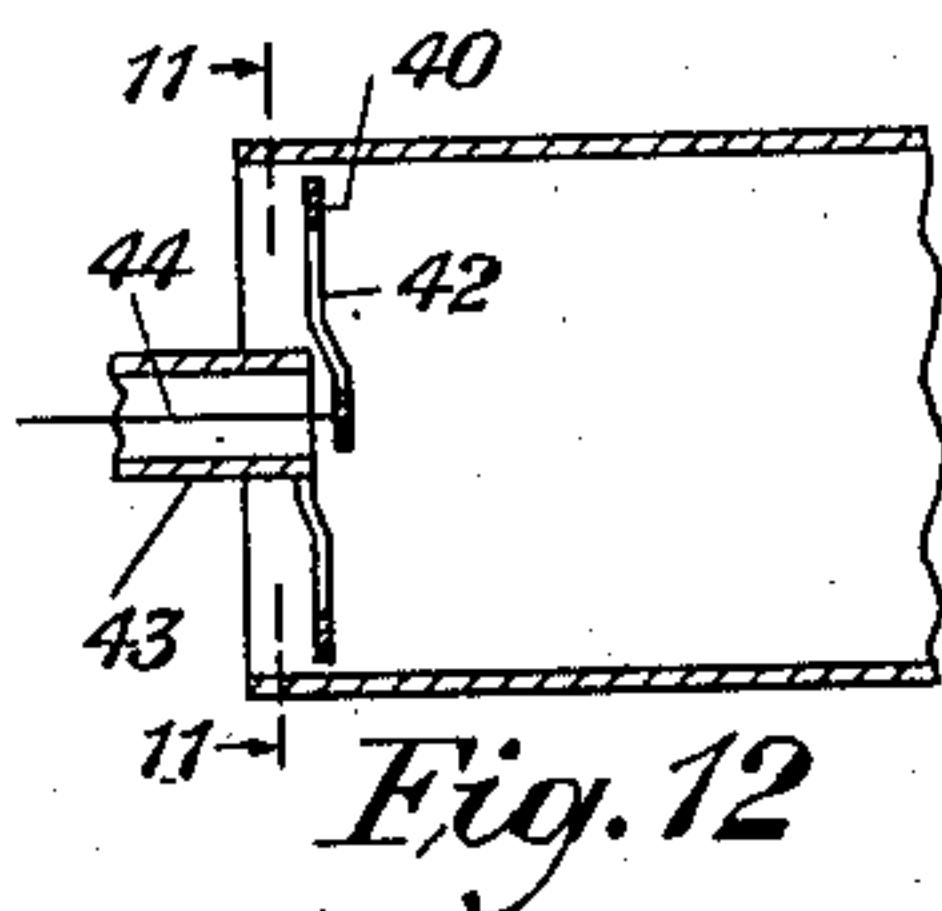
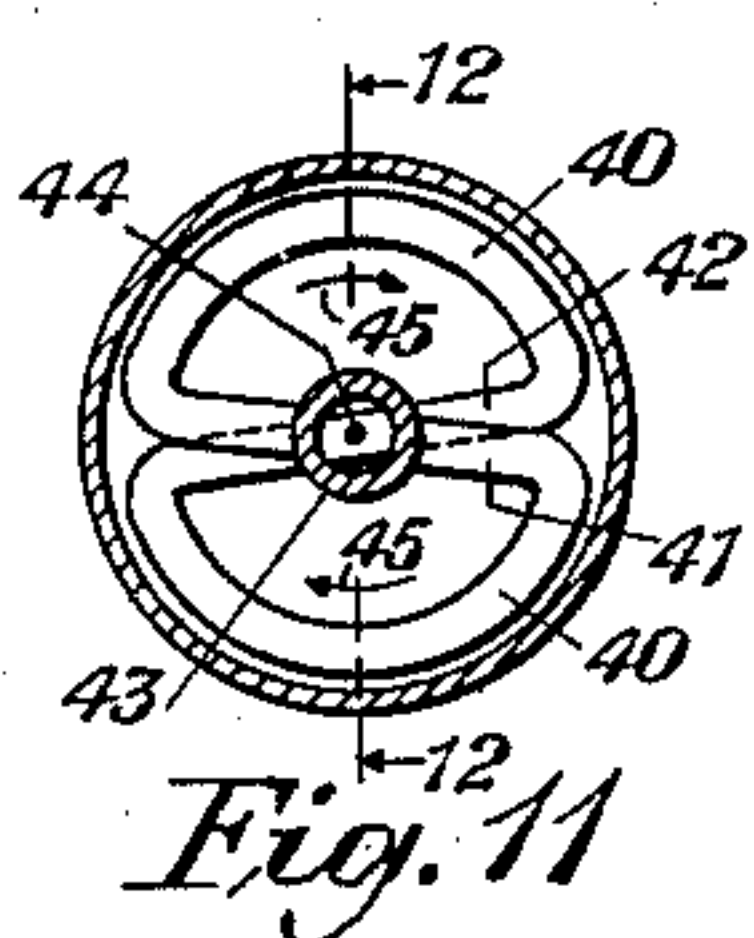


Fig. 22 Fig. 22a Fig. 22b Fig. 22c Fig. 22d Fig. 22e
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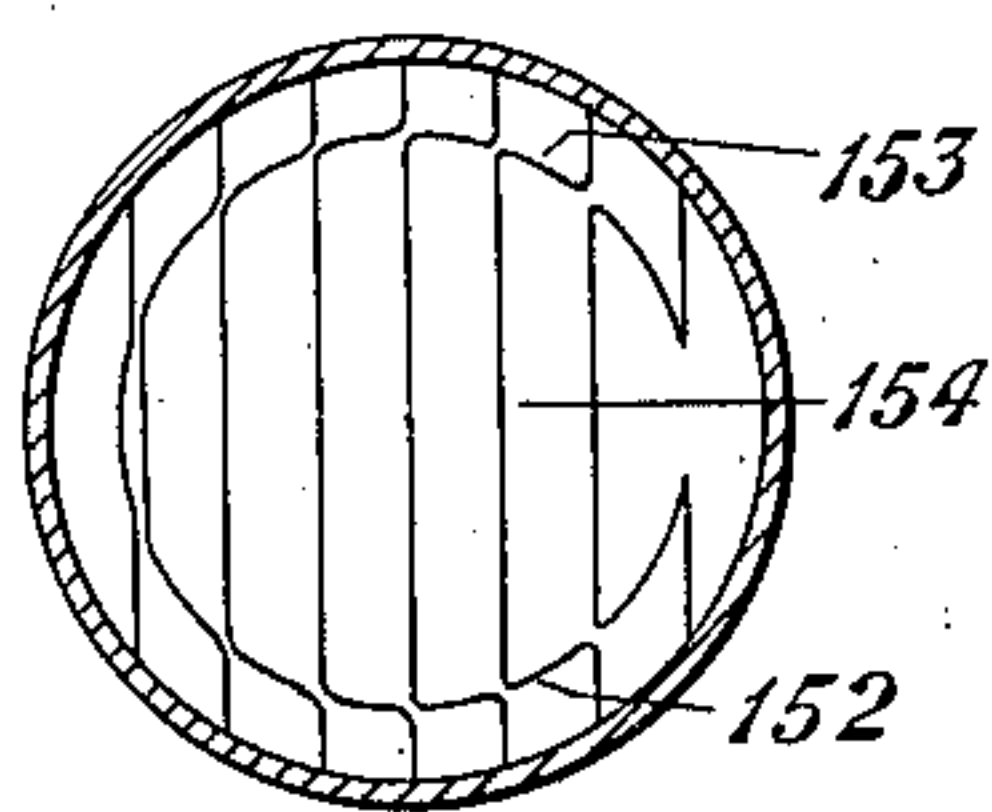


Fig. 23

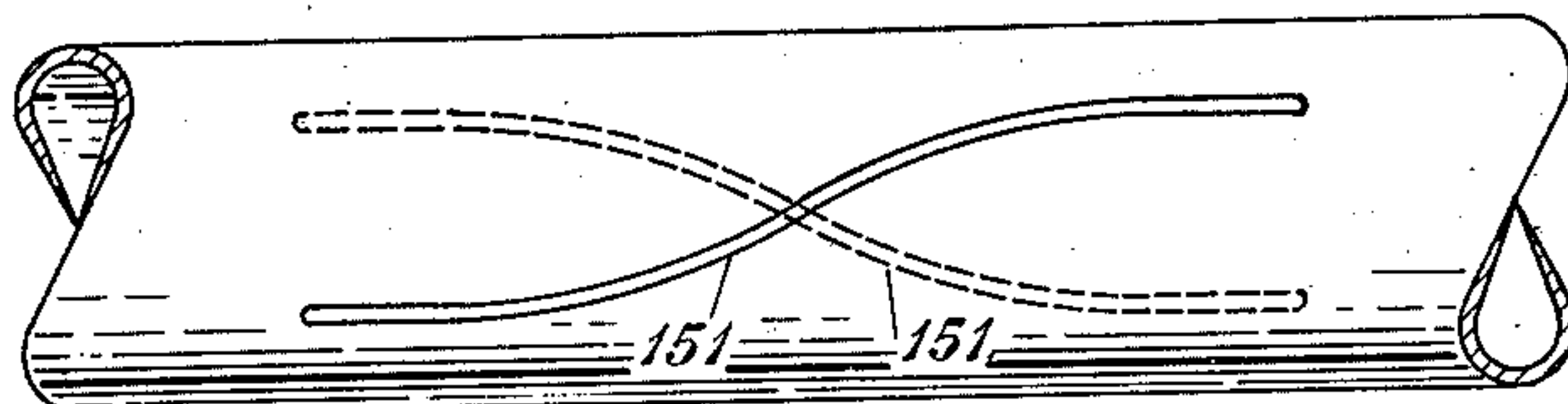


Fig. 24

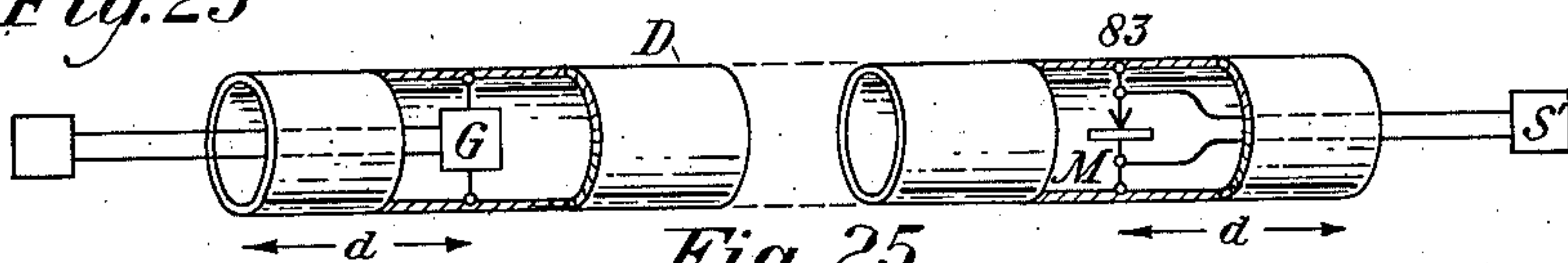


Fig. 25

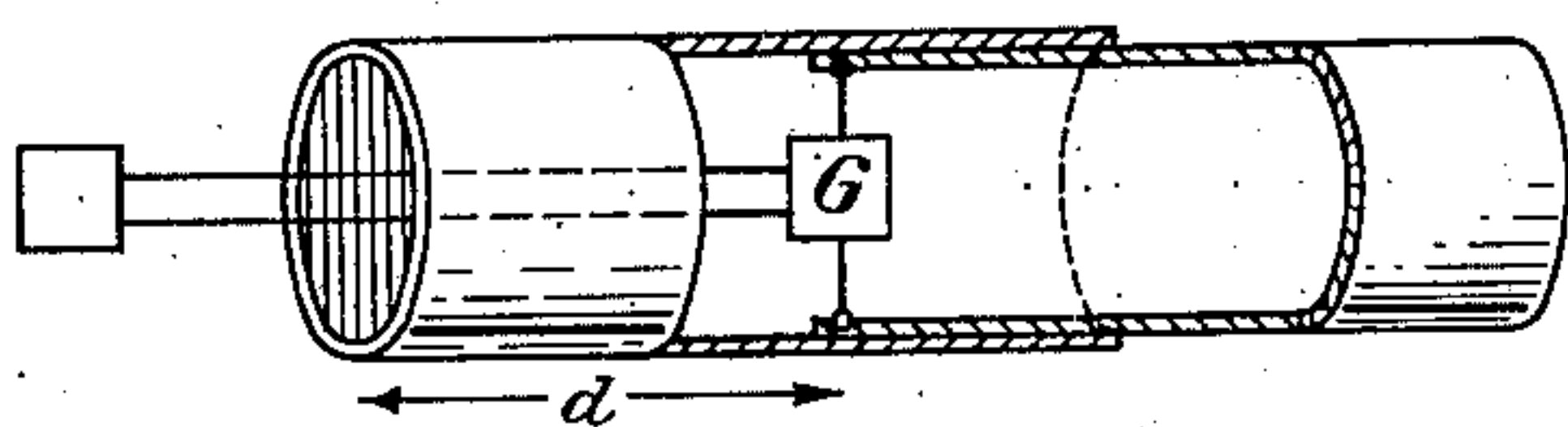


Fig. 26

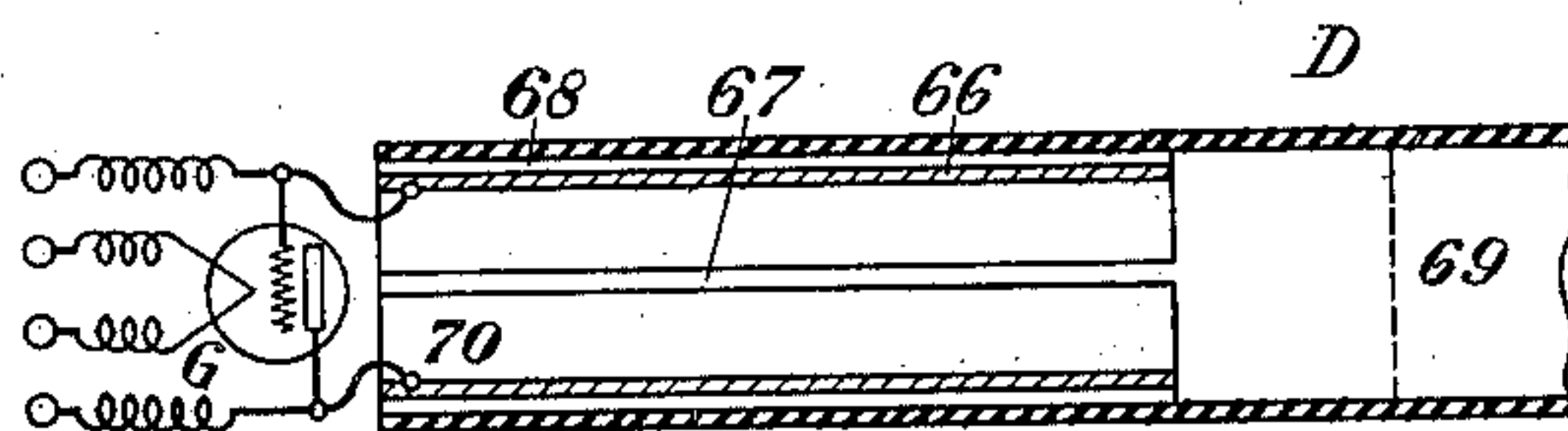


Fig. 27

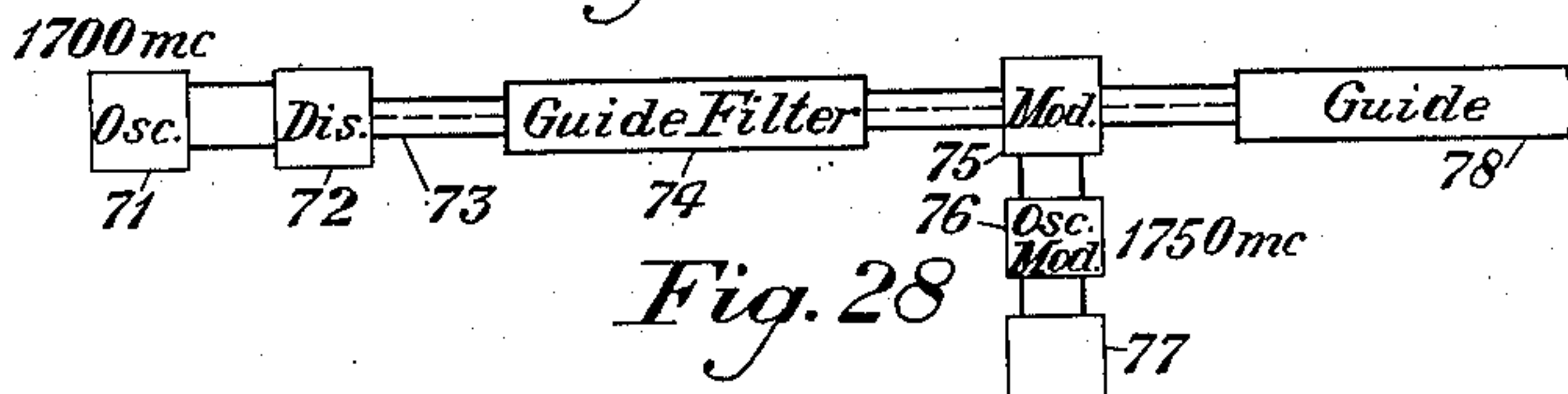


Fig. 28

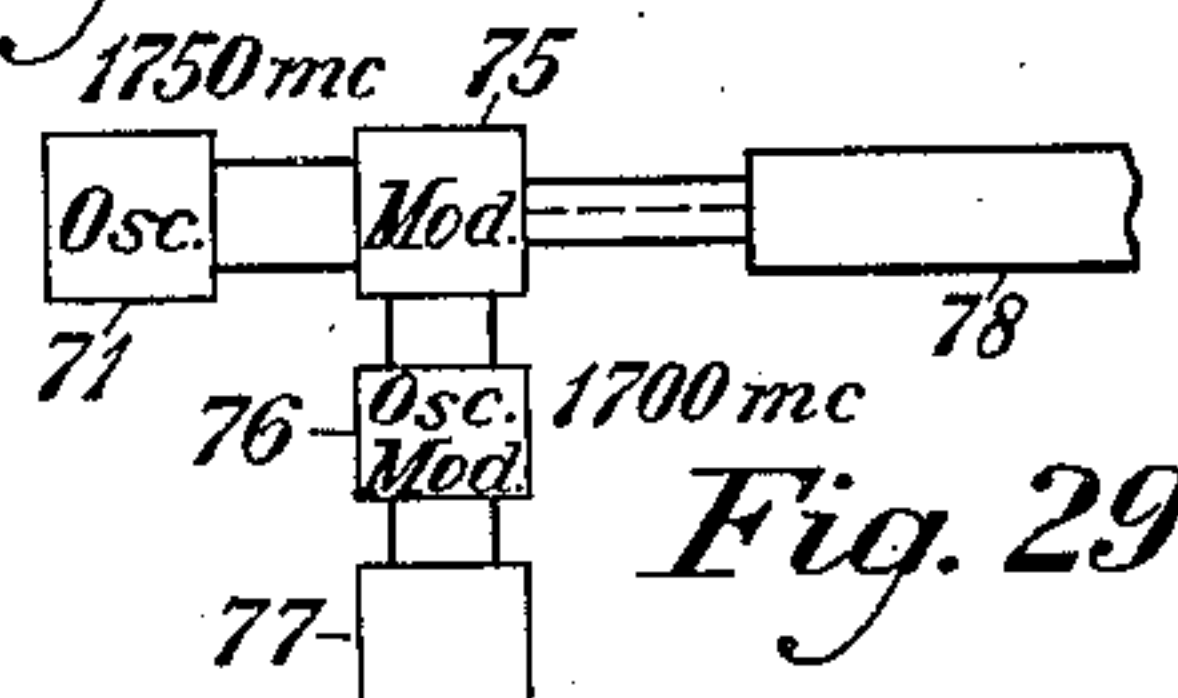


Fig. 29

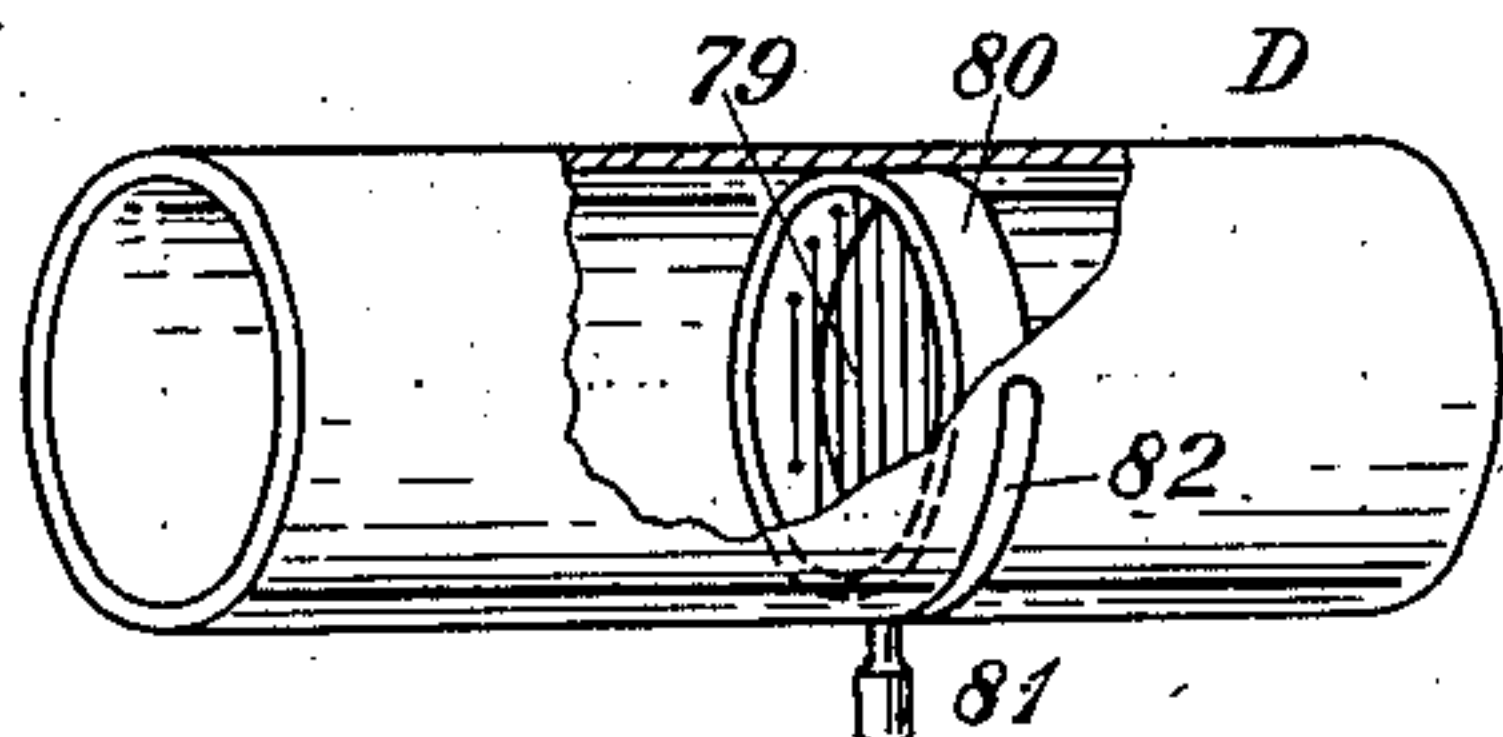


Fig. 30

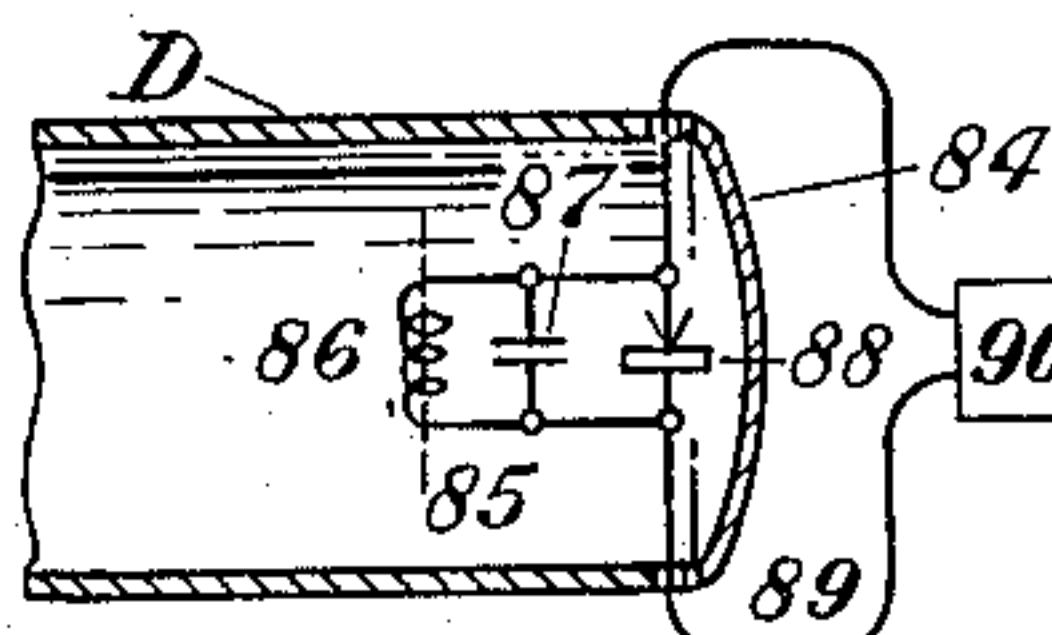


Fig. 31

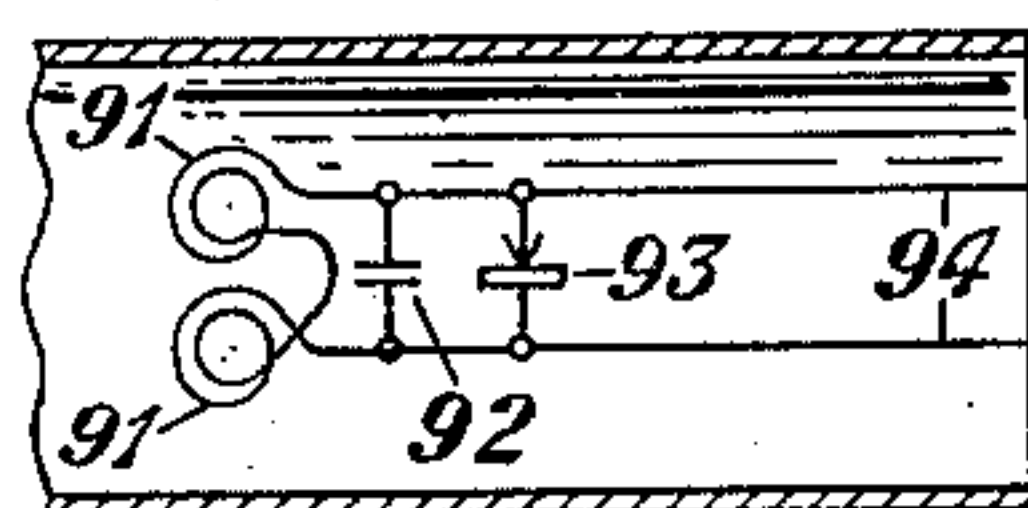


Fig. 32

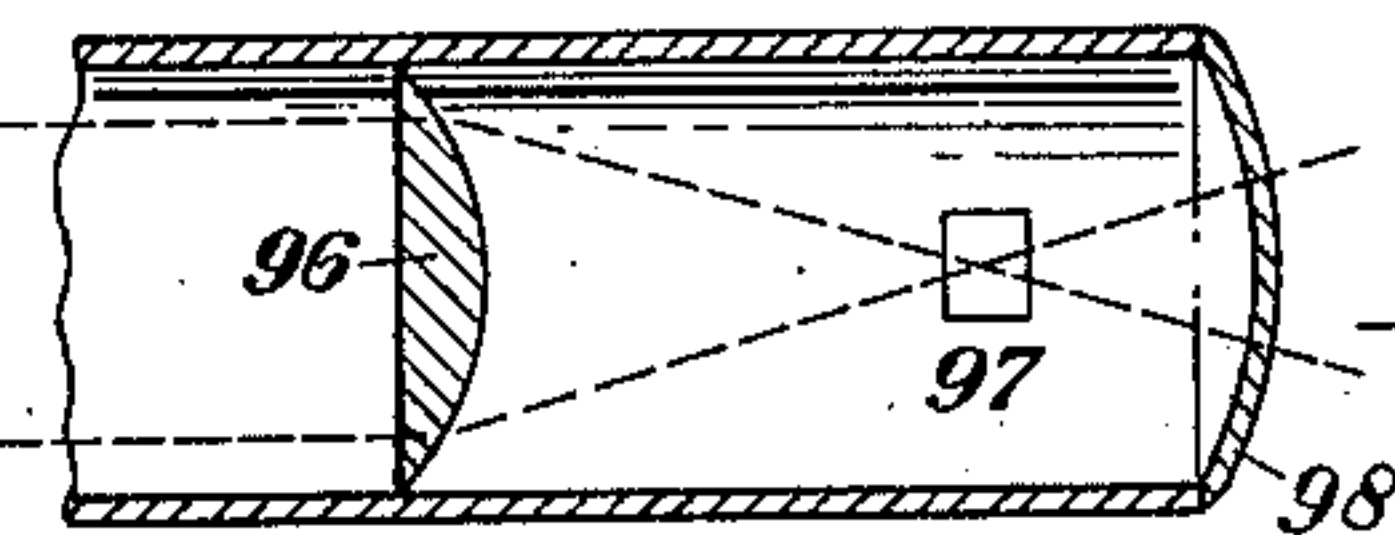


Fig. 33

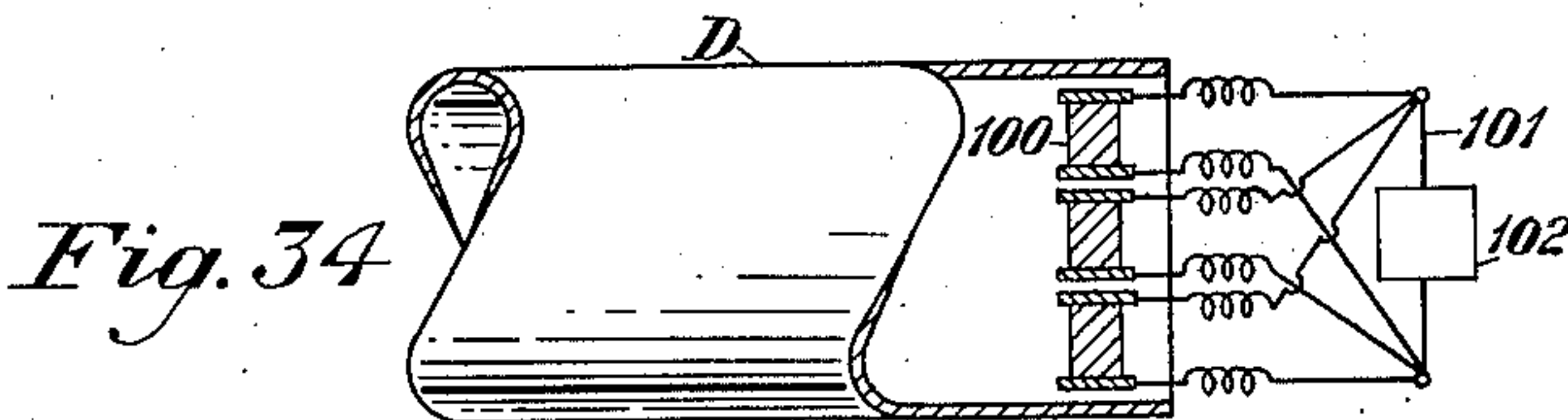


Fig. 34

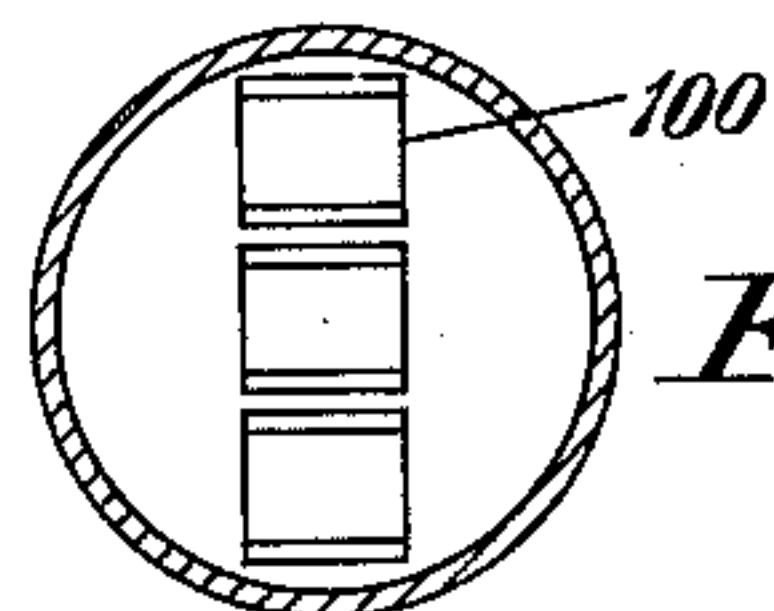


Fig. 35

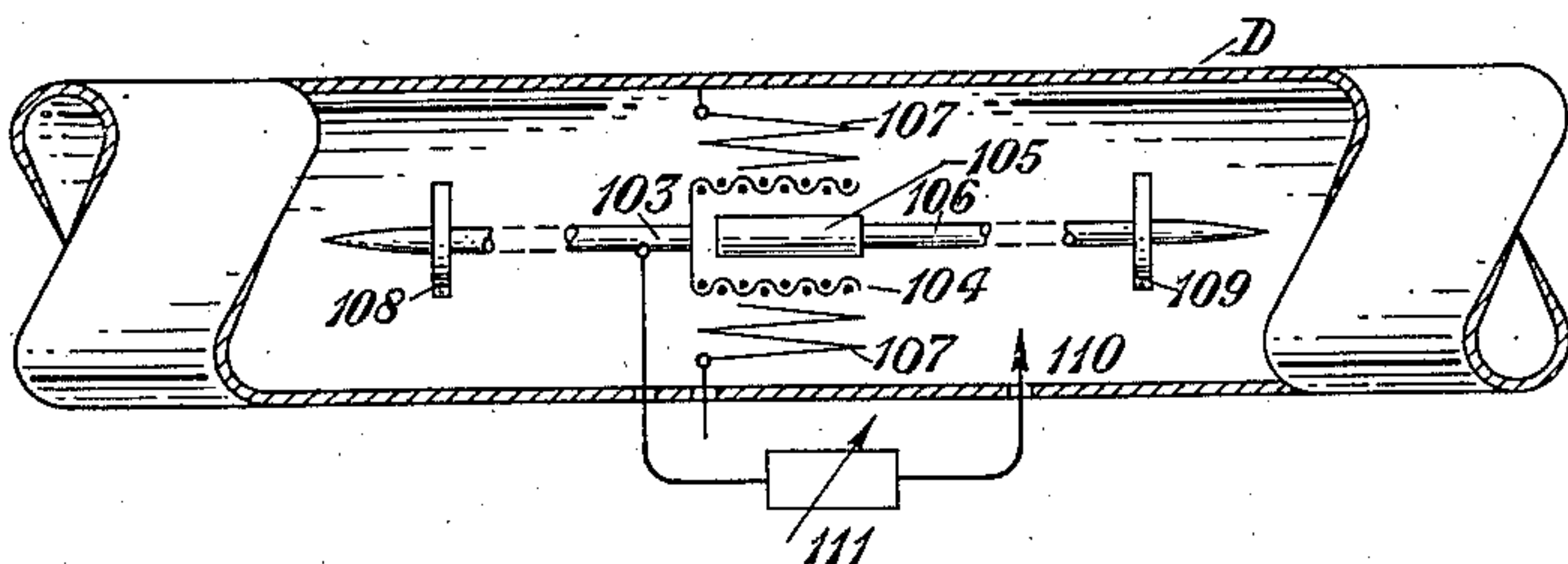


Fig. 36

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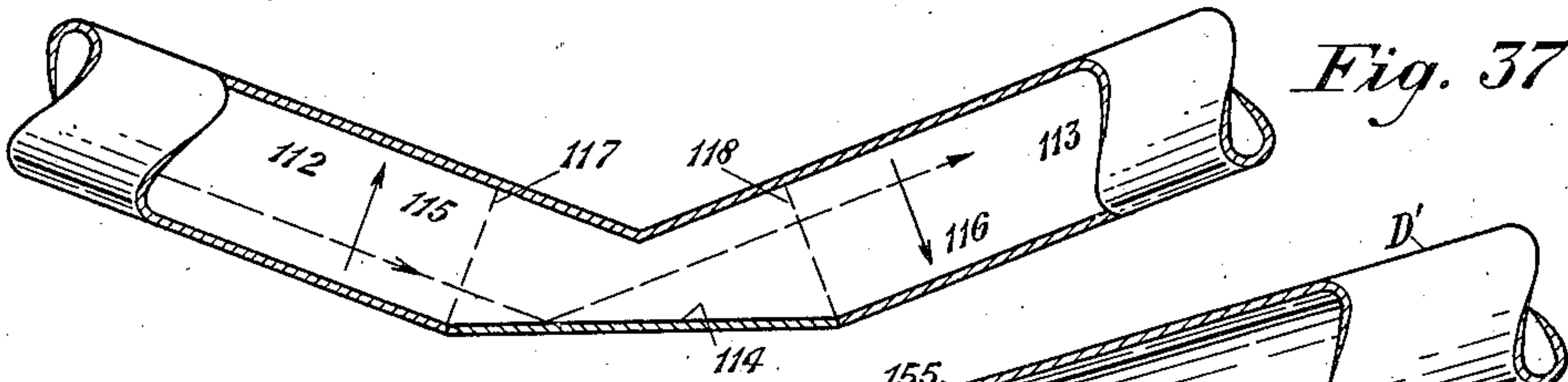


Fig. 37

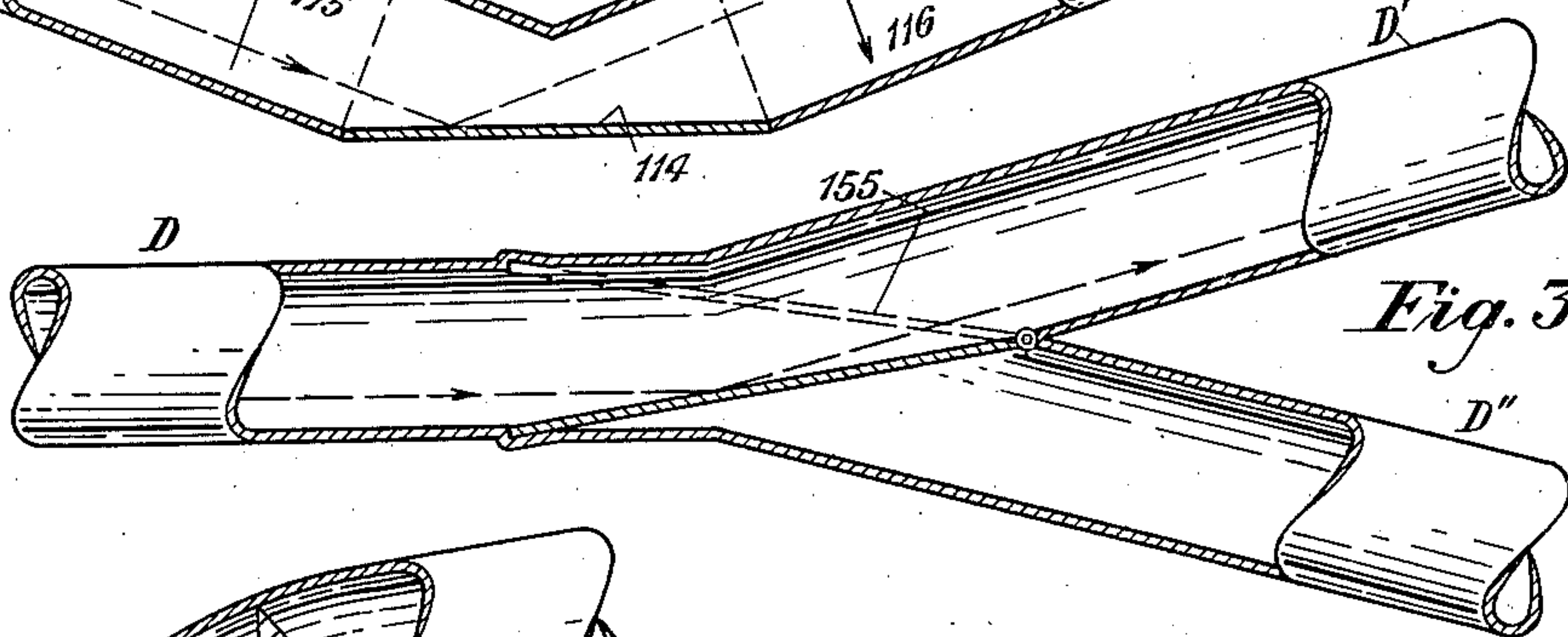


Fig. 37a

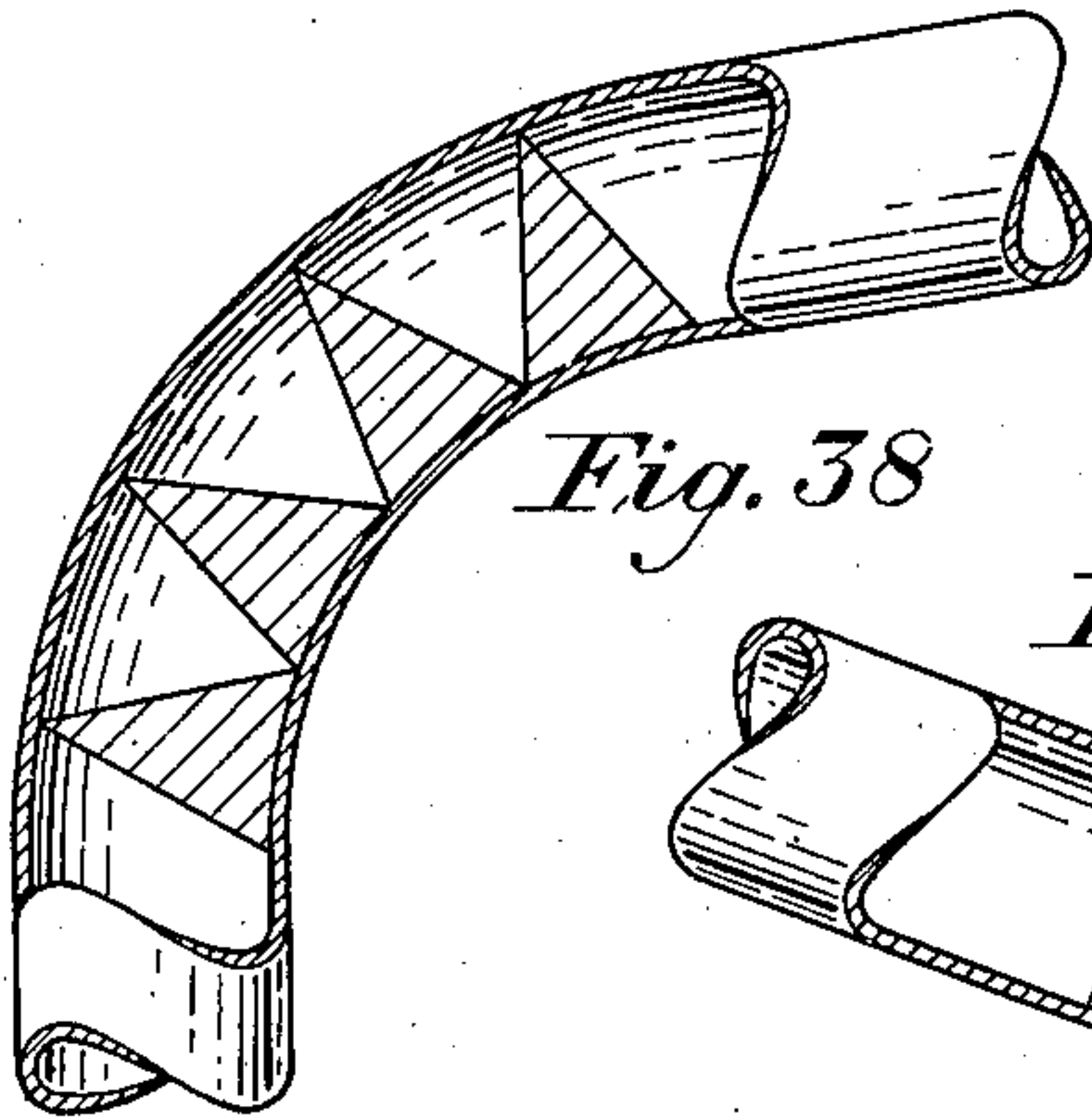


Fig. 38

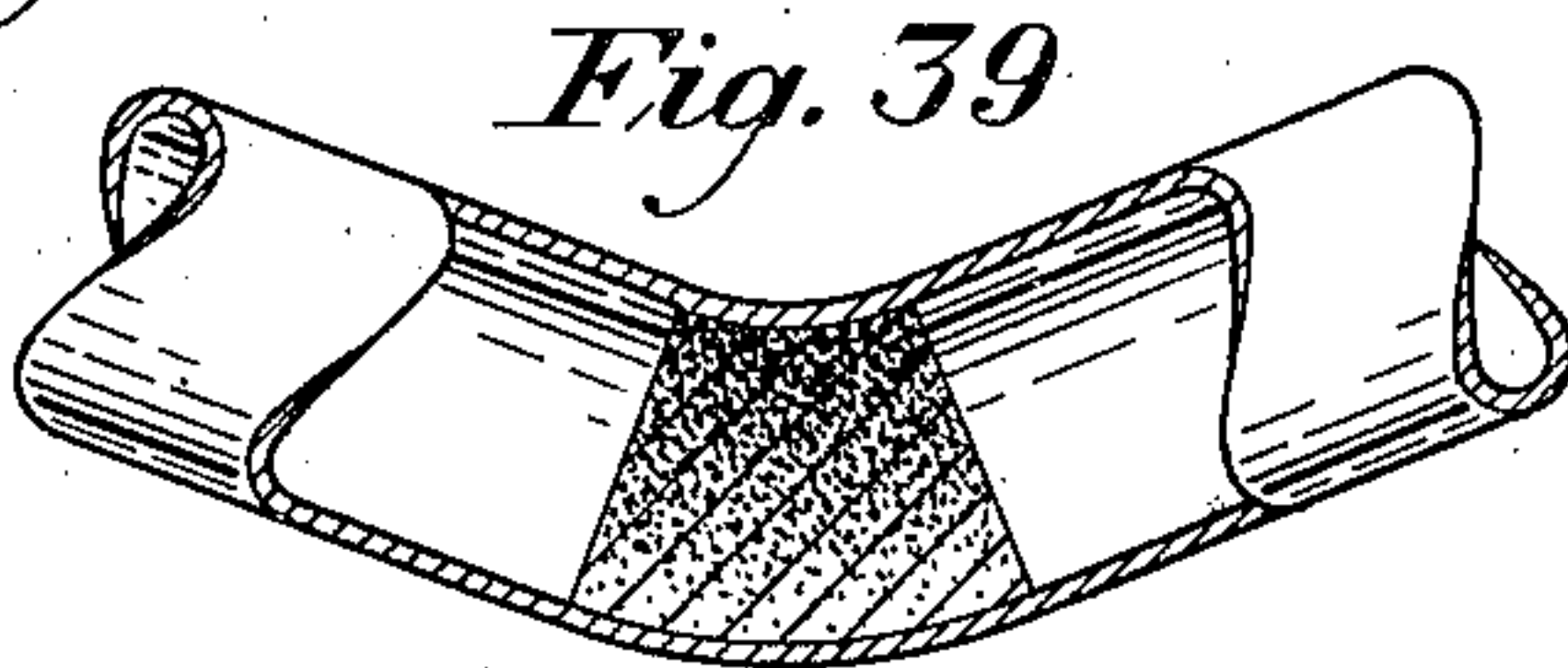


Fig. 39

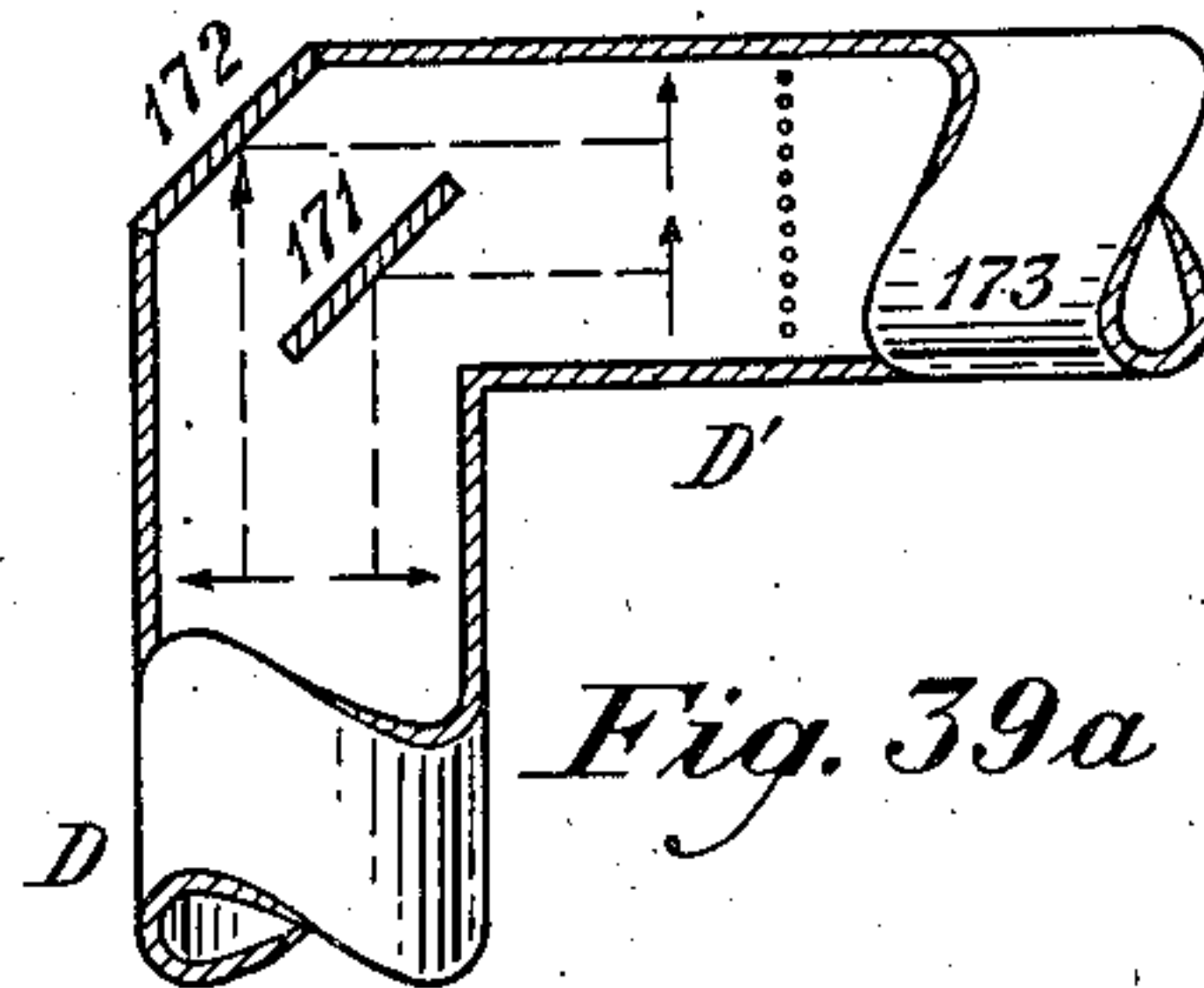


Fig. 39a

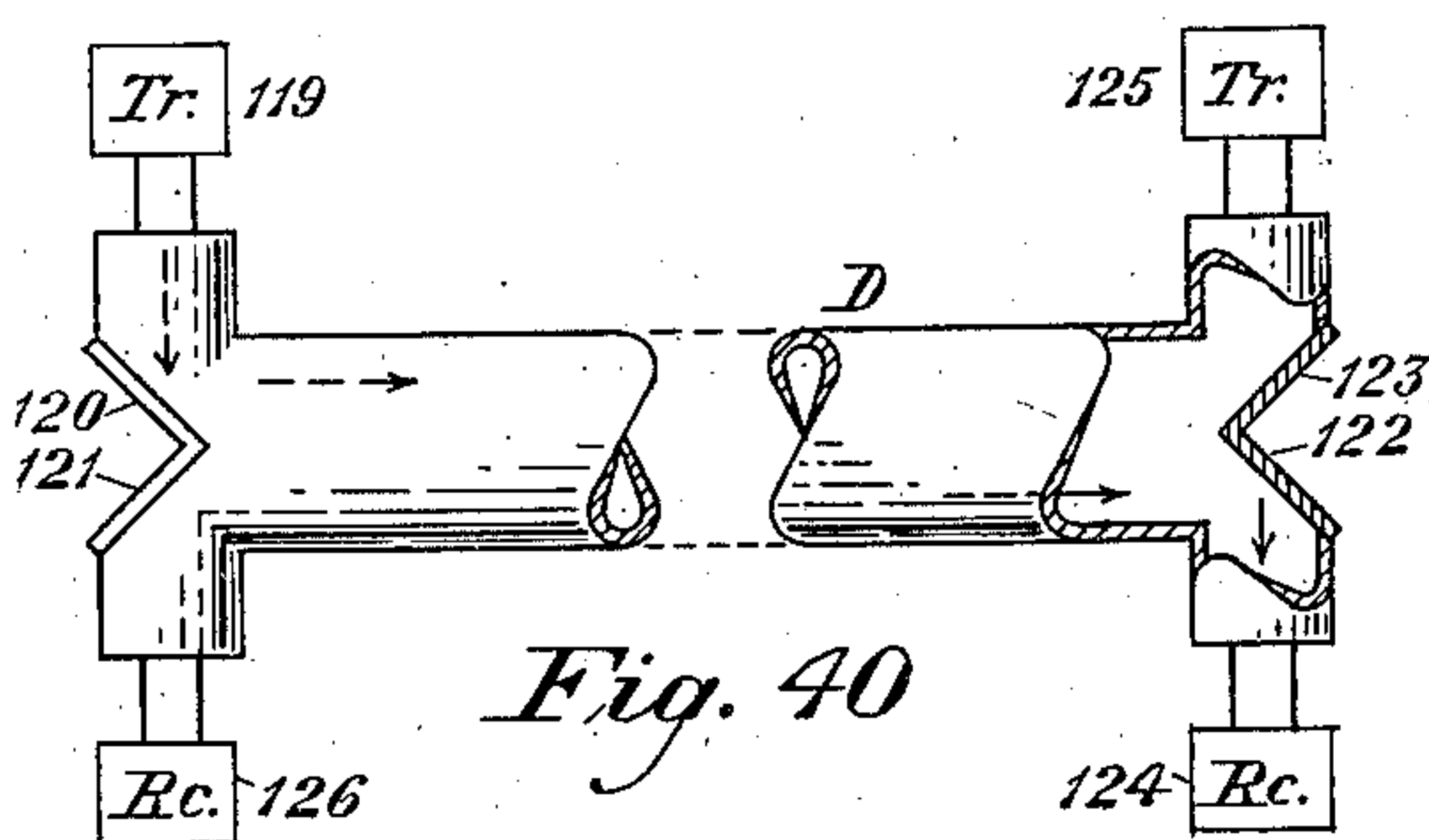


Fig. 40

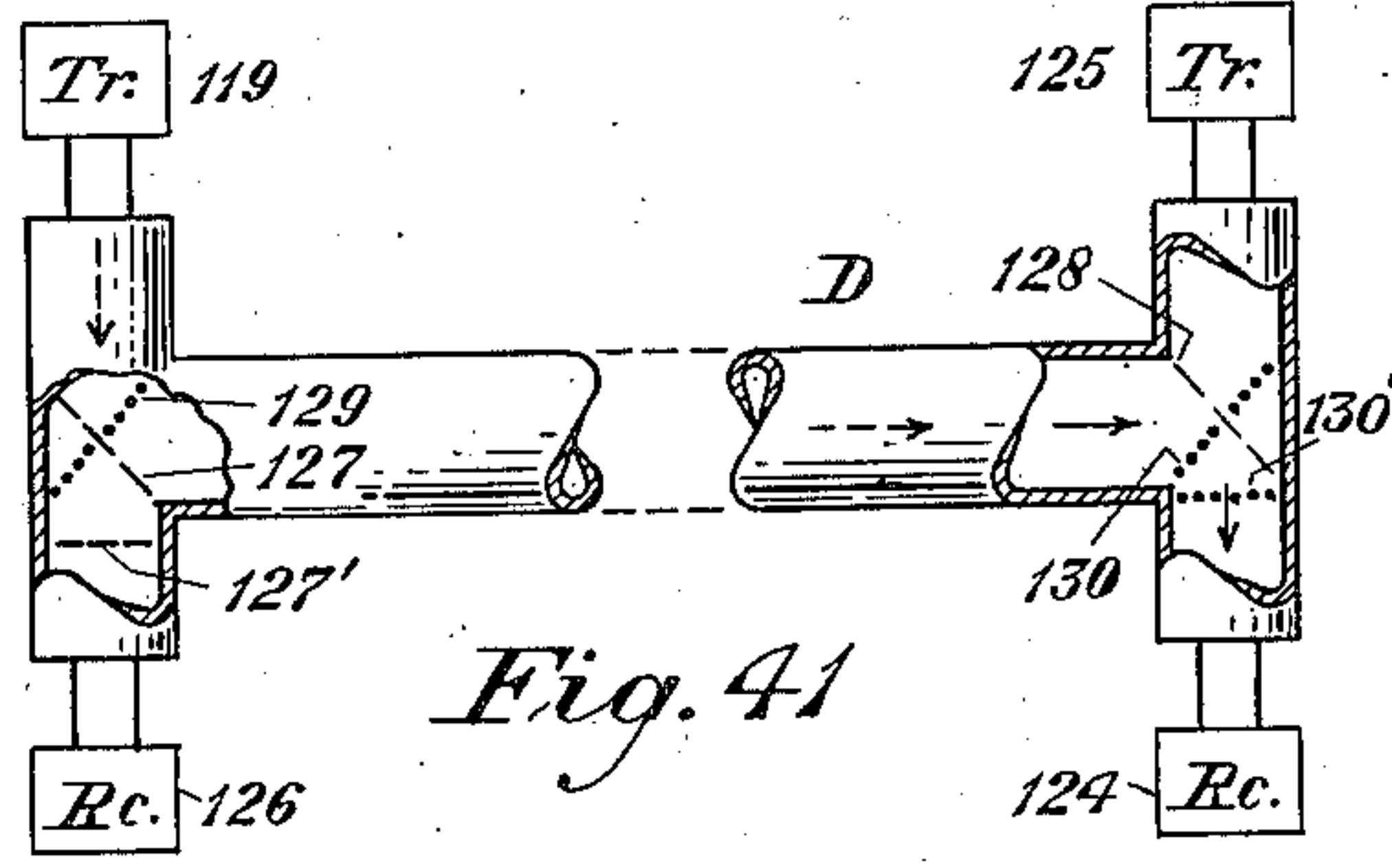


Fig. 41

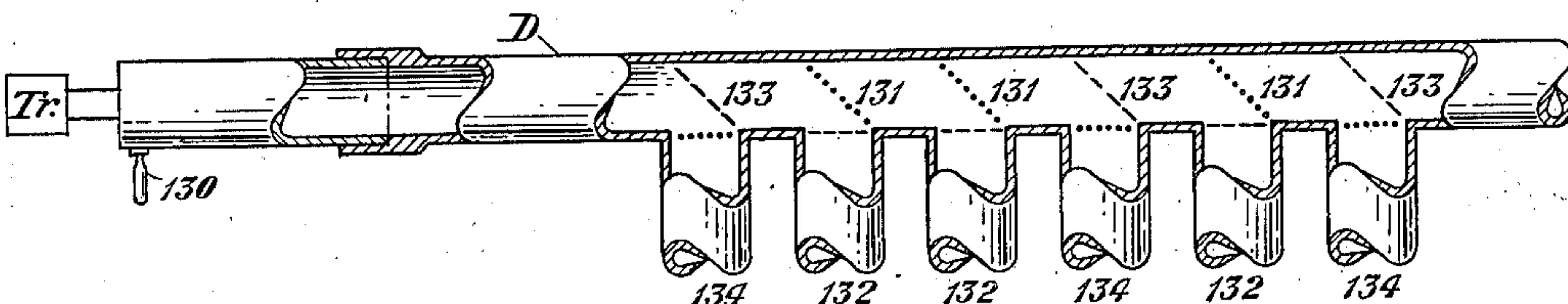


Fig. 42

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5 Sheets-Sheet 5

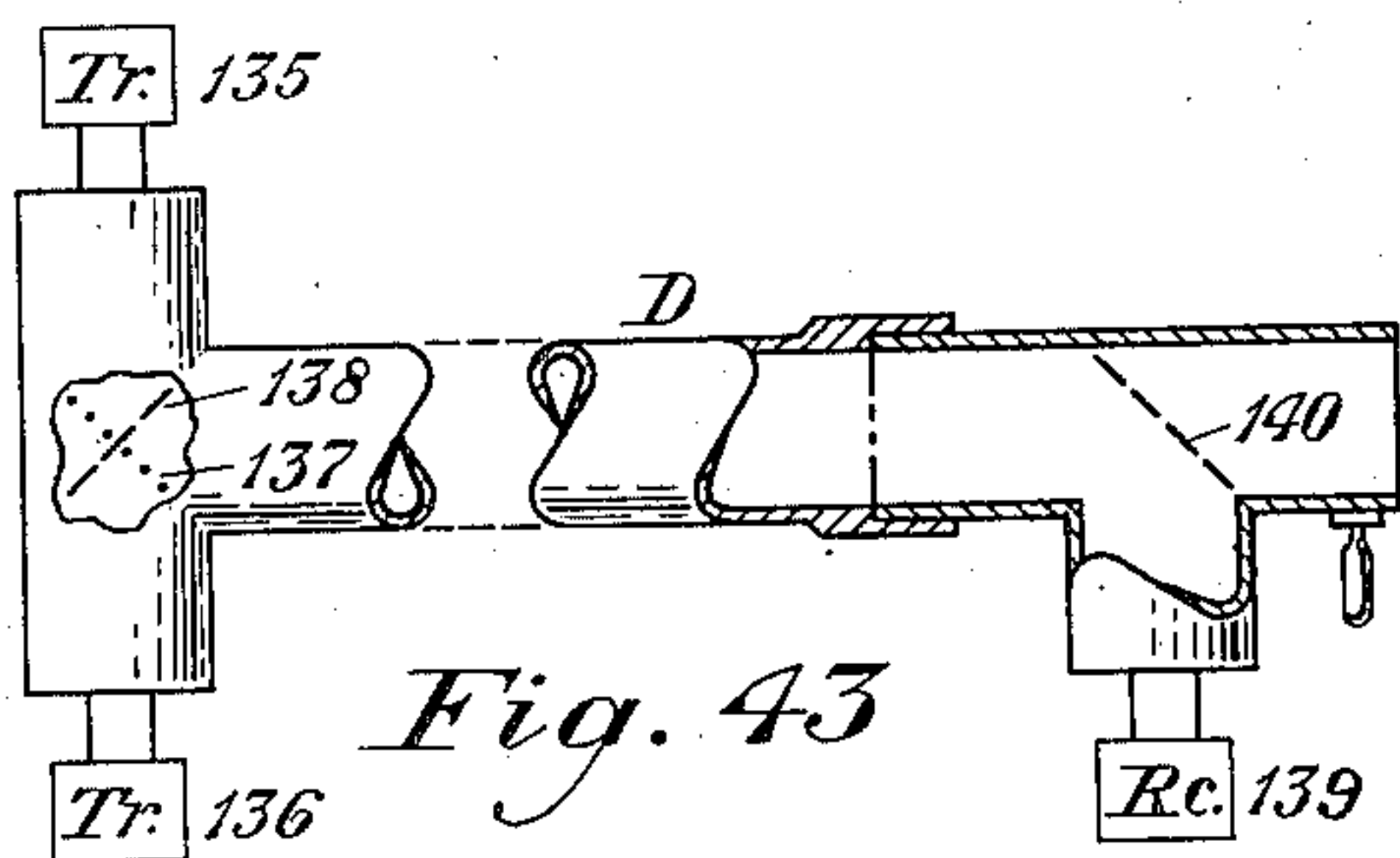


Fig. 43

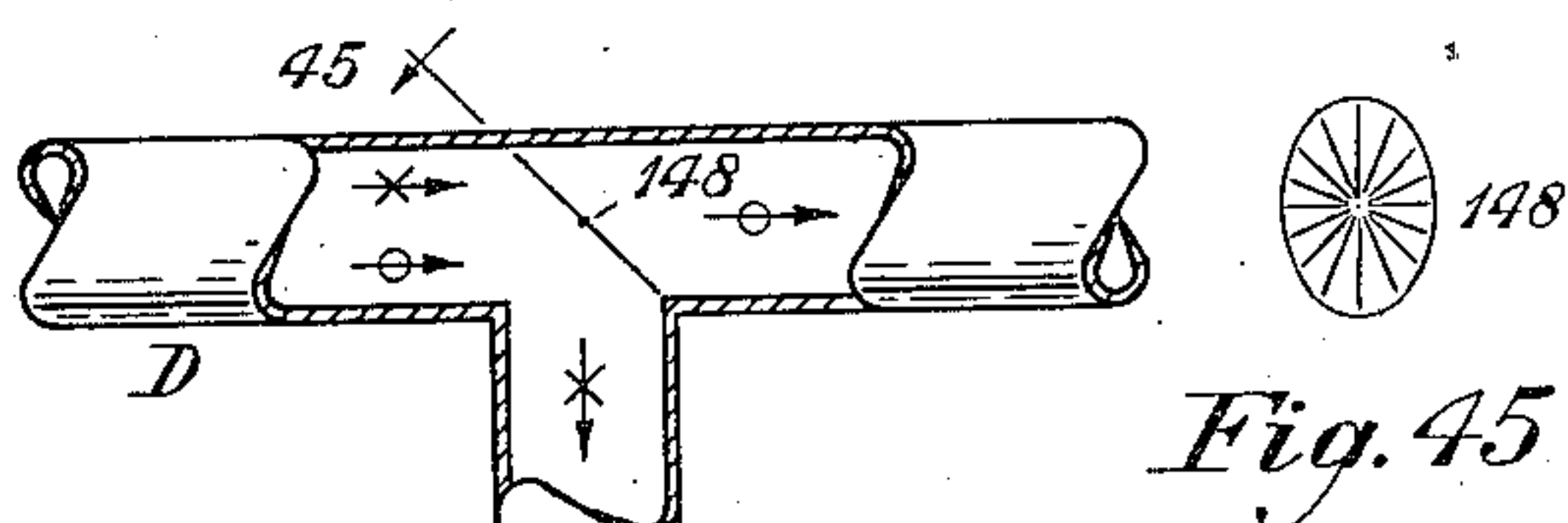


Fig. 45

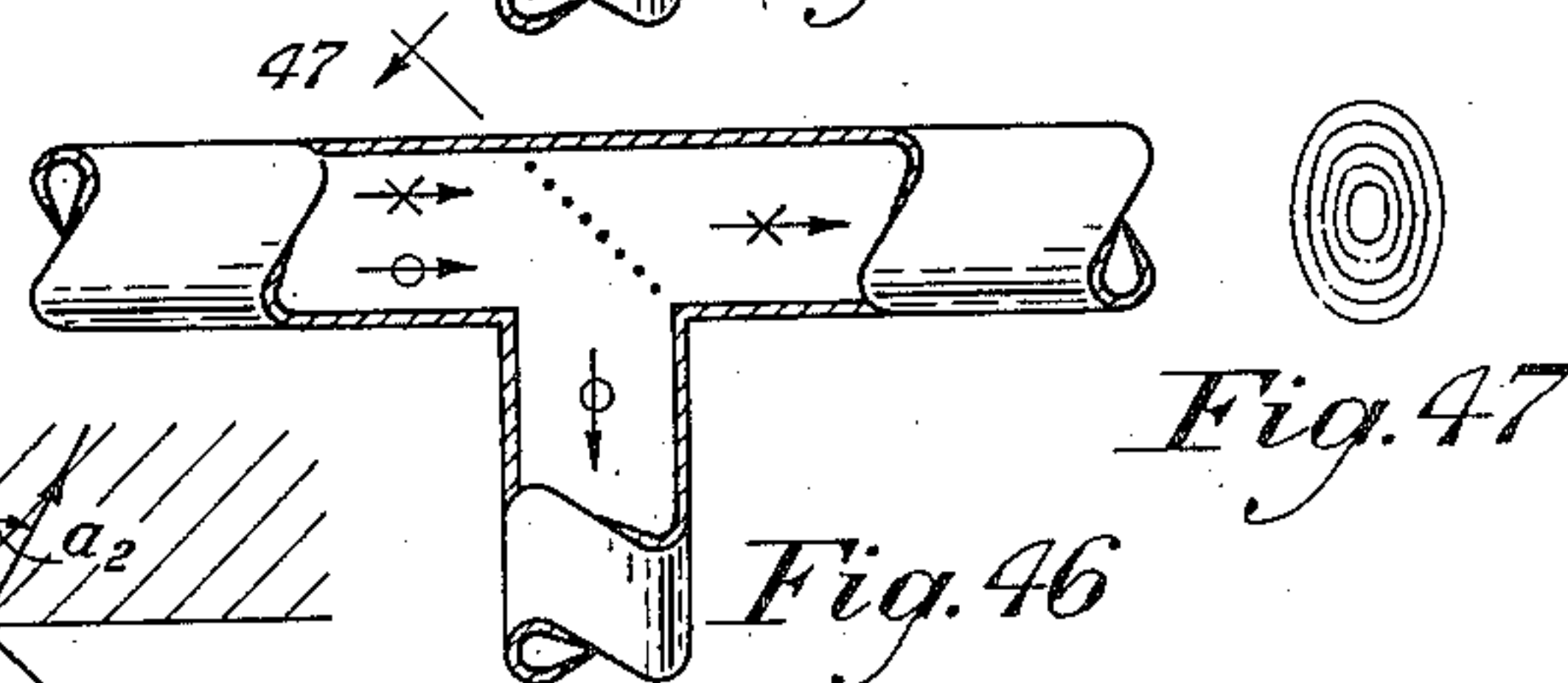


Fig. 47

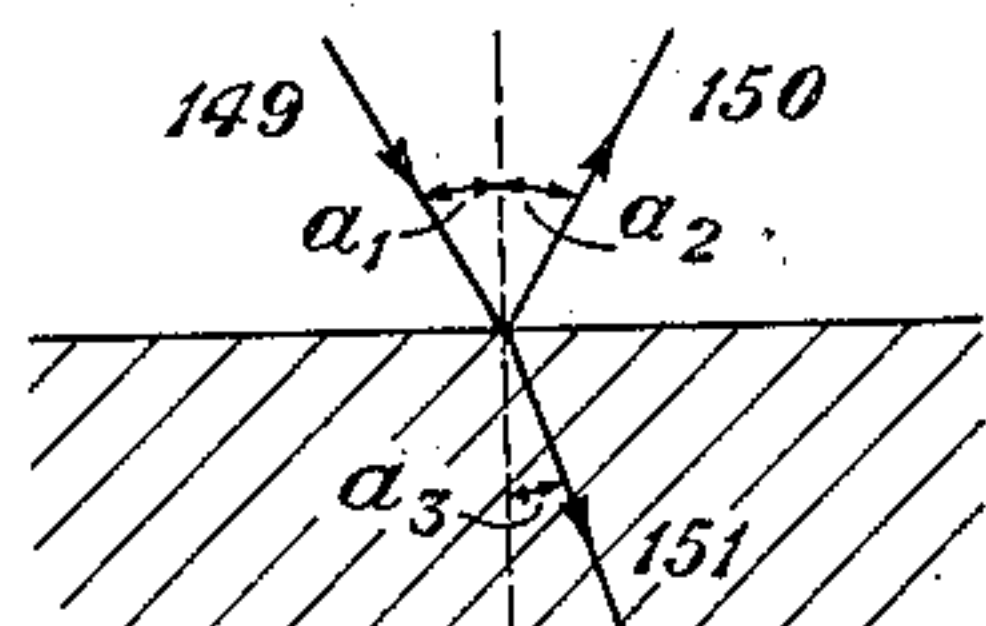


Fig. 48

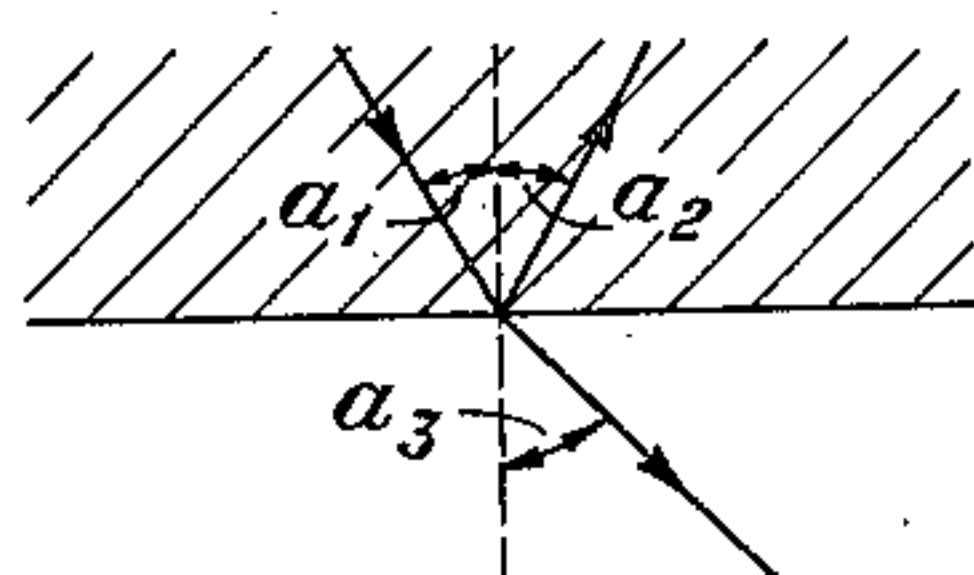


Fig. 49

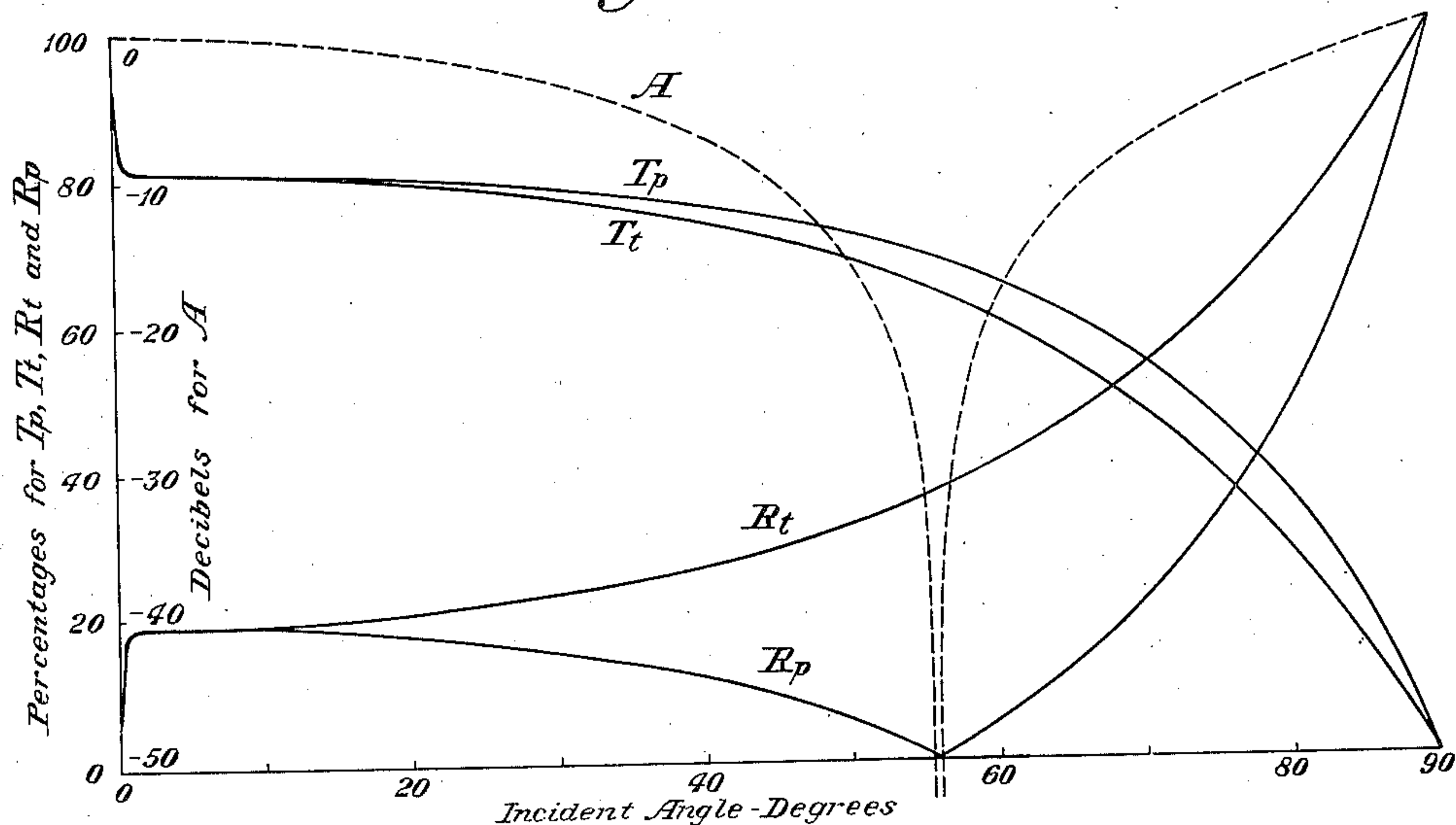


Fig. 50

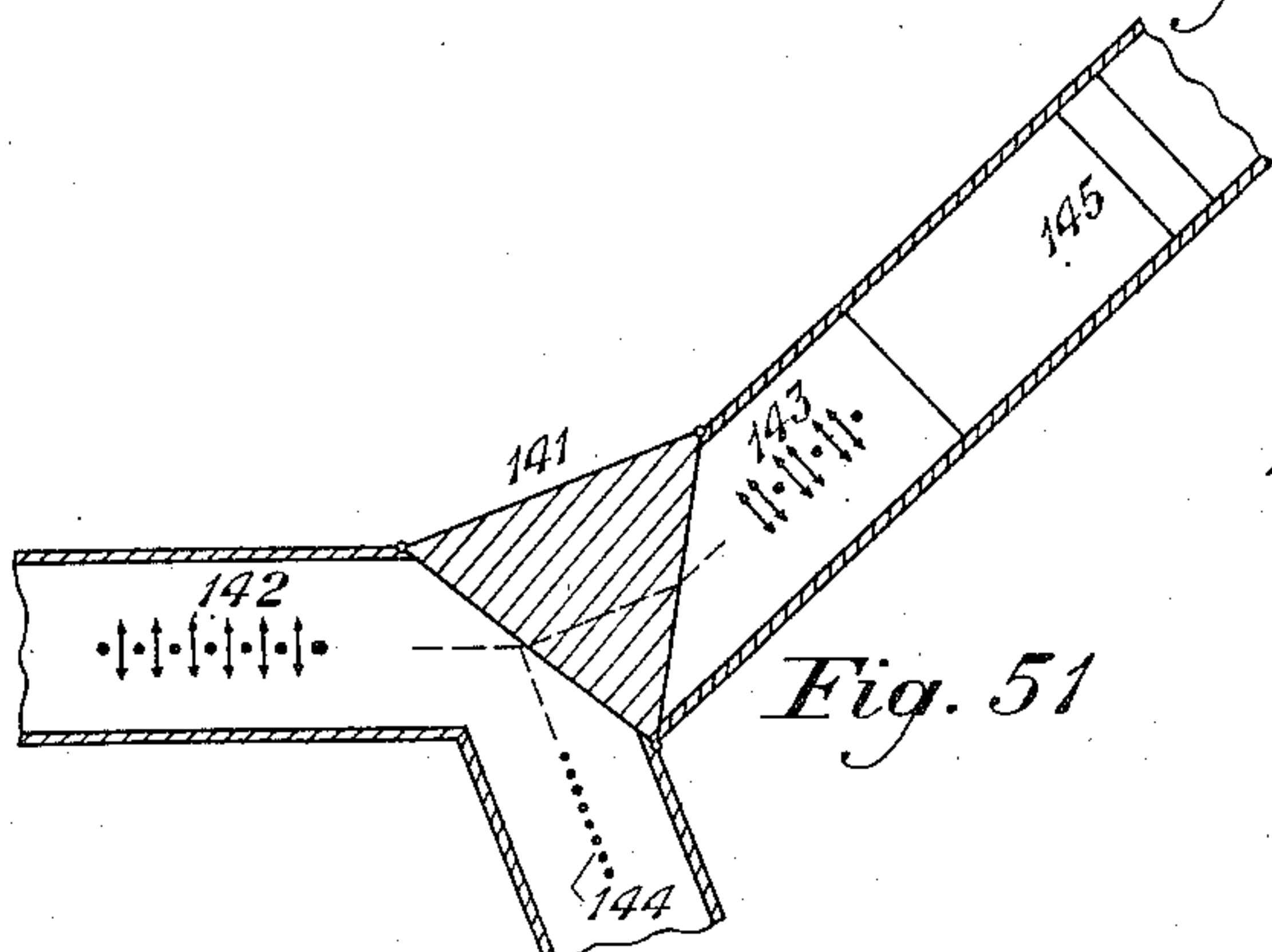


Fig. 51

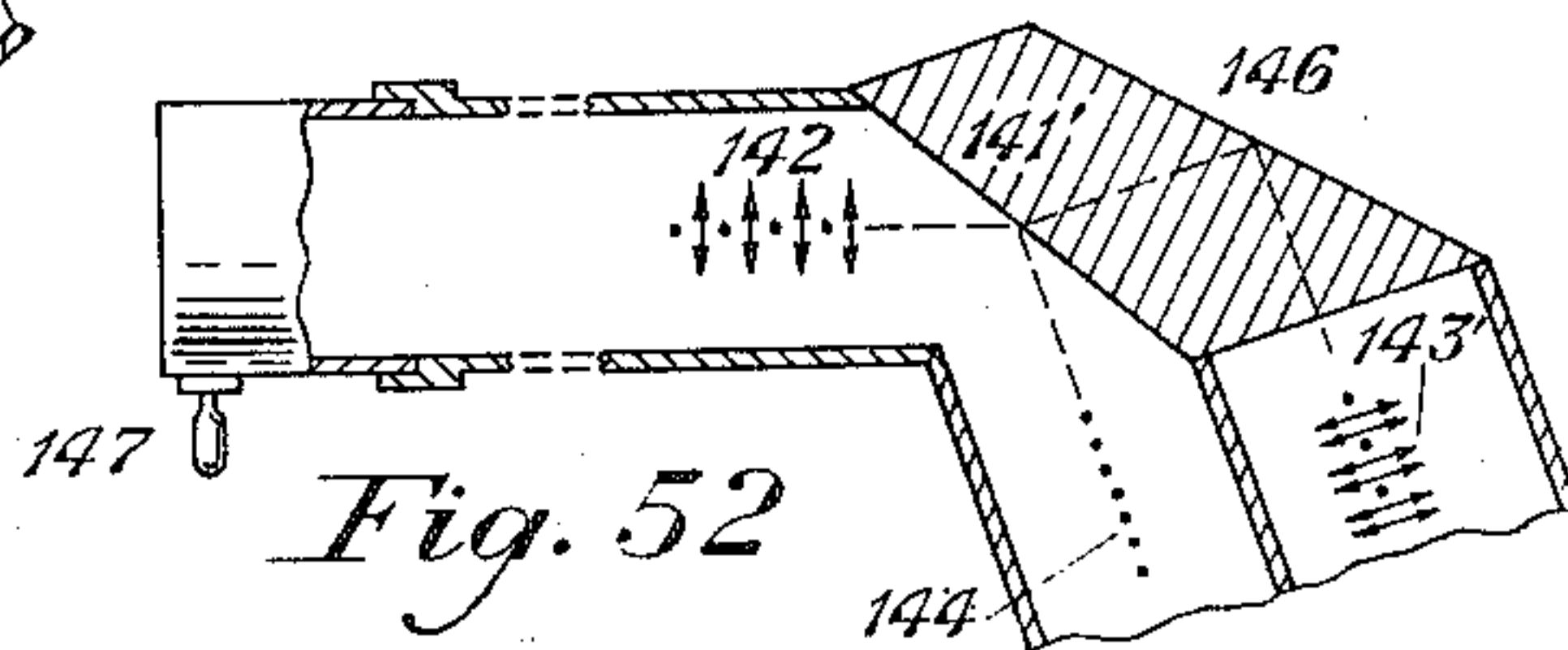


Fig. 52

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UNITED STATES PATENT OFFICE

2,129,712

TRANSMISSION OF ENERGY EFFECTS BY
GUIDED ELECTRIC WAVES IN A DIELEC-
TRIC MEDIUMGeorge C. Southworth, Ridgewood, N. J., assignor
to American Telephone and Telegraph Com-
pany, a corporation of New York

Application December 9, 1933, Serial No. 701,711

73 Claims. (Cl. 178—44)

An object of my invention is to provide a new and improved system and method for the transmission of electrical effects from one place to another place at a distance therefrom by means of electromagnetic waves in a restricted dielectric medium or guide extending between the two places. Another object of my invention is to provide for signaling along such a guide by means of such waves. Other objects are to provide for the generation of high frequency electric currents in a suitable medium in a local circuit at the transmitting end; to provide for the application of the energy of such currents to generate corresponding displacement currents to be transmitted as waves along a guide of dielectric material or medium; and to provide for translating the energy of the displacement currents at the receiving end into local circuit currents adapted to produce corresponding effects in suitable receiving apparatus. Another object is to transmit electrical effects along a dielectric guide within a sheath of conductive material.

All these objects and various 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 this specification. It will be understood that the following disclosure relates principally to these particular examples of the invention and certain scientific principles involved in its practice, and that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Figure 1 is a diagram showing a one-way dielectric wave guide with associated sending and receiving apparatus; Fig. 2 is a transverse section of such a wave guide; Figs. 3 and 4 show transverse sections of modified forms of wave guides; Fig. 5 is a curve diagram showing attenuation as a function of frequency for various types of waves and for different sizes of wave guides; Fig. 5a is a curve diagram showing wave length as a function of frequency for various types of waves; Figs. 6 and 6a are diagrammatic longitudinal and transverse sections showing the lines of electric and magnetic force for a certain type of wave designated E_0 ; Figs. 7, 7a, 8, 8a, 9 and 9a correspond to Figs. 6 and 6a but for other types of waves which are designated H_0 for Figs. 7 and 7a, E_1 for Figs. 8 and 8a, and H_1 for Figs. 9 and 9a; Fig. 9b shows the lines of electric force for a type H wave of higher order than H_1 ; Fig. 10 is a section of a guide at the sending end with an associated oscillation generator for sending type E_0 waves in the guide;

Figs. 11 and 12 are, respectively, transverse and longitudinal sections at the sending end of a guide for transmitting waves of type H_0 ; Fig. 13 is a transverse section of a guide at the sending end like Fig. 11 but with four quadrantal conductors instead of two semi-circular conductors as in Fig. 11; Fig. 14 is a transverse section at the sending end showing electrodes for sending E_1 type waves; Figs. 15 and 16 are, respectively, transverse and longitudinal sections at the sending end of a guide with apparatus for sending type H_1 waves; Figs. 17, 18 and 18a are, respectively, longitudinal and two transverse sections of a guide showing apparatus interposed therein to convert waves from type E_0 to type H_0 ; Figs. 19 and 20 to 20e are, respectively, a longitudinal section and a set of transverse sections of apparatus to be put in or across a guide for the conversion of type E_0 waves to type E_1 waves; Figs. 21 and 22 to 22e are, respectively, a longitudinal section and a set of transverse sections of a guide showing apparatus for converting type E_0 waves into type H_1 waves; Fig. 23 is a transverse section showing apparatus for converting type H_1 waves into type H_0 waves; Fig. 24 is a side elevation of a guide length for shifting the plane of polarization of an asymmetric wave through a certain angle; Fig. 25 is a diagram showing a guide and associated transmitting and receiving apparatus connected at points within the guide at optimum distances from its ends; Fig. 26 is a diagram showing one end of a guide like an end of Fig. 25 but with facility for adjusting the length of the end portion and with a reflector across the end; Fig. 27 shows a guide end and associated oscillation generator with means for selectively re-enforcing the oscillation frequency; Fig. 28 is a diagram of frequency multiplying apparatus to be used at the sending end of a guide; Fig. 29 is a diagram showing a frequency doubler at the sending end of a guide; Fig. 30 is a diagram showing an adjustable shutter for controlling the volume of transmission through a guide; Fig. 31 is a diagram of receiving end apparatus involving the use of a concave mirror and adapted for receiving type H_1 waves; Fig. 32 is a diagram of receiving apparatus adapted for E_0 waves; Fig. 33 is a diagram of receiving apparatus employing both a lens and a mirror for concentration of the wave energy in the receiver; Fig. 34 is a longitudinal section at the receiving end of the guide for practicing demodulation by the use of non-linear conductors; Fig. 35 is a transverse section corresponding to Fig. 34; Fig. 36 is a longitudinal sectional diagram of a guide showing an amplifier-

repeater interposed therein; Fig. 37 is a longitudinal section showing a reflector elbow interposed in a guide; Fig. 37a is a longitudinal section showing an adjustable reflector for sending waves from a main guide into either of two alternative branch guides; Fig. 38 is a section showing an elbow using refracting prisms; Fig. 39 is a section showing an elbow with refracting material of varying dielectric coefficient in its different parts; Fig. 39a is a section showing how wave conversion may be practiced by the use of reflectors in an elbow; Fig. 40 is a diagram of a system for simultaneous opposite-way transmission using reflectors; Fig. 41 is a diagram of a system for opposite-way transmission using polarized waves and suitably adapted reflectors; Fig. 42 is a diagram of a transmitting system adapted to be adjusted at the sending end to discriminate with respect to different receivers; Fig. 43 is a diagram of a system adapted to send on two channels with a receiver that can be selectively adjusted to receive on either channel; Figs. 44 and 45 are, respectively, a longitudinal section and a diagonal section of a guide adapted to separate the E_0 and H_0 components of a composite wave; Figs. 46 and 47 are, respectively, longitudinal and diagonal sections of modified apparatus to effect such a separation; Figs. 48 and 49 are diagrams to which reference will be made in explaining the reflection and refraction of dielectric waves at a boundary between two media of different dielectric coefficients; Fig. 50 is a curve diagram showing the magnitudes of transmitted and reflected rays for the two principal directions of polarity and at various angles of incidence; this figure also has a curve A showing the intensity at various angles of incidence of the reflected ray when the wave is polarized so that its lines of electric force lie parallel with the plane of incidence; Fig. 51 is a diagram showing how a separation of components of a wave according to their polarity may be made by reliance on the critical angle of reflection; and Fig. 52 is a diagram of a modified arrangement as compared with Fig. 51.

As set forth in my U. S. patent application, Serial No. 661,154, filed March 16, 1933, I have determined that under certain conditions electric waves may be transmitted a considerable distance along a dielectric guide consisting of a laterally bounded body of dielectric which may be bounded and enclosed by a sheath of conductive material, and that such waves may be utilized for signaling along the guide. In that application, of which the present application is in part a continuation, I have indicated how a dielectric guide may be used for television transmitting and for other purposes.

A system for signaling along a dielectric guide is represented diagrammatically in Fig. 1. Certain elements of apparatus are represented symbolically in this figure as by "boxes," but in some cases these may be broken apart into distinct elements, or may be consolidated with others. In Fig. 1 high frequency electric currents are generated in the generator G and passed along the conductor pair 31 so that their electromotive force is applied across the two points 32 and 33. Signaling currents of lower frequency are generated in the signal sending apparatus S and applied through the conductor pair 30 to the generator G to modulate its high frequency output. The generator G may, accordingly, be described more specifically as a combined generator and modulator, and the current in its output circuit 31 is a modulated high frequency current.

The guide D is a long cylindrical copper shell containing a suitable dielectric material which may be air or practically empty space, the dielectric coefficient in this case being approximately unity. If a higher coefficient than unity is desired, the shell D may be filled with a suitable substance such as camphor of coefficient about 10, or monochloro-benzene of coefficient about 5.4. The two conductors 31 are connected to the diametrically opposite points 32 and 33 at the end of this copper shell D.

At the receiving end on the right, the conductors 31' of a receiving circuit are connected to the diametrically opposite points 32' and 33' of the copper shell D. The two diameters 32—33 and 32'—33' are parallel. This receiving circuit 31' comprises the unilateral device or asymmetric resistance M. In shunt to this is a signal indicating device or receiver S'.

The output currents in the conductors 31 from the generator G must be of high enough frequency so that the corresponding waves will be transmitted in the dielectric within the guide D, at the diameter chosen for its enveloping copper shell. Although there is a conductive connection through the copper shell between the points 32 and 33 in Fig. 1, the alternations of the current in the conductor 31 are so rapid that lines of electric force of substantial intensity extend across directly in the dielectric between points adjacent to 32 and points adjacent to 33. These lines of force are whipped off and radiated, partly spreading out to the left and partly proceeding to the right in the dielectric medium within the copper shell D, this medium being air (equivalent to empty space) in the case more particularly assumed for the present exposition. Thus, the lines of electric force of the wave transmitted along the guide D from left to right lie in a plane containing the axis of the guide and the two points 32 and 33 and in planes parallel to that plane. The waves consisting of such lines of force arrive at the receiving end on the right of Fig. 1, and generate a corresponding electromotive force across the terminals 32' and 33' of the receiving circuit 31' which comprises the asymmetric resistance M. Accordingly, the alternate half waves of the conduction currents in these conductors 31' are shunted and integrated in their effect in the signal receiving apparatus S' which thereby manifests the signals that correspond to the signals impressed from the apparatus S at the sending end.

The guide D having a circular cross section of given diameter, there will be a certain critical frequency such that only those waves having higher frequencies will be transmitted. If a guide were to be employed having an elliptical cross section with its major diameter equal to that of the guide D, this critical frequency would be about the same. Therefore, if desired, a guide of elliptical cross section may be employed that will have less internal volume and less superficial area than the guide D and yet will carry waves up to as long a wave length. This is indicated in a comparison of Figs. 2 and 3. Similarly, if desired, the guide may be of rectangular cross section with its limiting wave length determined by the longer dimension, as indicated in Fig. 4. The minor diameter of the ellipse or the shorter side of the rectangle should not be too much reduced, for that would cut down the power too much.

The attenuation values at various frequencies and for several different diameters of the guide

have been computed and I have plotted some of the results logarithmically in Fig. 5. Different types of waves are represented in this figure, as will be explained later in this specification. For the present, attention is directed to the curve marked H_1 . This shows the relation of attenuation and frequency in a five-inch copper-shell air-core guide for waves of the type heretofore considered, having their lines of electric force in and approximately parallel with a single plane containing the axis of the guide. More particularly, in this case the plane referred to contains the two points 32 and 33 in Fig. 1. As indicated by the curve H_1 , waves having a frequency less than about 1,400 megacycles per second will not be transmitted in the wave guide D, which, therefore, functions as a high-pass filter in this respect. The same curve H_1 in Fig. 5 shows that for a frequency of 1,750 mc. the attenuation will be about 10.5 decibels per mile. If the frequency is 2,000 mc. the attenuation will be about 8.2 db. per mile. An overall attenuation from the transmitting end to the receiving end may properly be as much as 40 db. Accordingly, within this limit of attenuation the guide D may be about 4 miles long for a frequency of 1,750 mc., and about 5 miles long for a frequency of 2,000 mc. If the distance to which transmission is to be effected is greater than 4 or 5 miles, one or more repeaters may be interposed in the line. If it is desired to transmit over a greater distance between terminals or between repeater stations, the diameter of the guide can be increased, or the frequency increased, or both. For example, if we assume the guide to be of diameter 8 inches and the frequency to be 2,500 mc., then as shown by the curve H_1' in Fig. 5, the attenuation will be about 2.7 db. per mile. Let us also assume in this case that an overall attenuation of 75 db. is permissible from end to end of the stretch between terminals or between repeater stations, if there are repeaters. Dividing 75 by 2.7 we get about 28 miles for the length of the stretch.

In a demonstration model of this system of communication I used a guide consisting of an air-core pipe 875 feet in length and 5 inches in diameter made from sheet copper 0.022 inch thick. I operated the system comprising this pipe at a frequency of about 1,600 mc., which corresponds to a wave length in free space of about 18.75 centimeters. The wave length while propagated within the guide was ascertained by reflection and development of standing waves within the guide. By measurement of such standing waves, the wave length was found to be about 28 cm., and the attenuation from the transmitting end to the receiving end was about 2 db. In this case I received speech of good volume and quality without any amplification at the receiving end. According to my calculations, if the frequency had been increased to 4,500 mc., the attenuation would have been decreased to less than 1 db.

The energy of the transmitted waves in such a guide may be regarded as residing principally in the dielectric medium within the guide, and only in small part in the conductor shell. The currents flowing in the shell are limited to an extremely thin layer on its interior. Consequently, it is not necessary that the walls of the guide should be made thick except to a degree that will provide the proper mechanical strength. Hence, the pipe may be made of any relatively cheap and rugged material such as iron or steel, and coated on the interior with a thin layer of copper

or silver. The pipe need not be of metal but may be of insulating material with an inside coating of metal. If the pipe is of iron or steel, then after it has been constructed and laid, it may be filled with a solution of copper sulphate, and this may be left long enough to establish a copper coating on the inner wall of the pipe, then drawn off, and the inside copper coating will afford the desired conductivity. Or, the coating may be applied to the pipe sections by electrodeposition. While it is desirable that the inside conductive face of the shell shall be smooth and continuous, especially in a direction parallel to the planes containing the lines of electric force, occasional slip joints to take up thermal expansion will not be objectionable, provided there is a considerable overlap between consecutive sections.

When of sheet copper, the guide may conveniently be constructed in the field by providing long strips of sheet copper of a width equal approximately to the circumference of the guide, and in rolls for convenient transportation. This sheet copper may be unrolled on the ground and surrounded by a suitable die. As the die is moved forward the sheet will be brought to cylindrical pipe shape and the meeting edges will be beaded and soldered; thus the pipe may be constructed in situ by a continuous progressive process.

In the foregoing exposition in connection with Fig. 1, I have assumed the type of electromagnetic waves in which the lines of magnetic force lie along and approximately parallel with a single plane containing the axis. This type of wave is only one of several that may be considered. Certain principal types of waves are shown in Figs. 6 and 6a to 9 and 9a, in which full lines represent lines of electric force and dotted lines represent lines of magnetic force. It will be understood that lines of electric force in the dielectric core represent "displacement currents" but when they are continued in the conductive shell they represent conduction currents. At the high frequencies considered, both electric and magnetic lines in the shell will lie very close to its inner surface, but in Figs. 6 to 9a, for the sake of clearness, the shell has been shown thick and these lines are spaced from its inner surface.

The different types of waves shown in Figs. 6 to 9a may be named as follows:

1. Symmetric electric, abbreviated E_0 . Here all the components of the lines of electric force are radial and/or longitudinal, and the lines of magnetic force are transverse circles centered on the axis, as shown in Figs. 6 and 6a.

2. Symmetric magnetic, abbreviated H_0 . Compared with the E_0 waves, the electric and magnetic lines are interchanged in the H_0 waves, as shown in Figs. 7 and 7a.

3. Asymmetric electric, abbreviated E_1 . Here the lines of electric force lie in a plane containing the axis and approximately in planes parallel to that plane, and the lines of magnetic force lie in planes transverse to the axis, as shown in Figs. 8 and 8a.

4. Asymmetric magnetic, abbreviated H_1 . Compared with the E_1 waves, the electric and magnetic lines are interchanged in the H_1 waves, as shown in Figs. 9 and 9a.

The limiting values of the frequencies that will be transmitted in a guide may be different for the different types of waves. Referring to Fig. 5, which has been mentioned heretofore, all the curves in this figure except the curve marked H_1' are for a 5-inch guide. It will be seen that for

the 5-inch guide the cut-off frequency for asymmetric magnetic waves (H_1) is about 1,400 mc., for symmetric electric waves (E_0) about 1,800 mc., and for symmetric magnetic waves (H_0) and asymmetric electric waves (E_1) alike, it is about 3,000 mc. Stated qualitatively, the longest waves that can be passed in a guide of given diameter are of the asymmetric magnetic type (H_1), and if symmetric magnetic waves (H_0) or asymmetric electric waves (E_1) are employed, they must be reduced in length to less than half.

The curve H_1' in Fig. 5 is for the same type of wave as the curve H_1 , namely a wave of the asymmetric magnetic type, but curve H_1' is for a guide of diameter 8 inches whereas H_1 is for a guide of diameter 5 inches. In general, for any given type of wave, increasing the diameter of the guide will have the effect shown by comparing curve H_1' with curve H_1 ; that is, there will be an increase in the limiting wave length that will be passed by the guide and there will be a decrease of attenuation at a given frequency lying above both critical frequencies. Another way of stating the effect of increasing the diameter of the guide is to say that it produces little or no change of shape of the attenuation-frequency curve, and that curve is displaced down and to the left, as may be seen in the transition from H_1 to H_1' in Fig. 5. On the other hand, for a given frequency, by decreasing the diameter of the guide, a critical diameter will be reached at which transmission through the guide will cease for that frequency.

The types of waves E_0 , E_1 and H_1 all have minima of attenuation at certain frequencies, as shown by the curves of Fig. 5. That is, from the critical frequency up to a certain frequency value, the attenuation decreases to a minimum, and then above that frequency value the attenuation increases above that minimum value. But the type of wave H_0 is distinguished from the others in that at all frequencies above the critical frequency the attenuation decreases as the frequency increases. This advantage may be somewhat impaired by the necessity for a higher frequency to get above the critical frequency in a guide of given diameter.

The different types of waves involved in Fig. 5 can be produced experimentally and identified by the well-known practice of developing standing waves by reflection. It was by such means that I found a wave length of 28 cm. at 1,600 mc. as mentioned earlier in this specification in connection with my 875-foot 5-inch copper-shell air-core guide. In general knowing the dimensions and the dielectric constant of the core of the guide, the wave length may be computed as a function of frequency for each type of wave. These results are plotted in the continuous line curves of Fig. 5a, for which the guide diameter was taken to be 10 inches and the dielectric coefficient of the core was taken at the value 81, which is about the value for water. The wave lengths are expressed as ratios, compared with the wave lengths in free space. I have measured these wave lengths at various frequencies experimentally and plotted the values in Fig. 5a as shown by the indicated points.

The circumference C of a metallic shell guide is rather simply related to the longest wave length λ_c which may be propagated through it. More particularly, the two symmetric waves have a relation which involves the first root and the first maximum of the Bessel function of zero order whereas the asymmetric waves have a relation which similarly involves the first maximum and

first root of the Bessel function of the first order. For the symmetric electric wave the critical wave length is specified by $J_0(C/\lambda_c) = 0$. Thus occurs when $C/\lambda_c = 2.4$. This means that at the critical wave length the circumference of the guide must be 2.4 wave lengths. In a similar way we may show that for the symmetric magnetic wave the circumference must be 3.83 wave lengths and for the asymmetric magnetic and asymmetric electric waves it must be, respectively, 1.84 wave lengths and 3.83 wave lengths.

It will now be explained briefly how these various types of waves may be generated.

To generate the E_0 waves of Figs. 6 and 6a, the apparatus of Fig. 10 may be employed. A high frequency oscillation generator tube is placed coaxially in the guide with its filament-cathode 34 at the center surrounded by the grid 35. Outside this and closely adjacent within the shell D is the cylindrical plate-anode 36. The cathode heating circuit comprises the conductors 34', and the grid lead is 35'. The projecting electrode 37 is connected to the grid 35 and carries a telescopically adjustable extension 37' which in turn carries a transverse disk 37''. By adjusting this disk 37'' as to its size and its position on member 37', and adjusting the latter on member 37, the proper coupling and degree of impedance match may be attained and the frequency and wave length can be adjusted within a certain range. The tube as a whole can be adjusted along the pipe D and can be entirely withdrawn when desired.

To generate the H_0 waves of Figs. 7 and 7a, the apparatus of Figs. 11 and 12 may be employed. At or within the end of the guide D and lying in a transverse plane is the figure 8-shaped conductor frame that comprises the semicircular parts 40 and the crossed diametral parts 41 and 42. The outer shell 43 of a concentric conductor system is connected with the front diametral member 41 and the corresponding axial conductor 44 goes through a hole in the member 41 and is connected with the back diametral member 42. If the shell 43 is positive and the axial conductor 44 is negative, the currents in the semi-circular member 40 will flow in multiple in the same direction around the axis of the guide, as shown by the arrows 45. Lines of electric force will extend within the guide D from high potential points of members 40 to low potential points thereof, and at high frequencies these will whip off and link together to form continuous detached circumferential lines of force as shown by the full lines of Figs. 7 and 7a, and these will be propagated as waves through the guide.

It may be desirable to have a greater number of circumferential elements than the two that are shown at 40 in Figs. 11 and 12. Four are shown diagrammatically in Fig. 13. The supply current is applied across the points 43' and 44' and it will branch to the four quadrantal elements 40' in multiple and flow in like direction in them around the axis of the guide, as indicated by the arrows 45'.

The E_1 waves of Figs. 8 and 8a may be generated by means of the apparatus of Fig. 14. Looking into the open end of the guide D one sees the two opposite electrodes 46, between which the lines of electric force extend as shown. With a high frequency electromotive force applied through the conductors 47, these lines will be detached in closed loops and sent in waves along the interior of the guide, these waves having the configuration shown in Figs. 8 and 8a.

The H_1 waves of Figs. 9 and 9a may be gener-

ated as has been shown in Fig. 1 by connecting the terminals of the conductors 31 with the points 32 and 33 at the opposite ends of a diameter of the guide. A suitable connection of the generator G with the guide walls is shown more in detail in Figs. 15 and 16. The generator G is mounted centrally and so that it can be rotated about the guide axis. It carries the fan-shaped conductors 48 which have sliding contact engagement with the stationary fan-shaped conductors 49, which in turn are bent L-shape with the parts 50 spaced slightly from the inner face of the guide wall. Thus the circuit of the generator G is completed through two condensers in each of which one plate is 50 and the opposite plate is the neighboring wall of the guide D; and thus the output circuit of the generator G is blocked to direct currents, but passes high frequency alternating currents. By rotating the generator G about the guide axis the effective width of the conductors 48—49 may be varied and thereby a proper impedance match may be attained.

Of the various types of waves that may be sent along a dielectric guide, there are many that may be regarded as being higher orders of those shown in Figs. 6 to 9a. Fig. 9b compared with Fig. 9a illustrates this statement. In Fig. 9b the lines of electric force are shown for second order asymmetric magnetic waves as compared with such waves of first order in Fig. 9a.

Waves of one type may be converted to another type. From any one to another of the four types of Figs. 6 to 9a, there are twelve possible cases. Any conversion will be reversible in an obvious manner. Of the twelve possible cases, six are reverses of the other six. A few illustrative examples will be shown.

From E_0 to H_0 .—The apparatus shown in Figs. 17 and 18 is interposed in the guide. This consists of an axial conductor 51 of limited length terminated at one end by two opposite radial arms 52 each prolonged in a circumferential part 53 extending about half way around the guide and connected at its end 54 with the guide wall. The E_0 waves coming from the left will first have their radial lines of electric force tied between the axial conductor 51 and the wall of the guide D. Then these will be deflected by the extensions 52—53 and radiated on to the right in the form of H_0 waves. The sieve of radial wires 54' blocks any remnant of the E_0 waves and passes only the H_0 waves.

From E_0 to E_1 .—The apparatus shown in Figs. 19 and 20 to 20e is interposed in the guide. Beginning at 55 and continuing at 55' the metallic guide shell D is bevelled to a kidney-shaped conductor at 56. There is a conductive core 57 that is coaxial with the shell D at its complete part on the left, but as this core extends it is bent off at 57', and is also made kidney-shaped so that at 58 it is opposite the part 56 and is of similar shape. The cylinder D in addition to merging into the conductor 56 also expands as a cone into a complete shell at the right. The radial lines of electric force of the E_0 waves coming from the left have their respective ends tied to the shell D and the core 57; then they are reshaped between the parts 56 and 58 and sent to the right as E_1 waves. It may be advantageous to fill out the contour of the shell D around the elements 55—56 and 57—58 with insulating material in place of a metal as shown.

From E_0 to H_1 .—Apparatus adapted for this conversion is shown in Figs. 21 and 22 to 22e. An axial conductive core begins at 59 and ex-

tends to the right and at the same place the shell of the guide D is cut on an easy bevel as at 60. Proceeding to the right the core 59 becomes trough-like as at 62 and the bevel 60 is carried to the point 63 where half the shell D is cut away. Here at 64 the edge of the trough 62 begins to fill the place of the cut-away part of the shell D. At 65 these parts fill out the cylindrical contour and are separated at the sides by the narrow gaps 65, and just beyond to the right these gaps end and the normal complete cylindrical form of the guide D is restored. The gap in the wall of the guide D may be filled with a wall of insulating material as at 61. The radial lines of electric force of the E_0 waves coming from the left tie at their ends to the core 59 and shell D and as they progress they are drawn out and reshaped and detached at the right as H_1 waves.

From H_0 to E_1 .—Let the H_0 waves be received on a figure 8 conductive frame like 40—41—42 of Fig. 11 and carried as conduction currents in a short stretch of the concentric conductor system 43—44 of that figure. Let the outer conductor 43 be split and opened and carried to one side of the guide axis while the axial conductor 44 is carried to the opposite side, and let these modified conductors 43 and 44 be connected respectively with the conductors 47 of Fig. 14. Accordingly, E_1 waves will be thrown off from the electrodes 46 of Fig. 14 and the conversion will have been fully effected.

From H_1 to H_0 .—The lines of electric force of the H_1 waves are received on the conductors shown in Fig. 23 which lie in a plane transverse to the axis of the guide. These H_1 lines, acting on the chord parts 154 of the conductors shown, generate series-assisting electromotive forces in the circumferential parts 152 and 153, between which the chord parts 154 are connected. Also, these currents in the parts 152 and 153 are directed alike around the guide axis. From these circumferential segments such as 152 and 153 the lines of force are detached and radiated on along the guide core, linking together in the form of the desired H_0 waves. A sieve of radial wires like that at 54' in Fig. 18a may be placed on the output side of the conductor system of Fig. 23 to block any component corresponding to the input H_1 waves that might tend to get through to the output side.

All the foregoing examples of procedure in converting from one type of wave to another are of course illustrated diagrammatically in the drawings, without attention to the proper proportional dimensions. These dimensions, especially radial dimensions, will be made such as properly to match impedances all along the length of the guide section in which the conversion takes place.

For asymmetric electric waves or for asymmetric magnetic waves it may be desirable to make angular shift of the plane of polarization. This may be accomplished by interposing a guide section such as shown in Fig. 24. In the guide wall there are two opposite helical slots 151. These are given a quarter turn and their effect on the advancing waves is to rotate their plane of polarization by ninety degrees.

Referring to Fig. 1 and the asymmetric magnetic waves employed in this connection, the oscillator used to generate them, as represented at G, may be of a conventional type such as that of Barkhausen and Kurz (Physikalische Zeitschrift, vol. 21, pages 1 to 6, year 1920), or of Pierret (Comptes Rendus, vol. 186, pages 1,601 to 1,603, year 1928). These same oscillators may be used

advantageously for the generation of other types of waves.

There may be certain advantages in placing the oscillator within the guide as in Fig. 25, instead of at its end as in Fig. 1. Referring to Fig. 25, the generator G is located within the guide D at a distance d from its open end, where d is of the proper length to make the reflected wave coincide in phase with the direct wave for transmission to the right. Theoretically, with an open-ended guide, this distance should be an even multiple of a quarter wave length, but in practice an adjustment somewhat different from this may give the best effect. Accordingly, the end of the guide may be made in the form of a telescoping sleeve as in Fig. 26 which may be adjusted lengthwise to give the most advantageous effect. Or the generator may be mounted to slide in and out along the axis of the guide as shown in Fig. 10. There will be some radiation of energy from the open end of the guide and it may be better in this respect to have a reflector across the end.

In Fig. 26 the end of the guide is closed by a reflector consisting of a metallic diaphragm of conductive rods lying in a transverse plane and parallel to the direction of the lines of electric force. This is for waves of type E_1 or type H_1 . In case of such use of a reflector, the theoretical distance d from the oscillator to the end of the guide will be an odd multiple of a quarter wave length, but the precise value may be a little different and this may be obtained by longitudinal adjustment.

The conductors by which the power currents are fed to the generator G as in Fig. 25 for example, and by which signaling currents are impressed, should pass along lines of equal electric potential, that is, perpendicularly to the lines of electric force, which therefore may be along the lines of magnetic force. When there are standing waves set up within the end of the guide, as by reflection, the conductors may enter and leave the guide at nodes of voltage for any type of wave.

In Fig. 27 I show how the part of the dielectric guide at the sending end may be intimately associated with the oscillation generator so as to determine its output frequency. The plate-grid circuit of the generating tube G has its terminals connected with the two hemi-cylinders 66, which are spaced apart along the slots 67 and also spaced as at 68 from the shell of the guide D. At 69 a partially reflecting barrier is put across the guide D. This is adjusted along the guide D so that the distance from the end 70 is optimum for establishing a system of standing waves in the intervening space. This system of standing waves between 69 and 70 will reinforce the oscillating frequency of the generator G, but since reflection at 69 is only partial, continuous waves will be radiated across from left to right of 69 and transmitted along the guide D. The partial barrier 69 may be a screen of wires lying in the direction of the lines of electric force and spaced from each other enough to let considerable wave energy through between them. Or, it may be an iris, or a central disk of metal with an open space around its edge. Or, the space between 69 and 70 may be filled with a medium of different dielectric coefficient from that at the right of 69, so that there will be a discontinuity at 69 and partial reflection there. Any such partial reflection at 69 may serve for other types of waves besides the asymmetric magnetic waves

(H_1) such as would be sent with the generator shown connected as at the left of Fig. 27.

Instead of generating the desired high frequency currents directly at the transmitting end, currents of lower frequency may be generated and stepped up in frequency by frequency multipliers to get the high frequencies desired for transmission. This procedure is indicated by the diagram of Fig. 28. The oscillation generator 71 at 1,700 mc. delivers its output to the distorter or harmonic generator 72 which may be an asymmetric resistance or other non-linear device. The concentric conductor system 73 connects on its output side with the input end of the guide filter 74. I have already explained in connection with Fig. 5 how a wave guide will pass only those currents of frequency above a certain critical frequency. This guide filter 74 is designed with a critical frequency slightly below 6,800 mc., so it passes only the fourth harmonic, which is of this frequency. This 6,800 mc. component goes to the modulator 75. The signal current source 77 has its output applied to modulate the carrier of 1,750 mc. frequency in the oscillation modulator 76, from which the carrier and one side band go to the modulator 75. The guide 78 is designed to have its critical frequency slightly below 8,550 mc. Therefore the various modulation products from modulator 75 that are below 8,550 mc. are blocked from entering the guide 78 and it passes only that frequency.

A simple approximated frequency doubler is shown in Fig. 29. Here frequencies of 1,700 mc. and 1,750 mc. from oscillators 76 and 71 are applied in modulator 75, the former carrying with it the side band corresponding to the signal current source 77. The critical frequency of guide 78 is a little below 3,450 mc., hence lower frequency modulation products from modulator 75 are blocked and this 3,450 mc. frequency is passed.

Referring to Fig. 30, this shows a device for volume control of the energy transmitted in the form of asymmetric electric or magnetic waves along a metal sheathed dielectric guide. When the lines of electric force are transverse to the parallel wires 79, then no substantial electromotive forces are set up along those wires, and no energy goes into them, and the parallel wires are practically transparent to the waves. But, let the frame 80 carrying these wires 79 be given a quarter turn by means of the handle 81 projecting through the slot 82, and the wires 79 now become parallel with the lines of electric force and reflect or absorb the energy from them, and the device acts as a shutter to cut off the transmission along the pipe. At intermediate angles the device has an intermediate effect, and by adjustment to the proper angle the volume of the waves transmitted can be controlled as desired. For greater accuracy, the wires 79 may not be exactly parallel, but may take the directions of the lines of electric force as shown in Fig. 8a or Fig. 9a.

It will be readily understood that, to a considerable extent, the principles involved in the apparatus and methods employed at the sending end and described heretofore are applicable at the receiving end.

As shown in Fig. 25, there is an advantage in placing the receiver 83 at the proper distance d' from its end of the guide, similar to the advantage of placing the generator G at the proper distance d from its end. The box within the guide in Fig. 26 has been considered to represent a gen-

erator, but it may represent a receiver equally well.

Instead of the plane reflector shown in Fig. 26, a concave focusing reflector may be employed as shown in Fig. 31. We assume that this is at the receiving end of the guide D and the waves are of the type H_1 , with their lines of electric force perpendicular to the plane of the paper. The focus of the concave reflector 84 is on the axis 85 of the coil 86, and the tuned circuit 86—87 comprises this coil 86 and the condenser 87. In shunt to this circuit is the asymmetric resistance 88 which is also comprised in the low frequency receiving circuit 89 comprising the signal translating apparatus 90.

To receive the type E_0 waves, two coils 91 oppositely wound in series may be employed as shown in Fig. 32. The lines of electric force of the E_0 waves are radial and the effect of opposite lines in the circuit of coils 91 will be additive. By including the condenser 92 in circuit with coils 91 the circuit is tuned to the proper frequency. The shunt asymmetric resistance 93 and the low frequency circuit 94 and the signal indicating device 95 are all included in combination in the usual way.

The apparatus of Figs. 11 and 12 has been discussed as for use at the sending end for type H_0 waves, but it may be employed equally well at the receiving end for such waves. For sending, a generator will supply high frequency power currents through the conductors 43 and 44, to be radiated into the dielectric, but for receiving, these conductors will take the high frequency currents from the dielectric and deliver them to a detector.

Another assembly of apparatus for receiving is shown in Fig. 33. This may be compared with Fig. 31. In Fig. 33 the waves are refracted by the paraffin lens 96 to a focus at 97 and reflected by the spherical segment mirror 98 having its center at 97. A receiving circuit at 97 is represented diagrammatically by a "box." If the waves are of type H_1 , this receiver at 97 may be as shown in Fig. 31.

Here at 98, and wherever reflectors are employed, they need not necessarily be made of solid metal, but a mesh of crossed wires of good conductivity may be used. Or, closely spaced wires all in the direction of the lines of electric force may be used lying side by side to approximate the proper mirror surface. The reflector may be made of dielectric material, but ordinarily this will not be so effective as a reflector made of metal.

Lenses such as contemplated in connection with Fig. 33 may be of any suitable material having a substantial dielectric coefficient and such that when the material is used between the plates of a condenser it will give low loss. Corresponding to this low-loss property it will have the property of being transparent to the electric waves instead of opaque to them, and will serve suitably for a lens.

Receiving may be accomplished by demodulation in a conductor or conductors of non-linear resistance, as shown in Figs. 34 and 35. The material of the slabs 100 is of this character. It may be of thyrite, which is finely divided carborundum mixed with clay and baked. Since it gives a non-linear relation of voltage and electromotive force, it acts as a demodulator, and the demodulation output current will flow in the circuit 101 which comprises the receiver 102 and the slabs 100 in multiple. By letting the received

waves act on the slabs 100 in series, and connecting them in the receiving circuit in multiple, a proper impedance match may be attained.

A one-way repeater or amplifier is shown diagrammatically in Fig. 36, adapted for type E_0 waves. Such waves approaching from the left, their lines of electric force extending radially become tied at their inner ends to the axial conductor 103 and at their outer ends to the metallic shell D. The three elements of a three-electrode vacuum tube amplifier are connected as shown. The axial conductor 103 ends in the projecting grid 104 of cylindrical contour. Within this grid 104 is a plate 105 carried on the end of another axial conductor 106 in alignment with 103. Surrounding the grid 104 is a filament cathode 107 lying in a coaxial cylindrical surface and extending zigzag around it. The radial lines of force sweep along from the left and act across the grid 104 and cathode 107 and effect a corresponding amplified variation of the radial lines of electric force between the plate 105 and cathode 107; these are detached and proceed as electric waves to the right. By proper adjustment of the relative sizes of the plate and the grid, a degree of impedance match may be attained, and further facility to this end is afforded by a suitable longitudinal adjustment of the disks 108 and 109 along cores 103 and 106 and by suitable adjustment of the sizes of these disks. Such disks may also be designed and adjusted to produce a desired amount of regenerative action. Neutralization of capacity feed-back may be effected by tapping the output energy at 110 and feeding it back through the phase adjuster 111 to the grid core 103 on the input side.

While the waves within the hollow cylindrical guide may be made to follow easy curves in the guide axis, sharp bends or elbows should be avoided unless they are specially equipped in some such way as will now be described. Referring to Fig. 37, this shows a guide having two parts 112 and 113 with their respective axes intersecting at an angle. The parts associated with this change of direction may be called an elbow. This elbow has a plane reflector 114 with its face set perpendicular to the bisector of the angle of the axes of the two parts 112 and 113 of the guide. The waves coming from the left in the guide part 112 are reflected and proceed to the right in the guide part 113. Bends at any desired angle can be made in the same way as indicated in Fig. 37. It may be desirable to make a sharp change of direction by means of several easy changes in tandem, each like that in Fig. 37. At such a reflection as in Fig. 37, the phase of the electric force will be reversed as appears on comparing arrows 115 and 116, but there will be no distortion of the wave front. The space between the two boundaries 117 and 118 may be filled with a material of high enough dielectric coefficient so that the phenomenon of total internal reflection will occur at the face 114.

In Fig. 37a I have shown a pivoted reflector 155 adapted by adjustment to deflect incoming waves in guide D to either of two branch guides D' and D'' as may be desired.

Another way to effect a change of direction along the guide is by means of one or more refracting prisms arranged as shown in Fig. 38. Supposing that the material of the prisms is paraffin having a dielectric constant of 2.13, and therefore an index of refraction of 1.46, a suitable design will be to have four tandem prisms as shown in Fig. 38, each with an acute angle of

44.3 degrees where it rests against the outer curve of the inside face of the wall of the guide D.

Another device for changing the direction of the guide is an elbow such as shown in Fig. 39, filled with dielectric material of varying dielectric coefficient, that is, along any transverse line in the plane of the axes, the coefficient increases toward the center of the circle to which those axes are tangents. If the diameter of the guide is d , and n is the index of refraction of the dielectric material within the elbow along the circle of greatest curvature and having the radius r , and if the dielectric coefficient is unity along the circle of least curvature and having the radius $r+d$, then the dimensions and the index n are related according to the equation

$$r=d/(n-1).$$

Conversion from one type of wave to another may be effected by reflection or refraction of parts of the wave as suggested in Fig. 39a. An advancing symmetric electric wave in the guide D has one half of the wave front reflected by the reflector 171, the other half by the reflector 172, making a shorter path for the first half from the part of the guide at D to the part at D'. If the wave length is such that this difference is a half wave length, then the outgoing wave will have a diametral component which may be purified by the use of a screen 173 with its wires across the direction of that component.

The systems described heretofore have been adapted for one-way communication. Duplex or simultaneous opposite-way communication may be effected by a system constructed according to the diagram of Fig. 40. The waves from the transmitter 119 on the left are turned in greater part by the reflector 120 into and along the guide D as shown by the arrows. Receiver 126 is tuned to a different frequency from transmitter 119 and therefore any waves that may be diffracted across the edge of reflector 120 will be of no effect. On the right the waves are divided both ways by the reflectors 122 and 123. The receiver 124 on the right is tuned to the frequency of these waves, and the corresponding signal effects are produced accordingly. From the foregoing it will be seen how transmission is effected simultaneously from the transmitter 125 on the right to the receiver 126 on the left.

Another system of two-way communication, this time with the same frequency both ways, makes use of polarized asymmetric magnetic waves (H_1) as shown in Fig. 41. The waves from the transmitter 119 are polarized so that their lines of electric force lie in and parallel with the plane of the paper. The reflector 127 consists of wires all lying in a plane perpendicular to the plane of the paper and all parallel to the plane of the paper. Accordingly, this reflector 127 turns these waves from the transmitter 119 and they are transmitted along the guide in the direction indicated by the arrows.

At the receiving end on the right, these waves are likewise reflected by the reflector 128 and go into the receiver 124. At the sending end on the left there is another reflector 129 with its plane perpendicular to the plane of reflector 127 and with its wires all parallel to the intersection of the two reflector planes. Accordingly, the waves from the transmitter 119 pass freely through that part of the reflector 129 which lies above and to the right of the reflector 127, as viewed in Fig. 41. Similarly, at the receiving end on the right, these waves pass freely through the guard

reflector 130' and the part of the reflector 130 that lies below and to the left of the reflector 128. Waves from the transmitter 119 are kept out of the receiver 126 by the reflector 127 and also by the guard reflector 127'.

The transmission in the opposite direction will readily be understood from the explanation that has been given above. The waves from the transmitter 125 are polarized so that their lines of electric force are perpendicular to the plane of the paper. Hence, they pass freely through the reflectors 128 and 127 and 127' but are reflected by the reflectors 130 and 129.

If greater discrimination is required than afforded by this scheme, it may be had by tuning the transmitter and receiver for transmission one way to a different frequency from that for the opposite way.

The principle of the reflectors employed in the system of Fig. 41 may be utilized for selective transmission along two signaling channels, both in the same direction, as illustrated in Fig. 42. Here the transmitter 130 is rotatable through an angle of 90 degrees about the axis of the guide. At one extreme, with the lines of electric force perpendicular to the plane of the paper, the waves will be reflected by the three reflectors 131. These reflectors, made of parallel wires, are rather open so that they do not intercept all the energy, but some of it passes on through the first and second reflectors to the third of the series. Thus, from the sender 130 signals may be sent to the three branches 132 associated with the reflectors 131. None of the energy of these signals goes to the branches 134, for the reason that their respective reflectors 133 consist of wires lying in directions at right angles to the electric lines of force, and, therefore, the wave energy passes through these reflectors.

From the foregoing it will readily be understood that by adjusting the transmitter 130 so it will be turned 90 degrees around the axis of the guide, the roles of the two sets of reflectors 131 and 133 will be reversed and the signal energy will be delivered to the three branches 134 and not to the branches 132. By setting the transmitter at an intermediate angle, signal energy may be delivered to all the branches 132 and 134.

In the system shown in Fig. 43, two sets of signals may be sent out simultaneously on waves respectively polarized at right angles to each other. Thus, the signals from the transmitter 135 are carried by waves in which the lines of electric force are perpendicular to the plane of the paper, and, accordingly, these are reflected at 137 into and along the guide D. The signals from the transmitter 136 are carried by waves having the lines of electric force parallel with the plane of the paper, and these are reflected at 138 into and along the guide D. The end of the guide D carrying the receiver 139 is rotatable through an angle of 90 degrees around the axis of the guide. This receiver carries with it an inclined reflector 140 and at the extreme of adjustment shown in Fig. 43, it reflects the set of waves from transmitter 136 and by-passes the set from transmitter 135, but at the other adjustment, 90 degrees therefrom, the reflector 140 reflects the set of waves from 135 and by-passes the set from 136. Thus, a person at the receiver 139 can selectively intercept either set of signals he chooses, from 135 or 136.

The reflectors described in connection with Figs. 41, 42 and 43 are all adapted for the asymmetric electric and magnetic waves having the

lines of electric force in and approximately parallel with a plane containing the axis. A suitable reflector for such waves will consist of wires lying in or parallel to this plane. When signaling is done by means of symmetric electric waves, a reflector may properly be made to have radial wires. Thus, as shown in Figs. 44 and 45, the reflector 148 will lie in a plane at 45 degrees to the axis of the main guide D, the section made by this plane will be an ellipse, and the reflector will consist of radial wires arranged as shown in Fig. 45.

In the case when the waves are symmetric magnetic waves, the reflector will lie in the same plane as described for Figs. 44 and 45 but this time its wires will not be radial, but will be concentric, as shown in Figs. 46 and 47. Each reflector of Figs. 44 to 47 will reflect the type of waves for which it is adapted, but will by-pass freely the waves of the other type. In Figs. 44 and 46, an arrow with a little cross on it represents an E_o component, and an arrow with a little circle on it represents an H_o component. If the waves coming from the left in Figs. 44 and 46 are composite E_o and H_o types, then in Fig. 44 the E_o component will be deflected 90 degrees and the H_o component will pass freely to the right, but in Fig. 46 the H_o component will be deflected and the E_o component will be passed directly. If waves of these two types E_o and H_o were sent respectively from transmitters 119 and 125 of Fig. 41, and its reflectors were correspondingly replaced by reflectors of the types shown in Figs. 44 to 47, we should have an operative two-way system.

Another system for separating superposed signal waves according to their polarity will be described in connection with Figs. 48 to 52. When an electric wave in a certain medium is incident upon a surface separating that medium from a second medium of different dielectric coefficient, in general the incident wave will be split into two parts, one of which will be transmitted into the second medium with a certain degree of refraction while the other part will be reflected within the initial medium. These cases are illustrated in Figs. 48 and 49. In Fig. 48 the wave having the direction of arrow 149 in air or free space of dielectric coefficient unity, encounters the surface of a mass of paraffin indicated by the shading and having the dielectric coefficient 2.13. Since the index of refraction is the square root of the dielectric coefficient, so in this case the index of refraction of the paraffin is 1.46. Part of the incident ray 149 will be reflected as the ray 150, making the angles of incidence and reflection equal, as indicated at a_1 and a_2 . Another part will be transmitted as ray 151 at an angle a_3 and subject to the law that $1.46/1 = \sin a_1 / \sin a_3$.

When the transmission is initially in the denser medium, paraffin in the case supposed, it will be as shown in Fig. 49, with the law that

$$1.46/1 = \sin a_3 / \sin a_1.$$

The foregoing discussion relates to the directions taken by the reflected and refracted rays, as determined by the direction of the incident ray. The intensities of these different rays are indicated comparatively in Fig. 50 which discriminates according to the polarization of the incident waves. This figure shows four full-line curves, each giving the intensity of a transmitted or reflected component wave as a certain percentage of the intensity of the incident component wave. The curve T_p is for the transmitted

wave when the polarization is such that the lines of electric force are parallel to the plane of incidence, that is, the plane containing the incident ray and a normal to the boundary of the two media; T_t is for polarization at right angles to the foregoing; R_p is for the reflected wave when the polarization is the same as for T_p , and R_t is for the reflected wave when the polarization is the same as for T_t .

It will be seen that when the angle of the incident ray is at zero degrees, that is, when the incident ray is perpendicular to the plane separating the two media, all the energy goes into the transmitted waves and none is reflected. As the angle increases from zero to about 1 degree, the reflected energy rises from zero to about 19 per cent, and, correspondingly, the transmitted energy falls from 100 per cent to about 81 per cent.

As the angle goes on increasing from about 1 degree to 90 degrees, the transmitted energy of both polarities decreases faster and faster from 81 per cent till at 90 degrees it is zero.

Also, during this increase of the angle from 1 degree to 90 degrees, the energy of the reflected wave of polarity such that the electric vector is transverse to the plane of incidence increases faster and faster from 19 per cent to 100 per cent, as indicated by the curve R_t .

As the angle of incidence increases from about 1 degree the energy of the reflected wave of polarity such that the lines of electric force are parallel to the plane of incidence decreases as indicated by the curve R_p , and at about 56 degrees the magnitude of this reflected wave becomes zero. This angle which is here about 56 degrees (call it ϕ in general) is related to the index of refraction which is here about 1.46 (call it n in general) by the equation $\tan \phi = n$. Going on from 56 degrees to 90 degrees, the energy of the reflected wave of this polarity increases rapidly, and faster and faster, from zero to 100 per cent.

The ratio of the ordinates of the curves R_p and R_t has been expressed in decibels and plotted in the dotted line curve A of Fig. 50. This shows that as the angle of incidence is varied, a paraffin reflector gives high directional selectivity to extinguish the component of a reflected wave having its lines of electric force parallel with the plane of incidence. This property is utilized in the selective devices shown in Figs. 51 and 52. In Fig. 51 a composite wave is considered to be advancing from left to right as indicated at 142. It strikes the face of the paraffin prism 141 at the critical angle, which is about 56 degrees in Fig. 50. The component having its lines of electric force perpendicular to the plane of incidence, that is, perpendicular to the plane of the paper, is partly transmitted and partly reflected as shown by the ordinates of the curves T_t and R_t at 56 degrees in Fig. 50. This component is represented by the dots at 142, 143 and 144 in Fig. 51. The oncoming component having its lines of electric force in and parallel to the plane of incidence is partly transmitted as indicated by the ordinate of the curve T_p at 56 degrees in Fig. 50. This component is represented by the short transverse arrows at 142 and 143 in Fig. 51. At this angle, none of this component is reflected, and accordingly no arrows appear at 144. If two transmitters such as shown at the left of Fig. 43 are connected at the left of Fig. 51, then the waves therefrom will be as shown at 142 in Fig. 51 and the component from only one of the two transmitters will be received in the branch guide as at 144 in

Fig. 51. By putting another prism 145 across the wave train 143, with the edges of this prism 145 parallel to the plane of the paper, the other component represented by the transverse arrows at 143 will be sifted out by reflection, just as the component represented by the dots was sifted out at 144.

In the modification shown in Fig. 52 the prism 141' corresponding to 141 in Fig. 51 has been bevelled off at 146 at the proper angle to give total internal reflection, so that the beam 143' proceeds parallel with the beam 144, instead of diverging widely as does 143 compared with 144 in Fig. 51.

The system of Fig. 51 or Fig. 52 may be used for volume control. If the transmitter 147 at the left in Fig. 52 sends only waves whose lines of electric force are parallel with the plane of incidence, that is, parallel with the plane of the paper, then the intensity of the wave represented at 144 will be nil. If the transmitter 147 is turned through a certain angle about the axis of the associated guide, the intensity will vary as a function of this angle increasing from zero to about 36 per cent of the full intensity of the incident wave as shown by the curves R_p and R_t in Fig. 50. Thus an adjustable volume control will be accomplished in the branch guide carrying the wave train 144.

The propagation of waves along dielectric guides, as disclosed in this application and in my copending application, supra, appears to be sui generis in the realm of electromagnetic wave transmission and readily distinguishable from other forms of guided wave propagation. Comparison of dielectric guide systems with other systems for guiding electromagnetic waves may serve to emphasize some of the distinguishing features. In some cases the nature of the structure along which the waves are guided is itself the salient feature of differentiation; in other cases the guiding structures may be identical and the nature, characteristics and behavior of the guided electromagnetic waves must be looked to. In most cases, both the guiding structure and the waves will be seen to be essentially different.

Thus, dielectric guide systems may be contrasted with ordinary conduction current systems utilizing as the guiding structure a pair of metallic wires, shielded or unshielded or a pair of coaxial conductors. Considering first the nature of the guiding structure, it will be apparent that no structure falls in the category of conduction current systems that does not provide two or more conducting members suitable for the go-and-return flow of conduction current. There can be no confusion therefore between conduction current systems on the one hand and such typical dielectric guides, on the other hand, as consist wholly of dielectric material or of dielectric material with a single metallic core or of a single metallic pipe containing only a dielectric medium. A dielectric guide, however, may comprise a plurality of metallic conductors, and where it comprises, for example, both a metallic sheath and a metallic core, the structure is essentially the same as that of a coaxial pair, and if the one system is to be distinguished from the other the nature, characteristics, etc. of the waves guided along the structure must be examined.

In the ordinary coaxial conductor transmission system, as in all conduction current systems, the go-and-return flow of conduction currents is an essential and significant feature. In a dielectric guide system such current flow may be absent or there may be conduction current in only one conductor of the guide, e. g., in a metallic sheath.

In the conduction current system again there is no component of either the electric or magnetic field that lies in the direction of wave propagation, excepting, of course, to take account of the trailing of the wave front in the vicinity of imperfect conductors, this trailing representing a flow of energy into the conductors equal to the energy loss occurring therein. In all of the dielectrically-guided waves herein disclosed, on the contrary, either the electric field or the magnetic field has a substantial component in the direction of wave propagation, entirely independent of energy loss in metallic elements, this longitudinal component, in all of them too, being evident in a longitudinal flow of magnetic current or of displacement current through fairly well defined regions within the dielectric medium.

In other respects, too, the dielectrically guided waves herein disclosed differ radically from the waves associated with ordinary conductor systems. The velocity at which they are propagated along the guide, and therefore the wave-length within the guide, depends in a marked degree on a transverse dimension of the guide. The diameter is the significant dimension in the case of a simple cylindrical guide. This characteristic is in strong contrast with ordinary conductor systems, where the velocity and wave-length are substantially independent of the transverse dimensions.

Another striking characteristic of the waves herein described is the existence of a cut-off frequency separating a high frequency range of easy transmission from a lower frequency range of zero or negligible transmission. The frequency at which this cut-off occurs depends on a number of factors, such as the field pattern of the wave, the dielectric constant of the medium, and a transverse dimension of the guiding structure. Regardless of the factors involved, however, it is true that for any particular guide and type of dielectrically guided wave herein disclosed this anomalous behavior of the attenuation-frequency characteristic may be observed.

Electromagnetic waves of optical frequencies have been propagated within quartz rods and within polished tubes, but this involves a manner of transmission entirely distinct from that of a dielectric guide system. There are myriads of independent waves, each arising from an atom within an incandescent source, and all are in random frequency and phase relation. Each wave progresses along optical paths and is confined, not guided, within the dielectric medium by repeated internal reflection from the dielectric or metallic surfaces. Such waves have none of the important characteristics, hereinbefore described, that are generally attributable to dielectrically guided waves.

From the foregoing comparisons it is evident that the novel waves described in this application are essentially different from any waves heretofore known and used, as different in fact as radio waves and ordinary conduction currents differ from each other. It may well be, however, that the specific forms of waves herein disclosed are only representative of a broader class of waves, the limits or boundaries of which are yet to be accurately fixed, and it is impossible at this time to predict what feature or features of the several herein discussed might be found to be the common link between them all. The term "dielectrically guided" as used in the appended claims, therefore, is intended to embrace the various novel waves so denominated in this specification

and such other waves as may fairly be found equivalent thereto.

By "dielectric guide" is to be understood any wave-guiding structure capable of sustaining dielectrically guided waves. All such guides appear to be characterized in that they comprise a dielectric medium having an enclosing boundary defining a discontinuity in electrical properties.

I claim:

1. In combination, a wave guide comprising a metallic pipe, means for establishing within said pipe progressive electromagnetic waves of a character such that they subsist substantially only at frequencies above a critical frequency related to the physical constants of said guide, and means for utilizing said waves so established.

2. In combination, a wave guide consisting essentially of a metallic pipe, a high frequency electric generator and means associated therewith for establishing within said pipe corresponding electromagnetic waves that progress through said pipe with the wave energy largely confined therein, and means at some other point along said guide for withdrawing in substantial proportion the transmitted wave energy there available.

3. A system for the guided transmission of electrical energy comprising a metallic pipe containing a substantially gaseous dielectric medium and means for launching in said pipe for transmission therethrough electromagnetic waves of such character that they are propagated only at frequencies exceeding a critical frequency dependent on a transverse dimension of said pipe.

4. A system for the transmission of electrical energy from one place to another comprising a wave guide extending between the two places, said guide comprising a metallic pipe containing a substantially gaseous dielectric medium, means at the one place for imparting said energy to the guide in the form of dielectrically guided waves adapted for propagation through the interior of said pipe and means at the other place for withdrawing in substantial proportion the wave energy so transmitted.

5. The method of communicating electrical effects from one place to another which comprises providing a dielectric medium of restricted cross-section bounded by a metallic pipe extending from one to the other of said places, generating in said medium at one of said places electromagnetic waves of a character such that they are propagated through said pipe to the other place with a velocity exceeding that of light in said medium, and receiving said waves so propagated at said other place.

6. The method of signaling over a wave guide consisting essentially of a metallic pipe which comprises establishing progressive electromagnetic waves in the interior of said pipe, modulating said waves with signal intelligence to be sent, and demodulating them after transmission through said guide for the reception of the corresponding signal intelligence.

7. A system for the transmission of intelligence from one place to another comprising a wave guide extending between the two places, said guide comprising a metallic pipe enclosing a substantially gaseous dielectric medium, means at the one place for generating high frequency electromagnetic waves and applying them to said pipe for dielectrically guided propagation through the interior thereof, and means for modulating said waves with signals to be transmitted, and at the other place, means for receiving the said

waves propagated through the pipe and means for deriving the said signals therefrom.

8. A system in accordance with claim 7 including metallic means enclosing said generating and receiving means, respectively, and shielding them except from communication with the interior of said pipe.

9. In combination, a wave guide comprising a metallic pipe and means for generating in said pipe and propagating therethrough electromagnetic waves characterized in that the lines of electric force extend transversely through said pipe from one portion of the inner surface of the pipe to another.

10. In combination, a wave guide comprising a metallic pipe enclosing a dielectric medium, means for transmitting through said medium high frequency electromagnetic waves in which at least one of the two component fields, electric or magnetic, has one intensity component parallel with the axis of the guide and another intensity component transverse to the axis of the guide and in an axial plane, and means remote from said transmitting means for deriving at least a substantial portion of the energy transmitted by said waves.

11. In combination, a wave guide and means for generating and propagating therethrough electromagnetic waves characterized in that the lines of electric force form closed loops lying in planes orthogonal to the axis of the guide.

12. A combination in accordance with claim 11 in which said waves are further characterized in that said closed loops are coaxial with the guide.

13. In combination, a cylindrical wave guide and means for generating therein and propagating therethrough electromagnetic waves the electric field of which is circular and coaxial with said guide.

14. In an ultra-high frequency electrical transmission system, a wave guide comprising a metallic pipe enveloping a dielectric medium, and means for launching in said pipe for progressive transmission therethrough dielectrically guided waves of a type having a substantial longitudinal component of magnetic intensity.

15. A system in accordance with claim 14 in which said dielectric medium is essentially gaseous.

16. A system in accordance with claim 14 characterized in that said dielectrically guided waves are of symmetric magnetic type.

17. A system in accordance with claim 14 characterized in that said dielectrically guided waves are of asymmetric magnetic type.

18. In a wave guide system, a metallic pipe, a conductive circuit the conductors of which extend into the space within said pipe, and means for generating lines of force in said space with their ends on said conductors and for alternating the current in said conductive circuit at a frequency so high that the lines of force are detached and propagated as guided waves within the said pipe.

19. In combination, a wave guide comprising a metallic pipe, an electrode comprising a short length of conductor extending along the axis of said pipe, and means for establishing an alternating difference of potential between said conductor and pipe at a frequency so high that progressive dielectrically guided waves are generated within said guide.

20. A combination in accordance with claim 19 comprising in addition a metallic body mounted near one end of said conductor and partially

closing the space between said conductor and pipe.

21. In a signaling system, a wave guide comprising a metallic pipe containing only a dielectric medium, an electrode comprising an elongated conductor disposed axially within said pipe, and a high frequency translating device so related operatively with said electrode as to be in energy transfer relation with electromagnetic waves within said guide, said waves having a magnetic field that is substantially concentric with said pipe and an electric field that comprises a substantial axial component.

22. In combination, a wave guide comprising a metallic pipe containing only a dielectric medium, a metallic plate disposed transversely within said pipe with the edges thereof spaced from the wall of said pipe, and a generator of high frequency waves connected to establish a corresponding difference of potential between the edges of said plate and the wall of said pipe.

23. A combination in accordance with claim 22 in which said pipe is tubular and said plate is a disc concentric with said pipe.

24. In combination, a wave guide comprising a metallic pipe enclosing a gaseous dielectric medium, and means adapted for energy transfer relation with electromagnetic waves of symmetric electric type in said guide comprising a pair of concentric electrodes disposed in axial alignment with said guide and separated from each other to sustain a substantially radial electric field between them.

25. A wave guide consisting of a dielectric core and a cylindrical metal shell surrounding said core, and in combination therewith, means to generate in said core progressive electromagnetic waves of field pattern and length suitable for propagation therein with low attenuation, the length of said waves being comparable with the diameter of said shell.

26. In combination, a hollow metallic wave guide, means to generate high frequency electric currents, and means to feed their energy into said guide for propagation as polarized electromagnetic waves having their lines of force within the guide, the flow of energy being substantially in the one direction of propagation.

27. A system for transmitting effects electrically from one place to another comprising a metallic pipe extending between the two places, means at the one place to generate high frequency electromagnetic waves in the space within said pipe for propagation therethrough, and means at the other place for receiving such waves, said waves being of such character that they are transmitted through said pipe with moderate attenuation only at frequencies above a cut-off frequency dependent on a transverse dimension of said pipe.

28. A system for signaling from one place to another comprising a wave guide extending between the two places, said guide comprising a metallic pipe containing only a dielectric medium, means at the one place to generate high frequency electromagnetic waves, means for applying said waves to said pipe for dielectrically guided propagation therethrough and means for impressing signals on said waves, and at the other place, means for receiving the said waves propagated through said pipe and for deriving the signals therefrom.

29. In combination, means for generating a high frequency electric conduction current, means for modulating said current with a band

of currents of great absolute frequency range and small percentage frequency range, a metallic pipe guide, and means to generate displacement current waves within one end of said guide corresponding to the modulated high frequency conduction current, the lines of electric force of said waves terminating, if at all, at the periphery of said guide.

30. In combination, a set of metallic conductors, means to generate high frequency conduction currents therein, a wave guide consisting essentially of a metallic pipe, and a coupling between said conductors and said guide to convert the energy of the currents in said conductors into the form of dielectrically guided displacement current waves in the said guide.

31. In combination, a wave guide comprising a metallic pipe, means to send high frequency electromagnetic waves in the space within said pipe, said waves being of such nature that there is a certain frequency separating the operative frequency range from a lower frequency range of zero or negligible transmission, receiving apparatus comprising a metallic conductor circuit and a coupling between said guide and said circuit adapted to receive the energy of the waves in the guide and convert such energy into the form of conduction currents in said circuit.

32. In combination, a wave guide adapted to carry electromagnetic waves within it, said guide comprising a metallic pipe containing only a dielectric medium, a metallic conduction circuit associated with said guide at a point along its length and adapted to carry conduction current waves, and a coupling between said guide and circuit for the transfer of wave energy from the one to the other.

33. A combination in accordance with claim 32 in which the waves within the guide are characterized by the flow of electric displacement current in longitudinal paths in said dielectric medium.

34. A combination in accordance with claim 32 in which the waves within the guide have a substantial longitudinal component of magnetic intensity.

35. In combination, a conductive circuit, a wave guide consisting essentially of a metallic pipe containing only a dielectric medium, and an impedance matching coupling between said conductive circuit and said guide for high frequency electromagnetic waves.

36. In combination, a conductor pair and a wave guide comprising a metallic pipe, said conductor pair being operatively associated with one end of said guide and shaped and spaced to match the impedance of said conductor pair and of said guide, said guide carrying high frequency electromagnetic waves of such nature that the velocity of propagation is functionally related to a transverse dimension of said guide.

37. The method of generating electric waves having radial lines of force for propagation in a wave guide with a metallic shell, which consists in establishing radial lines of force between the shell and an electrode on its axis, and alternating the polarity of these lines at a frequency so high that they are detached and propagated as waves within the shell.

38. Means to generate electromagnetic waves of the type having radial lines of electric force for propagation within a wave guide comprising a metallic pipe, comprising an oscillation generator having one of its two output terminals connected to the wall of the guide and the other such termi-

nal in the form of a rod projecting from the generator along the axis of the guide.

39. In combination, a wave guide consisting of a dielectric core and a metallic cylindrical shell surrounding said core, a central electrode adjacent to one end of said core, a peripheral electrode conductively connected to the corresponding end of the metallic shell and a conductive circuit to said electrodes for energizing them at a frequency sufficiently high to produce progressive waves within said guide.

40. In combination, a wave guide comprising a metallic pipe, an oscillation generator at the sending end having one of its two output terminals connected to the wall of the guide, and a telescopic member lying in the axis of the guide and serving as the other terminal of said generator, said generator being adapted to operate at a frequency above the cut-off frequency of said guide.

41. The method of generating electric waves having their lines of electric force in coaxial circles for propagation within a wave guide, which consists in establishing conduction currents in like phase around the axis of the guide, and alternating them so rapidly that their lines of force are detached and linked in coaxial circles for propagation along the guide.

42. In a signaling system, a wave guide comprising metallic means defining the lateral boundary thereof and a dielectric medium within said boundary, said guide carrying signal-modulated dielectrically guided waves of symmetric magnetic type, a signal circuit and means for establishing an energy transfer relation between said waves and said circuit comprising means for sustaining high frequency conduction currents in substantially like phase around the axis of said guide.

43. In combination with a wave guide, means for generating therein electromagnetic waves of the type having their lines of electric force in coaxial loops, said means comprising a substantially figure 8 conductor structure lying across the guide, and means for applying to said structure currents having a frequency so high that waves of said type are produced in said guide.

44. In combination with a wave guide comprising a dielectric medium enclosed by a surface defining an abrupt discontinuity in electromagnetic properties, means for generating in said guide waves of the type having their lines of electric force in coaxial circles, which consists of conductors having segments lying circumferentially and connected to be energized so that the current flow in all the segments is in like phase in the same direction around the axis of the guide.

45. In a wave guide comprising a metallic pipe carrying symmetric magnetic waves in its interior, a terminal structure for said guide comprising a plurality of substantially arcuate conductors disposed within and concentric with said pipe, and a high frequency translating device connected to said conductors in such manner as to be in energy transfer relation with said symmetric magnetic waves.

46. The method of generating asymmetric magnetic waves for propagation within a wave guide comprising a metallic pipe which consists in generating a high frequency alternating electromotive force across diametrically opposite electrodes associated with said guide whereby the corresponding lines of electric force become detached and propagated within the guide.

47. In combination, a wave guide comprising a

metallic pipe containing only a dielectric medium, a pair of conductors in substantial alignment with each other disposed within said pipe and transversely to the length thereof, and a high frequency translating device connected in energy transfer relation with said pair of conductors, said pair of conductors being adapted for energy interchange with electromagnetic waves within said pipe.

48. In combination, a wave guide comprising a metallic pipe for the transmission of high frequency waves in the space enclosed thereby, an oscillation generator, and a circuit connecting said generator to diametrically opposite points of the guide.

49. In combination, a wave guide comprising a tubular metallic pipe containing only a dielectric medium, a pair of radial wires disposed within said pipe and ending at diametrically opposite points thereof, and a source of high frequency waves connected to the adjacent ends of said wires, whereby progressive electromagnetic waves may be established within said guide.

50. In a signaling system, a wave guide having a metallic lateral boundary and a substantially gaseous dielectric medium enclosed thereby, said guide carrying signal-modulated electromagnetic waves of asymmetric magnetic type, a signal circuit and means for establishing an energy transfer relation between said waves and said circuit comprising a conductor disposed within said metallic boundary in substantial alignment with the transverse electric field of said waves.

51. In a system comprising a metallic pipe guide, the method which comprises establishing a flow of high frequency alternating current from one side of said guide to the other, said current being principally conduction current and the frequency being so high that asymmetric magnetic waves are generated in said guide and propagated therethrough.

52. In combination, a wave guide comprising a metallic pipe, an oscillation generator lying on the axis of the guide, and opposite fan-shaped conductors connected to and spreading from said generator to the walls of the guide, said generator being of a kind adapted to operate at a frequency exceeding the cut-off frequency of said guide.

53. In combination, a wave guide comprising a metallic pipe, an oscillation generator lying on the axis of the guide and opposite fan-shaped conductors spreading from said generator to the walls of the guide, said fan-shaped conductors being angularly adjustable to match the impedance of the generator to the impedance of the guide.

54. In combination, a guide for electromagnetic waves of high frequency consisting essentially of a metallic pipe and an enclosed dielectric medium, and a translating device within the guide near its end connected at points of widely different potential in the system of said waves within the guide, the length of the guide between said end and the points of connection of said translating device being such that the direct waves and the waves reflected from said end are in phase at the said points of connection.

55. In combination, a dielectric guide consisting essentially of a metallic pipe, a translating device within the guide connected to diametrically opposite points thereof and an adjustable sleeve extension for the guide by which direct and reflected waves therein may be brought in phase at the translating device.

56. In combination, a dielectric guide the only essential metallic element of which is a laterally enclosing element, a translating device within the guide and a reflector at the end of the guide, the distance of the reflector from the translating device being such as to bring the direct and reflected waves in phase at the translating device.
57. In combination, a wave guide comprising a metallic pipe and carrying within it progressive electromagnetic waves of a character such that propagation takes place substantially only at frequencies above a critical frequency related to a transverse dimension of the guide, means for reflecting waves within said pipe, and means in front of said reflector and in energy transfer relation with said progressive waves.
58. The invention in accordance with claim 57 in which said reflecting means and said means in energy transfer relation are so spaced that the energy transfer is substantially maximum.
59. In combination, a wave guide consisting essentially of a metallic pipe, means for establishing progressive electromagnetic waves in the interior of said pipe, means within said pipe for reflecting said waves and means near said reflecting means for withdrawing wave energy from said pipe, the two last-mentioned means being spaced an optimum distance apart for the withdrawal of wave energy.
60. The combination in accordance with claim 59 in which said means for withdrawing wave energy comprises a receiver spaced approximately an odd number of quarter wave-lengths from said reflecting means.
61. In combination, a wave guide consisting essentially of a metallic pipe, means including a terminal structure within said pipe for launching high frequency electromagnetic waves therein, and means for limiting said waves to progression in one direction only through said guide.
62. A combination in accordance with claim 61 in which said limiting means comprises a reflecting barrier across said pipe.
63. In combination, a wave guide comprising a metallic pipe containing only a dielectric medium, and means for launching progressive electromagnetic waves in said pipe comprising a high frequency generator, a terminal structure energized thereby and laterally enclosed by a metallic shield continuous with said pipe and a metallic reflector spaced roughly an odd number of quarter wave-lengths from said terminal structure so that the waves produced at said terminal structure are efficiently directed into said guide.
64. In a wave guide consisting of a metallic pipe carrying within it electric waves of the type having radial lines of electric force, a receiver comprising two coils on opposite sides of the guide axis and with their axes transverse thereto, said coils being oppositely wound in series, a condenser in series with said coils to make a tuned circuit, and a non-linear resistance device in shunt to said condenser.
65. A wave guide consisting essentially of a metallic pipe having a change of direction along its length, and means to change the direction of transmission of electric waves within the guide to correspond to the change in the direction of the guide itself without substantial loss of energy and without substantial distortion, said waves having a length comparable with the transverse dimensions of said guide.
66. In a system including a wave guide comprising a metallic pipe and means for transmitting therethrough electromagnetic waves of a

character such that there is a cut-off frequency defining the lower limit of the wave propagation range, means to change the direction of the guide comprising a reflector having its face perpendicular to the angle bisector of the axes of the parts of the guide having the two different directions, said waves having a length comparable with the transverse dimensions of said guide.

67. In combination, a wave guide comprising a metal pipe, a metal electrode centered on the guide axis at one end, and a high frequency alternating current generator having one of its two output terminals connected to said electrode and the other such terminal connected to the guide shell near said electrode.

68. In combination, a concentric conductor system, a wave guide consisting essentially of a metallic pipe, two electrodes at the end of said guide connected respectively with the two conductors of the said concentric conductor system, the dimensions of the said concentric conductor system and of the metallic pipe guide and the design of the said two electrodes being such that there is impedance match between the said concentric conductor system and the said guide.

69. In a wave guide comprising a metallic pipe carrying within it electromagnetic waves of the type having radial lines of electric force and a cut-off frequency related to the transverse dimensions of said pipe, a receiver comprising a coil placed eccentrically in relation to the cross-section of the guide, and a receiving circuit comprising said coil.

70. In a system comprising a metallic pipe and means for producing therein guided electromagnetic waves of a character such that there is a cut-off frequency defining the lower limit of the useful frequency range, a receiver of said waves comprising a circuit including at least one loop of conductor disposed within said guide so that it is linked by the magnetic field of said waves, and means for detecting the corresponding voltage induced in said circuit.

71. In a signaling system, a wave guide consisting essentially of a metallic pipe, means for producing signal-modulated progressive electromagnetic waves within said pipe, and a receiver of said waves comprising a conducting coil the turns of which are linked with the magnetic lines of force in said waves, and a detector connected to said coil for deriving the signals from said waves.

72. In combination in a signaling system, a wave guide comprising a metallic pipe containing only a gaseous dielectric medium and respective terminals for sending and receiving over said guide signal-modulated electromagnetic waves of a character such that propagation occurs substantially only above a critical frequency determined by a transverse dimension of said pipe, one of said terminals comprising a metallic circuit that is linked with the magnetic field of said waves within the guide.

73. As a means for communicating electrical effects from one place exclusively to one other place or to a limited number of other places, an extended body of dielectric extending from the one place to the other place or places and bounded laterally by a metallic conductive enclosure, and means for generating therein at the one place electromagnetic waves of frequency sufficiently high that they are dielectrically guided therein to the other place or places, and to such place or places only.