

Aug. 26, 1947.

W. H. DOHERTY

2,426,185

TRANSLATION OF MICROWAVES

Filed Sept. 27, 1941

2 Sheets-Sheet 1

FIG. 1

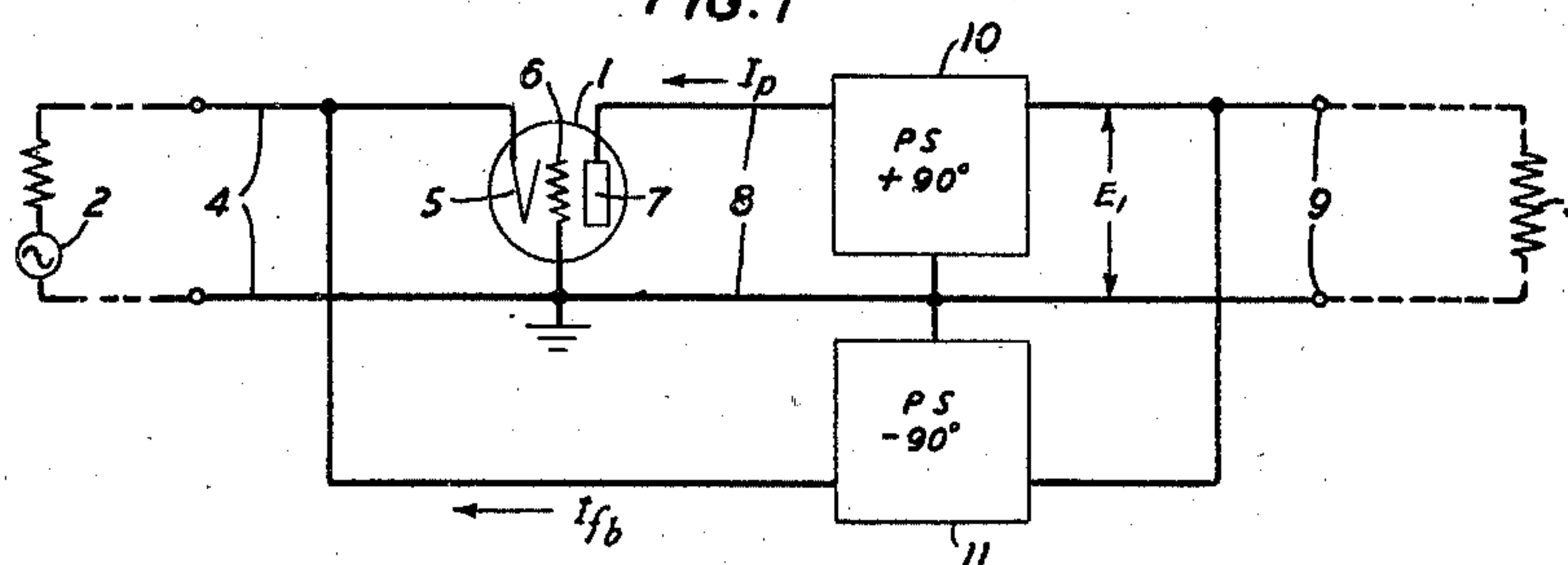
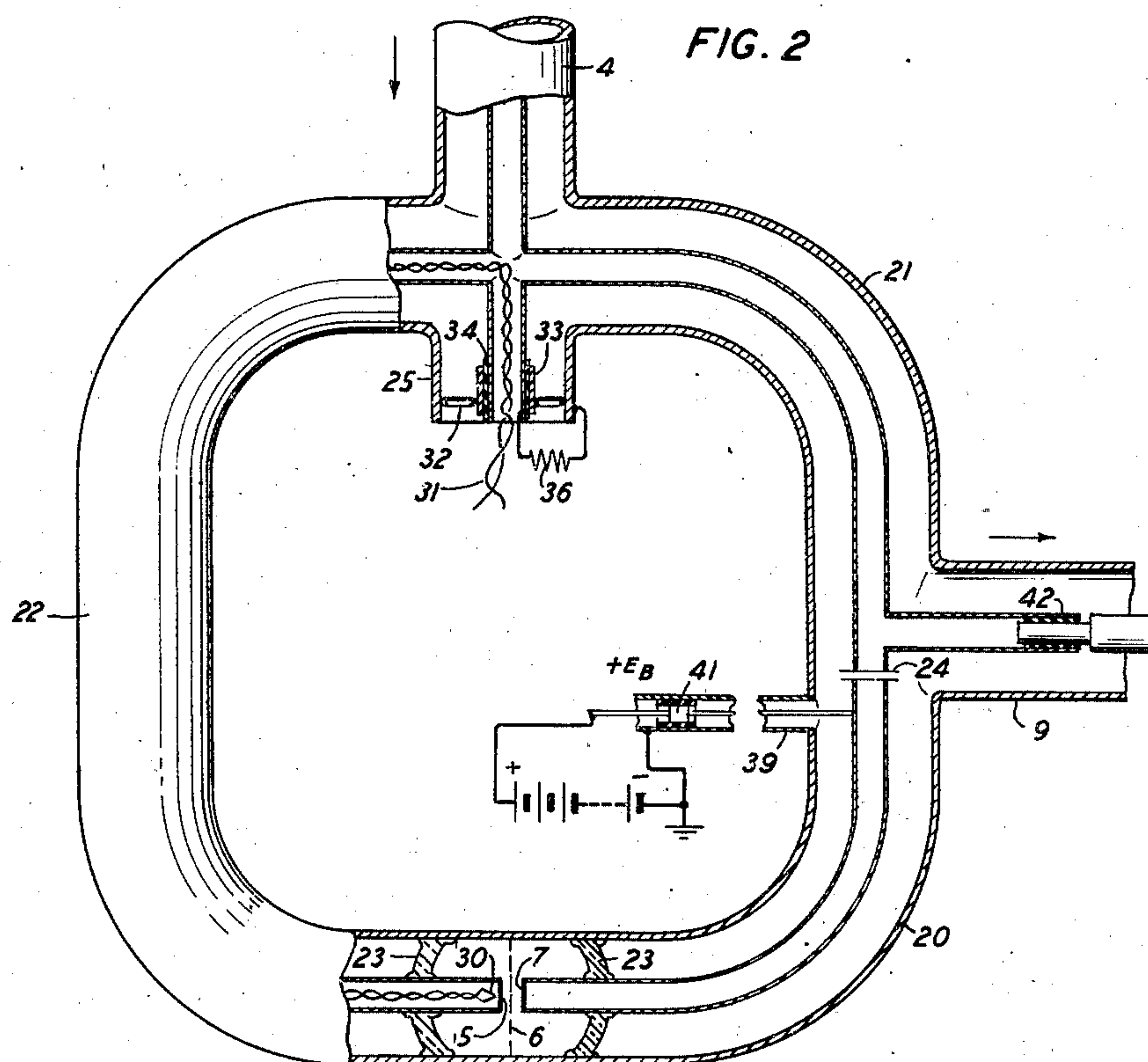


FIG. 2



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2 Sheets-Sheet 2

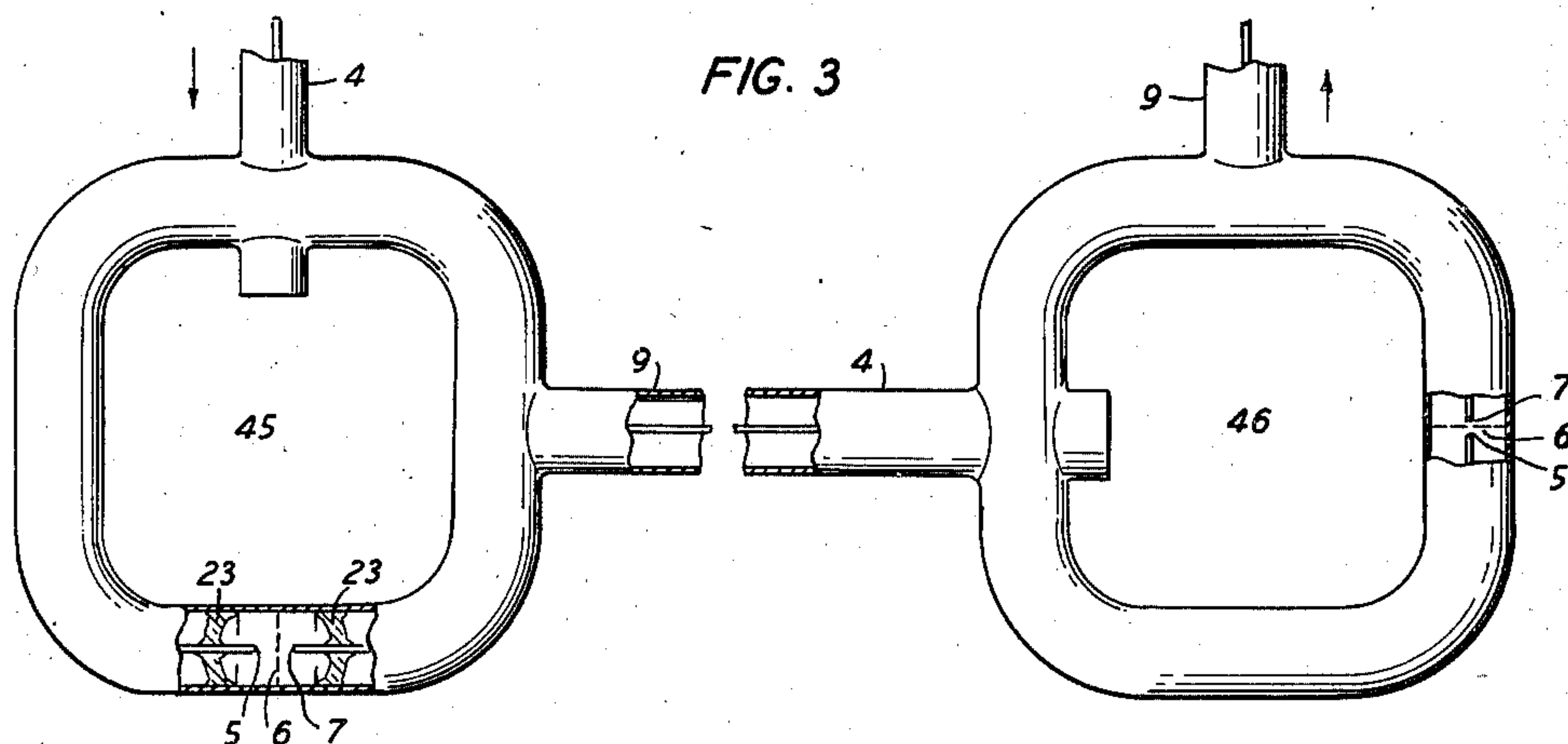


FIG. 4

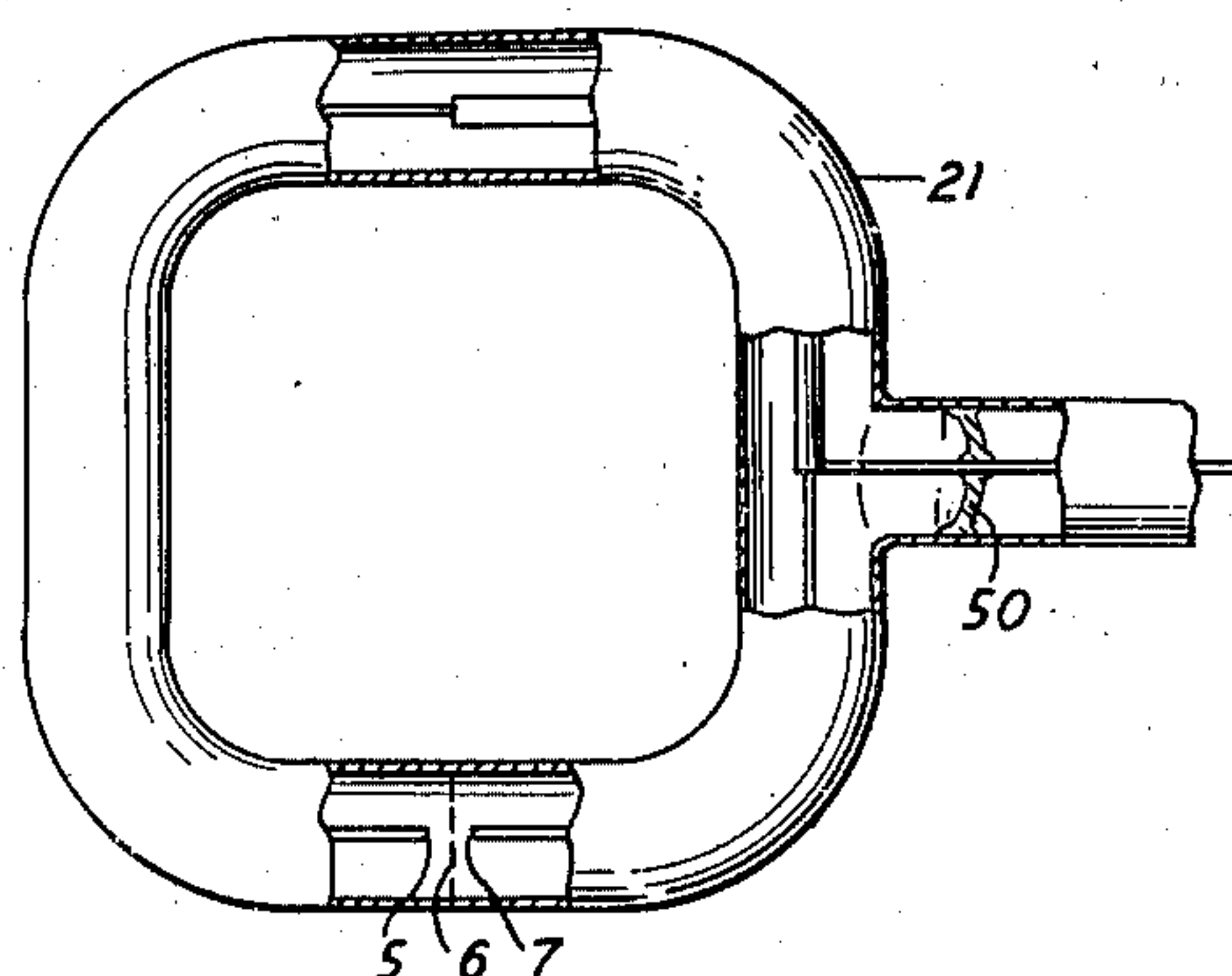
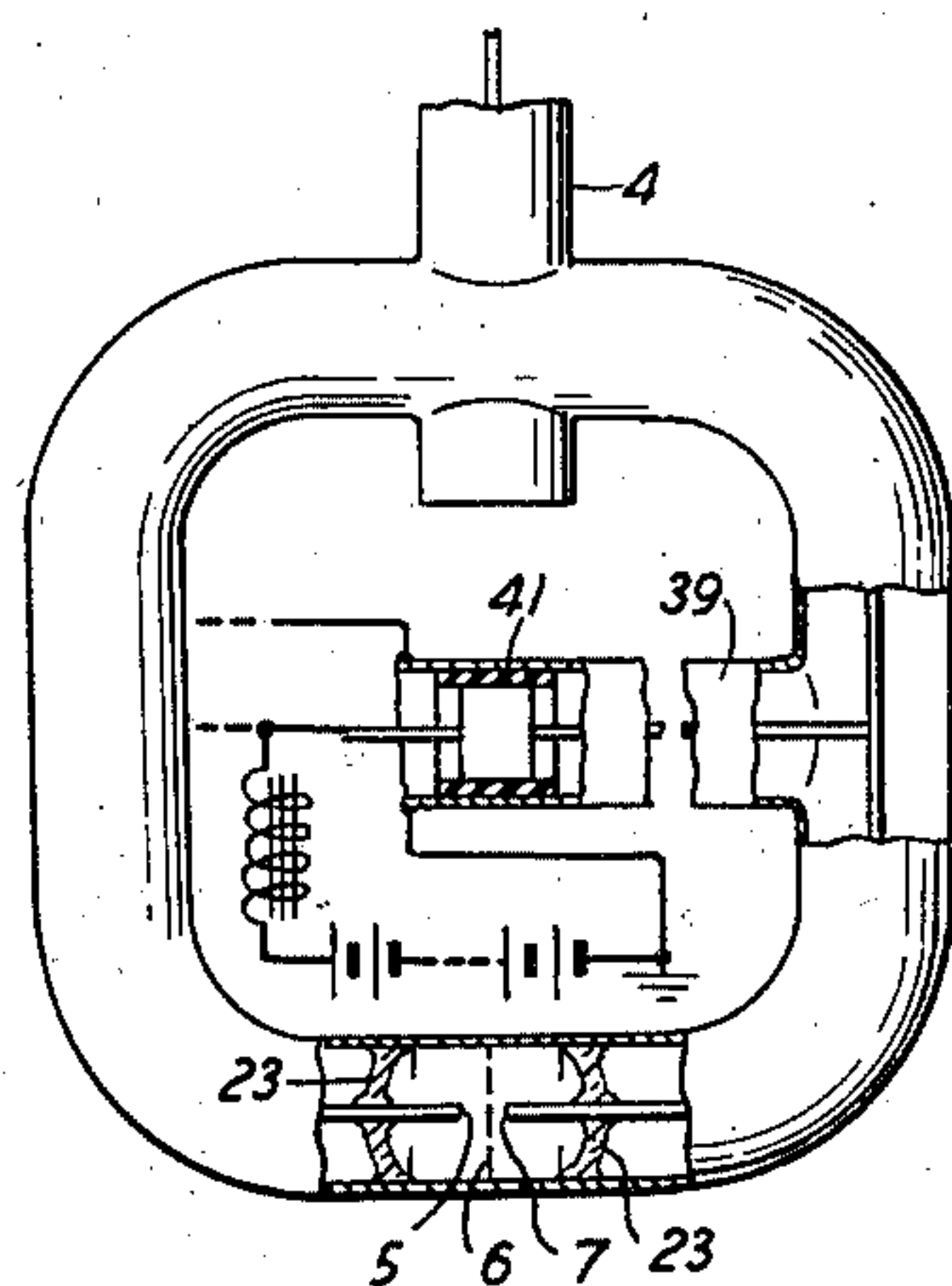


FIG. 5



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TRANSLATION OF MICROWAVES

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17 Claims. (Cl. 179—171)

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This invention relates to electrical systems for the translation of electromagnetic waves of ultra-high frequency and more particularly to systems involving amplifiers or amplification of waves in the wave-length range below one meter.

Objects of the invention include the neutralization of degenerative feedback in a grounded-grid amplifier, reduction of the effects of active input loss and loss due to electronic grid current in such amplifiers, neutralization of interelectrode impedances where these impedances are not directly accessible, and the elimination or reduction of end effects. Still another object is to reduce the effect on an amplifier of variations in the impedance of the connected load.

In accordance with a feature of the present invention an amplifying space discharge device is incorporated in a looped transmission line of shielded type with input and output connections to the loop at points thereof critically related to the operating wave-length. In accordance with another feature, embodied in an amplifier comprising a space discharge device with grounded grid, a feedback connection is established between a point in the output circuit of the device the potential of which is in phase quadrature with the anode current of the device and a point in the input circuit of the device, the electrical length of the feedback connection being such that the feedback is of positive sign.

Further features of the invention are found in a multistage amplifier comprising interconnected amplifying transmission loops, and still others will be pointed out hereinafter.

The nature of the present invention and its various features, objects and advantages will appear more fully from a consideration of the embodiments chosen for presentation herein and illustrated in the accompanying drawing.

In the drawing,

Fig. 1 shows in circuit schematic a grounded-grid amplifier in accordance with the invention;

Fig. 2 shows structural details and additional features thereof;

Fig. 3 illustrates the cascading of amplifier sections such as shown in Fig. 2; and

Figs. 4 and 5 illustrate, respectively, an oscillator and a frequency converter incorporating certain features of the invention.

Referring more particularly now to Fig. 1, there

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is represented schematically the high frequency circuits of a microwave amplifier comprising a three-electrode amplifying space discharge device 1, together with the source 2 of waves to be amplified and the useful load 3 connected to the output of the amplifier. The input circuit 4 of the amplifier is connected on the one side to cathode 5 of the discharge device and on the other to grid 6, which is grounded. The output circuit 8 is connected similarly to grid 6 and anode 7. One attribute of a grounded-grid amplifier such as this is the favorable distribution of the interelectrode impedances, for the comparatively large grid-anode capacitance is eliminated as a source of feedback, provided the reactance of the grid lead is negligible, and the cathode-anode impedance, which is in a position to produce feedback, is small inasmuch as the cathode is shielded by the interposed grid.

Due to the fact that in a grounded-grid amplifier the high frequency current in the anode circuit flows also through the input electrodes, i. e., the cathode, there is developed at the cathode a shunt conductance that tends to load up the input circuit and reduce the over-all gain. This may be considered to be inherent negative feedback. Positive feedback is obtained in Fig. 1 by selecting a point in the output circuit 8 where the alternating potential differs by 90 electrical degrees from the alternating current flowing into the anode 7 and feeding a part of the output currents from that point back to the input through a path of such electrical length as to make the feedback positive or regenerative. More particularly, there is interposed between the amplifying device 1 and the output terminals 9 a four-terminal network 10 that is adapted to introduce a 90-degree phase shift in the currents traversing it, this phase shift obtaining throughout the frequency range of interest. Another 90-degree phase shifter 11 is connected between the output of phase shifter 10 and the input electrodes of amplifying device 1. With regard to the sense or sign of the phase shifts in the devices 10 and 11 it is desired that the total phase shift in the feedback connection from anode 7 to cathode 5 be either zero or multiple, including unity, of 360 degrees. Thus, device 10 may introduce a positive phase shift and device 11 a negative phase

shift, whereby the total phase shift in the feedback is zero.

If the surge impedance of network 10 be represented by Z_1 and the alternating anode current by I_p , the alternating voltage E_1 at the output of network 10 is

$$E_1 = jI_p Z_1 \quad (1)$$

This is a fundamental relation which holds for 90-degree phase shifting elements entirely irrespective of the magnitude or the phase angle of the impedance of the load or other terminating impedances. If similarly the surge impedance of network 11 be represented by Z_2 , then the current I_{fb} that flows back to the cathode is

$$I_{fb} = jE_1 / Z_2 \quad (2)$$

$$I_{fb} = -\frac{Z_1}{Z_2} I_p \quad (3)$$

This relation again is a fundamental one and holds regardless of any voltage that may be present at the cathode or any impedance that may be connected between cathode and ground. If now the two surge impedances Z_1 and Z_2 be made exactly equal to each other, it is evident from Equation 3 that the feedback current will be exactly equal and opposite to the anode current and the loading effect of the anode current on the driving source thereby completely cancelled. Again it is important to note that the neutralization of inherent negative feedback as secured in this manner is quite independent of the nature of the load impedance and is therefore not affected if the load 3 happens to vary or is intentionally changed in respect of either magnitude or phase angle or both.

The foregoing considerations will show also that the relative surge impedance of networks 10 and 11 can be controlled to adjust the amount of feedback or degree of neutralization without disturbing the inherent immunity of the circuit to variations in load impedance.

In the embodiment of the invention that is illustrated in Fig. 2 use is made of sections of shielded transmission line for the phase shifting elements and for the connecting circuits. The amplifying discharge device is itself incorporated within a shielded line whereby the entire amplifier is completely shielded and constituted by an enclosed transmission loop. The coaxial type of shielded line is especially well adapted for the purposes of the present invention, and line sections of this type are employed in the Fig. 2 structure.

In Fig. 2 a closed transmission loop is formed by coaxial conductor line sections 20, 21 and 22. The input circuit of the amplifier comprises a coaxial conductor line 4 which is connected to the loop at the junction of sections 21 and 22, and the output circuit comprises a coaxial conductor line 9 which is connected to the loop at the junction of sections 20 and 21. At the third junction point is the grounded-grid amplifying space discharge device 1. The latter is disposed wholly within the outer of the coaxial conductors constituting the transmission loop and with the grid 6 arranged as a septum or barrier across the interior of that outer conductor. The thermionic cathode 5 and anode 7 are disposed on opposite sides of the grid septum symmetrically within the outer conductor and each is connected to, and may constitute virtually a continuation of, the inner conductor of the looped coaxial pair. Gas-tight seals 23 of glass or the like cooperate with the outer conductor to form an envelope or chamber enclos-

ing the several electrodes. Discharge devices of this general character are known in the art and no restriction of the invention is intended by the foregoing description of a typical form.

Coaxial line section 20, which is interposed between the output of the amplifying device and output circuit 9 in the relative position of phase shifting network 10 of Fig. 1, has a length that is approximately a quarter of the wave-length of the waves to be amplified, or an odd multiple thereof, and more particularly such length that the phase of the amplified waves delivered to output circuit 9 is in quadrature with the waves appearing at anode 7. In the simplest case section 20 is one quarter wave-length long and thereby operates as a positive 90-degree phase shifter. Line sections 21 and 22 combined have a total electrical length such that the wave power fed back to the input of the amplifying device through the transmission loop is in regenerative or positive feedback phase relation. For the case illustrated this means that the electrical length of the transmission loop is equivalent to an integral number of wave-lengths at the operating frequency. As to the manner in which the electrical length required of sections 21 and 22 combined should be apportioned to the respective sections, advantages are to be secured by making section 22 a half wave-length long, or a multiple thereof, and section 21 a quarter wave-length long or such odd multiple thereof as may be required. In the simplest case again section 21 is a quarter wave-length and section 22 a half wave-length, as illustrated.

In one aspect the Fig. 2 system may be considered as comprising two 90-degree positive phase shifters 20 and 21 of equal surge impedance disposed in circuit in the manner of the respective networks 10 and 11 of Fig. 1, with a half wave-length line constituting a perfect phase-reversing transformer of unity impedance ratio interposed between the input terminals of the amplifying device and the point of connection of the feedback circuit thereto.

The impedance into which the amplifying device works is a function of the impedance presented by the output circuit at its junction with the transmission loop and of the characteristic impedance of the line sections comprising the loop, hence one or both of these factors may be adjusted for maximum power output or impedance matching. In an illustrative case in accordance with Fig. 2 where all of the coaxial line sections have a characteristic impedance of 200 ohms and the resistive impedance presented by the load circuit is 40 ohms, and assuming the amplifying device to give a voltage amplification of 10 when operating with grid grounded, it can be readily shown that the impedance presented to the output of the amplifying device is 1100 ohms.

The Fig. 2 system as above-described, and other features thereof hereinafter to be described, involve utilization of a peculiar property of half-wave lines, viz., the fact that the current at one end of a uniform lossless half-wave line is exactly equal in magnitude and opposite in phase to the current at the other end, regardless of the manner in which the ends of the line are terminated and regardless of any shunt impedance that may be connected at its mid-point. Thus the shunt impedance presented by the load at the mid-point of the half-wave line comprising sections 20 and 21 has no effect on the performance of the two sections as a perfect phase-reversing current transformer of unity impedance ratio; just as,

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in Fig. 1, the relation between I_b and I_p , as indicated by Expression 3, is entirely independent of the shunt impedance 3 connected at the junction of the two 90-degree networks. A companion property of half-wave lines is that the voltage at one end of a uniform lossless half-wave line is exactly equal in magnitude and opposite in phase to the voltage at the other end, regardless of the terminations and regardless of any series impedance that may be connected at its mid-point. If the two quarter-wave sections making up the half-wave line are of different surge impedance, these two properties still hold except that a transformation ratio other than unity is obtained.

Interelectrode admittances in the amplifying device may be so substantial in some cases as to have a deleterious effect on the performance of the amplifier. Thus, if the admittance of the capacity between anode 7 and grid 6 or ground be comparable with the admittance into which the amplifying device works, the current supplied to section 20 will not be identical with the anode current that affects the input. To compensate for this effect a lumped capacitance 24 is inserted in series in the transmission loop at the junction of output line 9. The series impedance Z_3 of this capacitance appears at anode 7 as a shunt impedance Z_1^2/Z_3 , where Z_1 is the surge impedance of the intervening quarter-wave line section. The apparent shunt impedance is inductive and may be adjusted to neutralize or antiresonate with the capacitive anode-grid impedance.

Stray capacitance between cathode 5 and grid 6 or ground results in a finite, fixed input susceptance at the cathode and also at the junction of input line 4. This could be compensated in the same manner, that is, by inserting a series capacitance a quarter wave-length from the cathode. In Fig. 2, however, a shunt inductance at the half-wave point is provided for this purpose, the inductance comprising a short, inductive coaxial line stub or branch 25 at the junction of input line 4. The stub line 25 is advantageously arranged as an extension of the input line, as shown.

In view of the fact that the amplifier is completely shielded so that access to the input and output electrodes for cathode heating, etc. cannot readily be had, special provision is made in Fig. 2 as follows. Associated with thermionic cathode 5 and disposed within the hollow inner conductor of coaxial line section 22 is a cathode heater 30. Current supply leads 31 for the heater extend through the inner conductor of section 22 to the input junction where they are brought out through the hollow inner conductor of the coaxial stub 25 to a heating current source not shown. Grid bias for the discharge device is supplied through line section 22 from a source at the zero potential end of coaxial stub 25, the latter being short circuited for radio frequencies but not for direct current. As illustrated, the short circuiting means comprises a metallic reflector or piston 32 which rides on a metallic sleeve 33 that is separated from the inner conductor by an insulating sleeve 34. Resistor 36, connected across the short-circuited end of stub 25 is traversed by the steady component of anode current and the resultant voltage drop across it provides the desired grid biasing voltage.

Anode current is supplied from a battery or other suitable source that is connected through a coaxial line 39 to the inner and outer conductors of the transmission loop at the output junction.

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At the latter point the radio frequency potential is much lower than at the anode. Condenser 24 may be designed to serve as a blocking condenser adapted to confine the high anode battery voltage to line section 20. Line 39 is terminated by a reflecting piston or barrier 41 which is insulated from the outer conductor so as to permit passage of the direct current from the anode battery, and the barrier is placed approximately a quarter wave-length from the output junction or at such other point that line 39 presents high impedance at the output junction.

The self-bias voltage developed on the inner conductor of line sections 21 and 22 by virtue of resistor 36 may be prevented from reaching subsequent circuits by means of a blocking condenser 42 interposed in the inner conductor of output line 9. The condenser may be constructed, as illustrated, by breaking the inner conductor and inserting a sleeve of dielectric material between the inner face of one of the conductor portions and the outer face of a metallic extension, of reduced diameter, of the other portion.

The effects of active input loss and electronic grid current on the input of the amplifying device may be reduced by supplementary positive feedback, that is, by over-compensating for the inherent negative feedback. For this purpose the characteristic impedance of line section 21 may be reduced relative to that of section 20 thereby increasing the current fed back, as indicated by Expression 3, without impairing other properties of the system, or with the same effect the quarter-wave portion of section 22 that is adjacent the cathode may be so reduced in impedance. This may be done by using a larger inner conductor, for example, in that portion.

The Fig. 2 amplifier structure readily lends itself to concatenation of amplifier stages, as will appear from Fig. 3. Each of the stages, 45 and 46, may be of the Fig. 2 form, with the output line 9 of the one stage continuing as the input line 4 of the next stage. Compact mechanical arrangements of the multistage amplifier are readily obtained inasmuch as the shape of the transmission loops and the configuration of the interstage line may be varied as desired.

Positive feedback in the Fig. 2 structure may be increased to the point where oscillation occurs, as by modifying the relative impedances of the several line sections. Fig. 4 shows in simplified form an oscillator in accordance with this phase of the present invention. The construction is or may be much the same as that shown in Fig. 2 except for the omission of the input circuit 4. In accordance with one feature the impedance of line section 21 is reduced, by making the inner conductor of that section of larger diameter, to increase the positive feedback to the oscillation point. The frequency of oscillation is determined approximately by the total electrical length around the loop. A principal feature is the use of a single glass seal 50 instead of two seals as in Fig. 2, and the placing of this seal at a point outside the oscillation loop, in the output line, where the radio frequency potential is much lower than in the vicinity of the anode.

The Fig. 2 structure is adapted also for use as a frequency converter or modulator, utilizing nonlinear distortion in the space discharge device. For this use, as illustrated diagrammatically in Fig. 5 the output line 9 is omitted and the desired modulation products are taken off through the quarter wave-length line 39. The waves to be intermodulated, such as a radio signal side-

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band and locally generated beating oscillations, are supplied together over the input line 4. Various modulation products are generated, by virtue of non-linearity in the characteristics of the discharge device, and the desired products, such as the difference frequencies or original audio frequency signal, are selected from line 39. The selection may be accomplished by means of barrier 41 alone in many cases, but it will be evident that other and more elaborate arrangements may be employed which will pass direct current and a given band of frequencies while providing a reflecting termination for all other frequencies.

What is claimed is:

1. An amplifying space discharge device, a shielded transmission line enclosing said discharge device and connected to form a loop for the loop transmission of waves of predetermined frequency, and a wave output circuit connected to said loop.

2. An amplifying space discharge device, a shielded transmission line enclosing said discharge device and connected to form a loop for the loop transmission of waves of predetermined frequency, and a wave output circuit connected to said loop at a point thereof that is spaced from the output of said discharge device a quarter wave-length or odd multiple thereof.

3. An amplifying space discharge device, a shielded transmission line enclosing said discharge device and connected to form a loop for the loop transmission of waves of predetermined frequency, and a wave output circuit connected to said loop, said discharge device comprising an electrode shaped and disposed as a septum across the interior of said shielded line.

4. An amplifying space discharge device for electric waves, a multi-conductor line comprising a shielding conductor that encloses said discharge device, said line being looped from the output of said device to the input thereof and having such electrical length as to provide positive feedback, and a load connection to said looped line spaced from the output of said device a distance equivalent to an odd multiple of 90 electrical degrees at the frequency of said waves.

5. An amplifying space discharge device for electric waves, a multiconductor line comprising a shielding conductor that encloses said discharge device, said line being looped from the output of said device to the input thereof and having such electrical length as to provide positive feedback, a load connection to said looped line spaced from the output of said device a distance equivalent to an odd multiple of 90 electrical degrees at the frequency of said waves, and an input connection to said looped line spaced from said output connection a distance equivalent to an integral multiple of 180 electrical degrees at the frequency of said waves.

6. A space discharge device and means adapting it for operation as a grounded grid amplifier, a load connection from the output of said amplifier, a 90-degree phase shifter in said load connection, and a 90-degree phase shifter connected between the output of said first-mentioned phase shifter and the input of said amplifier.

7. A space discharge device and means adapting it for operation as a grounded grid amplifier, a load, a first quarter wave-length line connecting the output of said amplifier and said load, a second quarter wave-length line connected to the load end of said first line, and a phase reverser connecting said second line to the input of said amplifier.

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8. A combination in accordance with claim 7 in which said amplifier is subject to inherent negative feedback that is a function of the impedance of said load, the impedances of said lines being of such relative proportions that said negative feedback is neutralized by positive feedback through said second line irrespective of the impedance of said load.

9. A grounded grid amplifier adapted for the amplification of ultra-high frequency waves, said amplifier being subject to the effects of inherent negative feedback, a positive feedback loop including said amplifier and a pair of tandem quarter wave-length lines, and a load connected to the junction of said quarter wave-length lines.

10. In combination, a phase reversing transformer for electric waves comprising a transmission line having an electrical length of 180 degrees or multiple thereof at the frequency of the waves being transmitted, and a circuit of variable impedance connected in wave transfer relation with said line, said circuit being connected to said line at a point thereof such that the phase reversing effect of said line is independent of variations in said impedance.

11. In combination, a multielectrode space discharge device having input and output lines connected thereto, and means for neutralizing inter-electrode coupling comprising a reactor connected to one of said lines at a distance from said device of a quarter wave-length or multiple thereof.

12. In combination, a shielded transmission line constituting a closed wave transmission loop adapted for the loop transmission of waves of predetermined frequency, wave translating means localized in said loop and comprising a space discharge device disposed within said line, and an output circuit connected to said loop.

13. In combination, a shielded transmission line constituting a closed wave transmission loop adapted for the loop transmission of waves of predetermined frequency, wave translating means localized in said loop and comprising a space discharge device disposed within said line, said discharge device being adapted to intermodulate waves applied to it, means for introducing waves of different frequencies into said loop, and output circuit means connected to said loop for selectively diverting desired modulation products.

14. In combination, a shielded transmission line constituting a closed wave transmission loop adapted for the loop transmission of waves of predetermined frequency, a grounded grid amplifier comprising a space discharge device having an electrode shaped and disposed as a septum across the interior of said shielded line, and wave input and output circuits connected to said loop.

15. In combination, a shielded transmission line constituting a closed wave transmission loop adapted for the loop transmission of waves of predetermined frequency, a grounded grid amplifier comprising a space discharge device having an electrode shaped and disposed as a septum across the interior of said shielded line, and wave input and output circuits connected to said loop, said loop having such electrical length as to provide positive feedback for said amplifier.

16. In combination, a coaxial conductor transmission line constituting a closed wave transmission loop adapted for the loop transmission of waves of predetermined frequency, a grounded grid amplifier comprising a space discharge device having a grounded grid electrode shaped and disposed as a septum across the interior of said

line, an input circuit and a load connected at respective points to said loop, said loop having such electrical length as to provide positive feedback for said amplifier, said amplifier being subject to inherent negative feedback that is a function of the impedance of said load, and said load being connected to said loop at such point that said negative feedback is neutralized by positive feedback irrespective of the impedance of said load.

17. The combination, in accordance with claim 16, in which the said points at which said input circuit and load are connected to said loop, are spaced apart a distance equivalent to an integral

multiple of 180 electrical degrees at the frequency of said waves.

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