

Aug. 19, 1947.

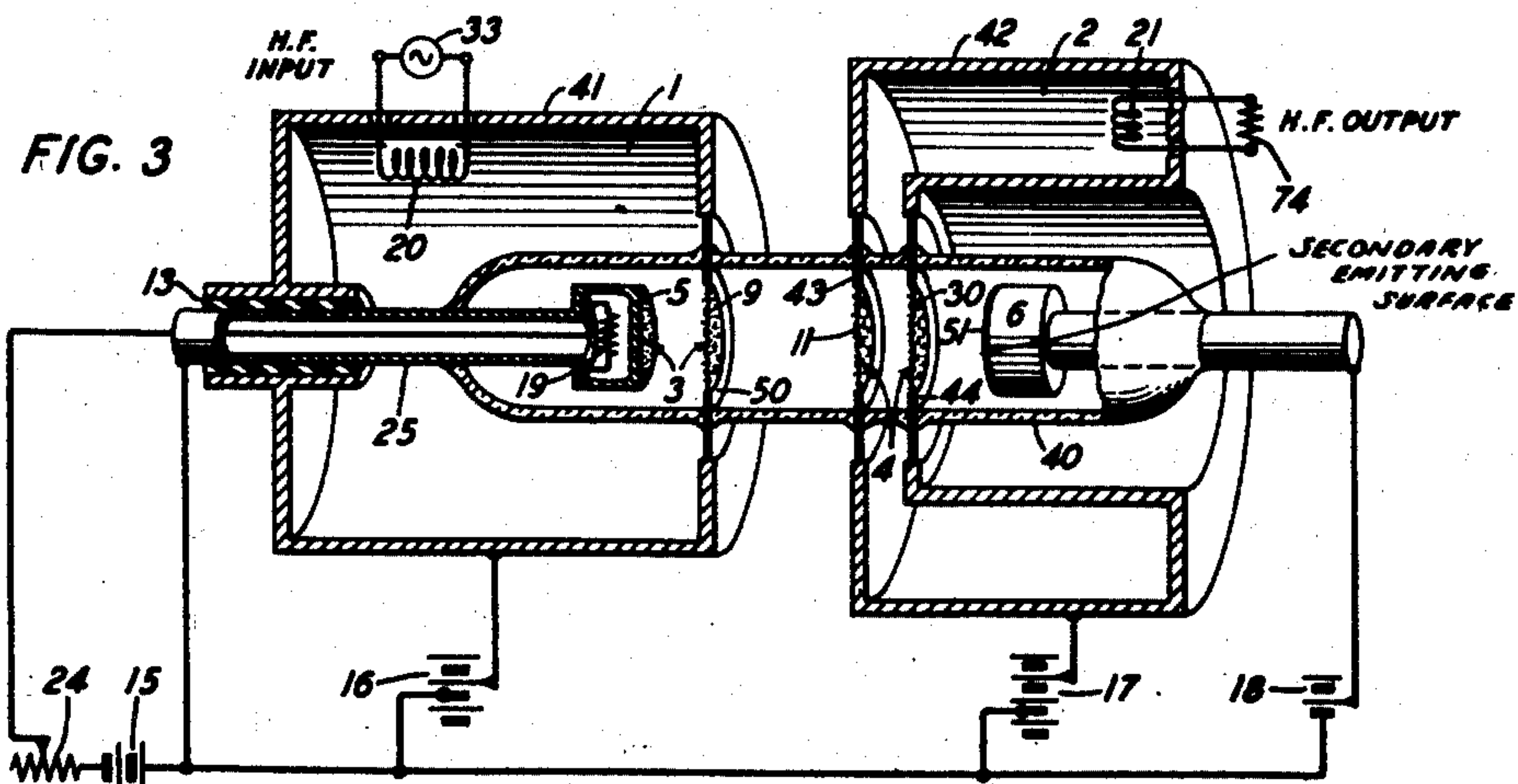
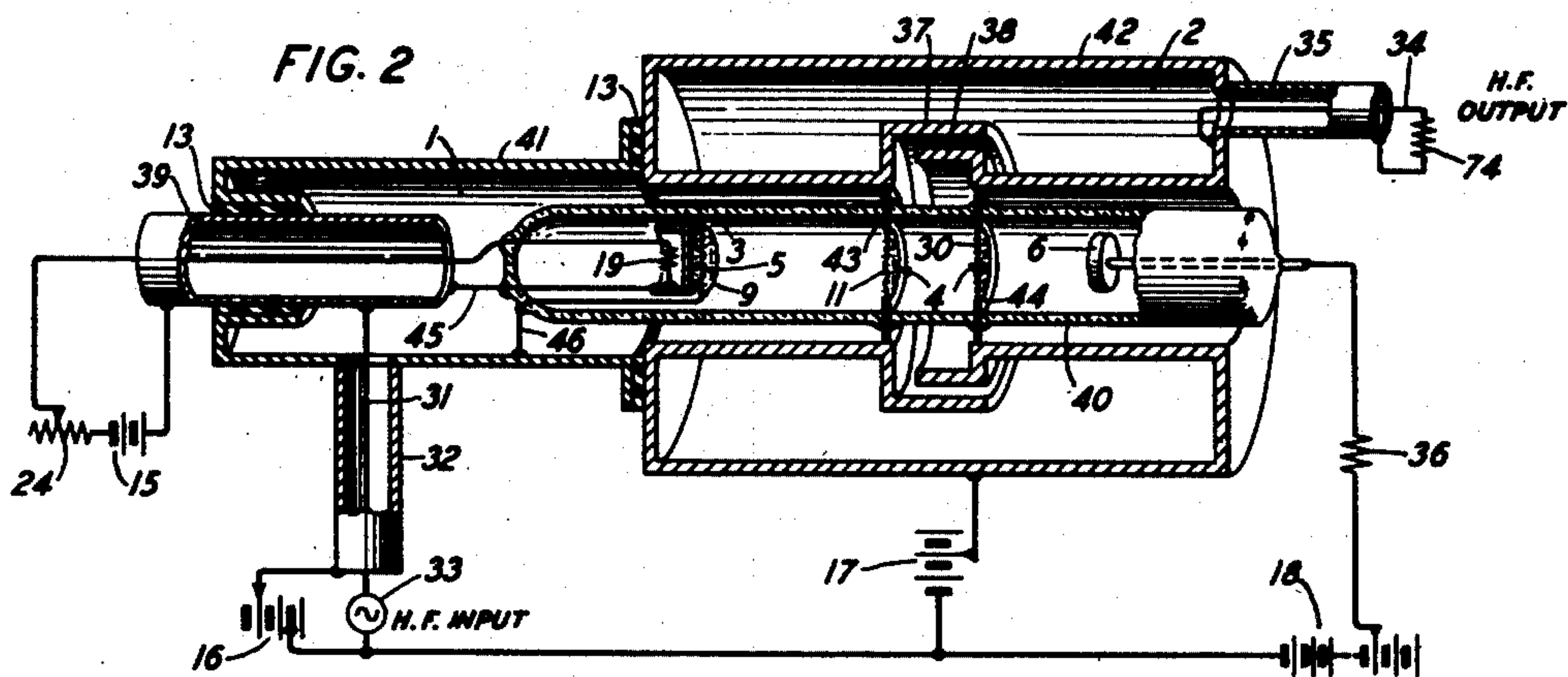
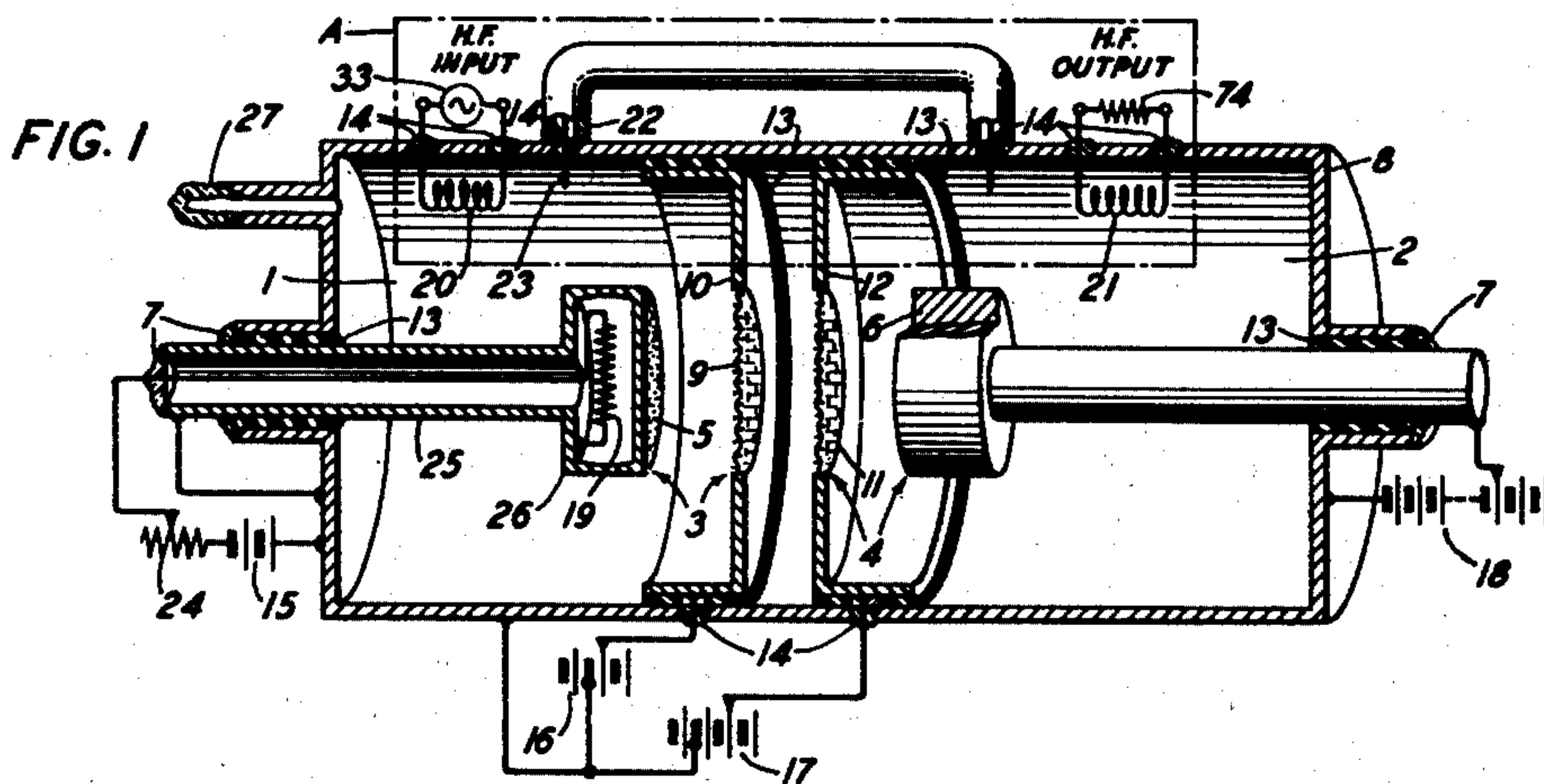
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2,425,748

ELECTRON DISCHARGE DEVICE

Filed March 11, 1941

3 Sheets-Sheet 1



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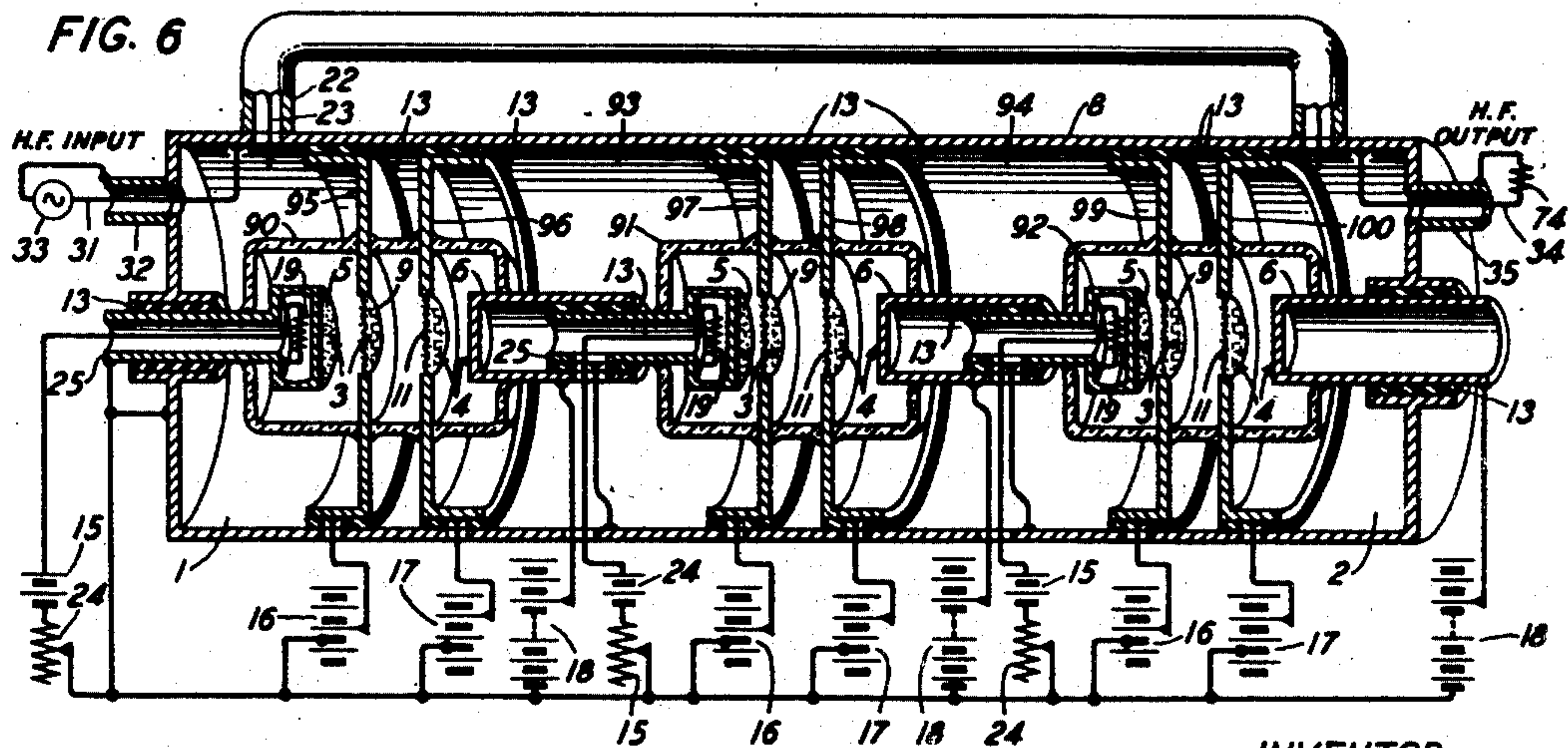
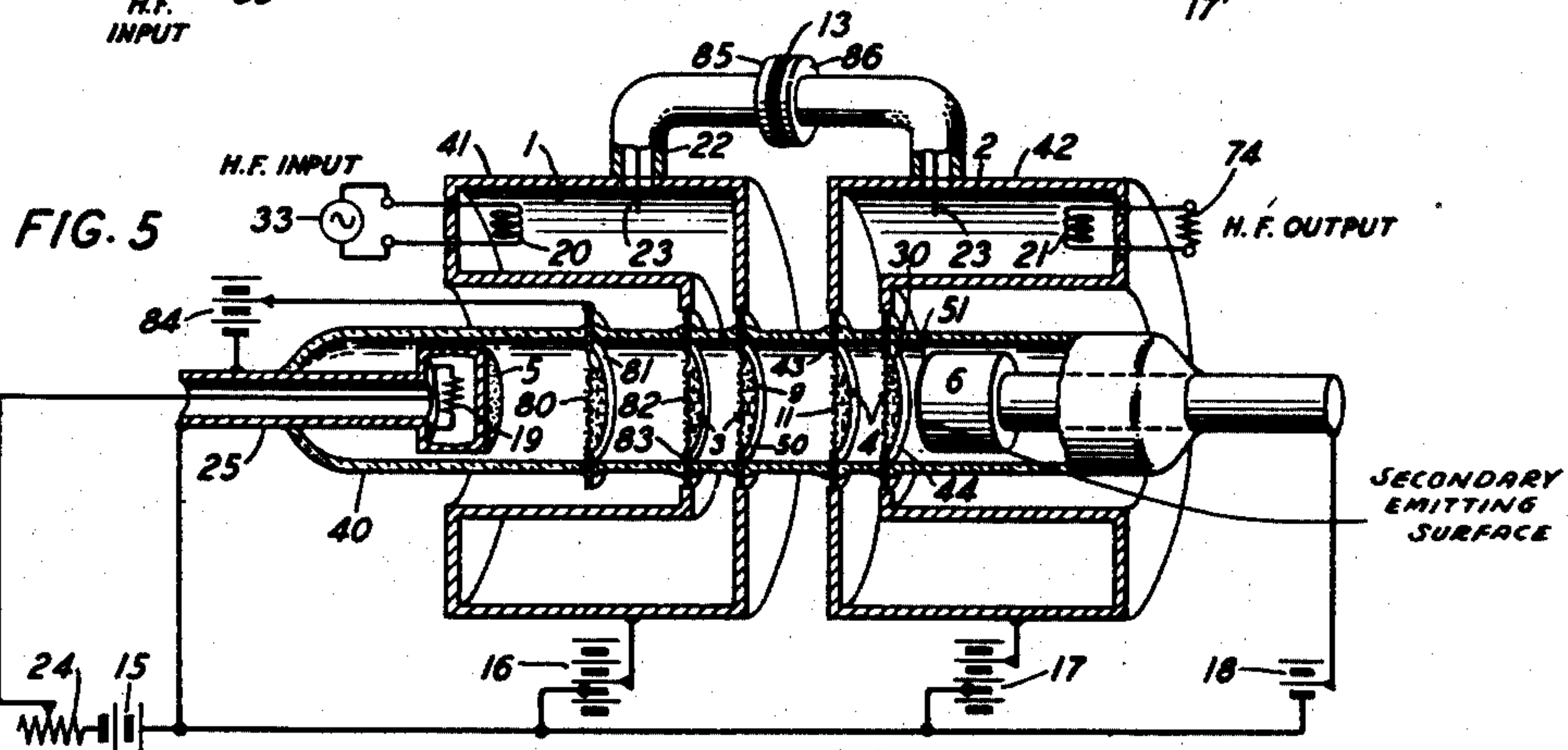
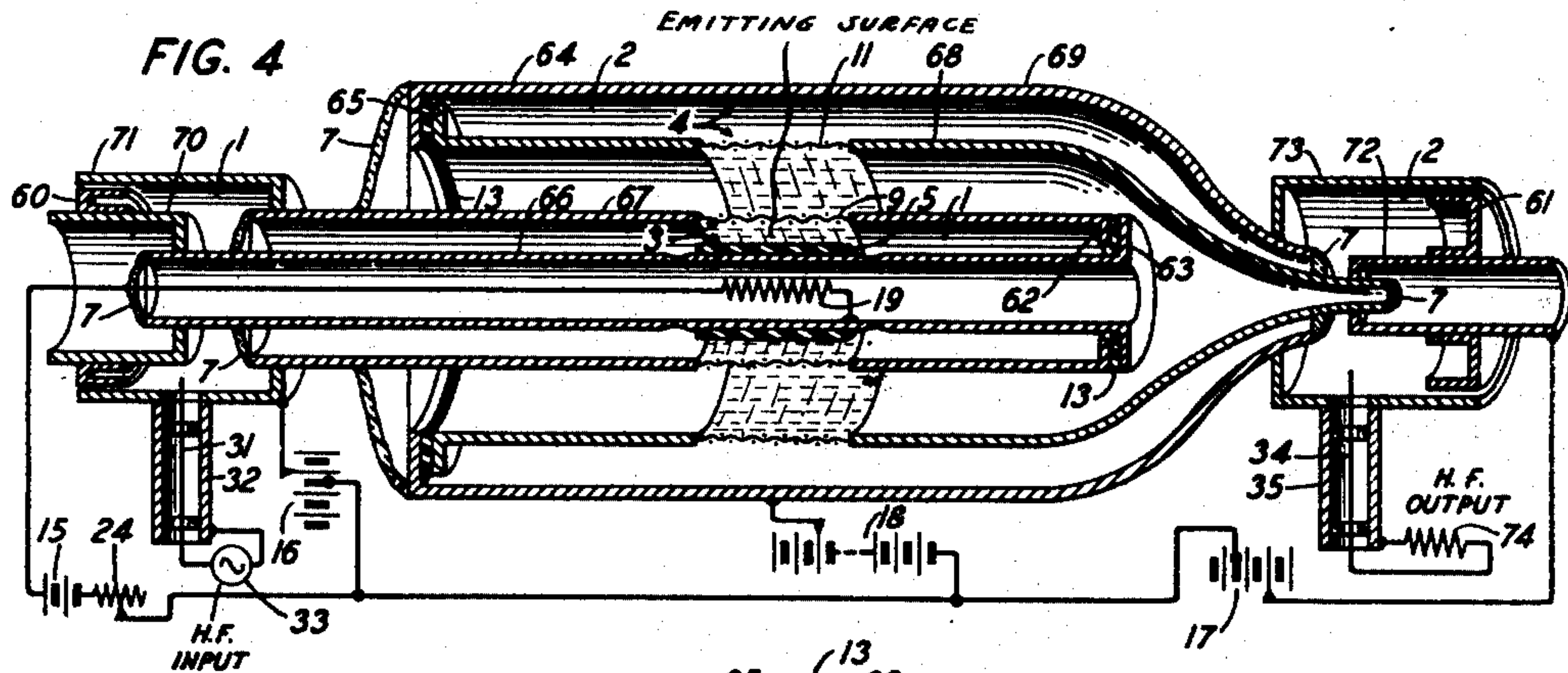
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ELECTRON DISCHARGE DEVICE

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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

FIG. 7

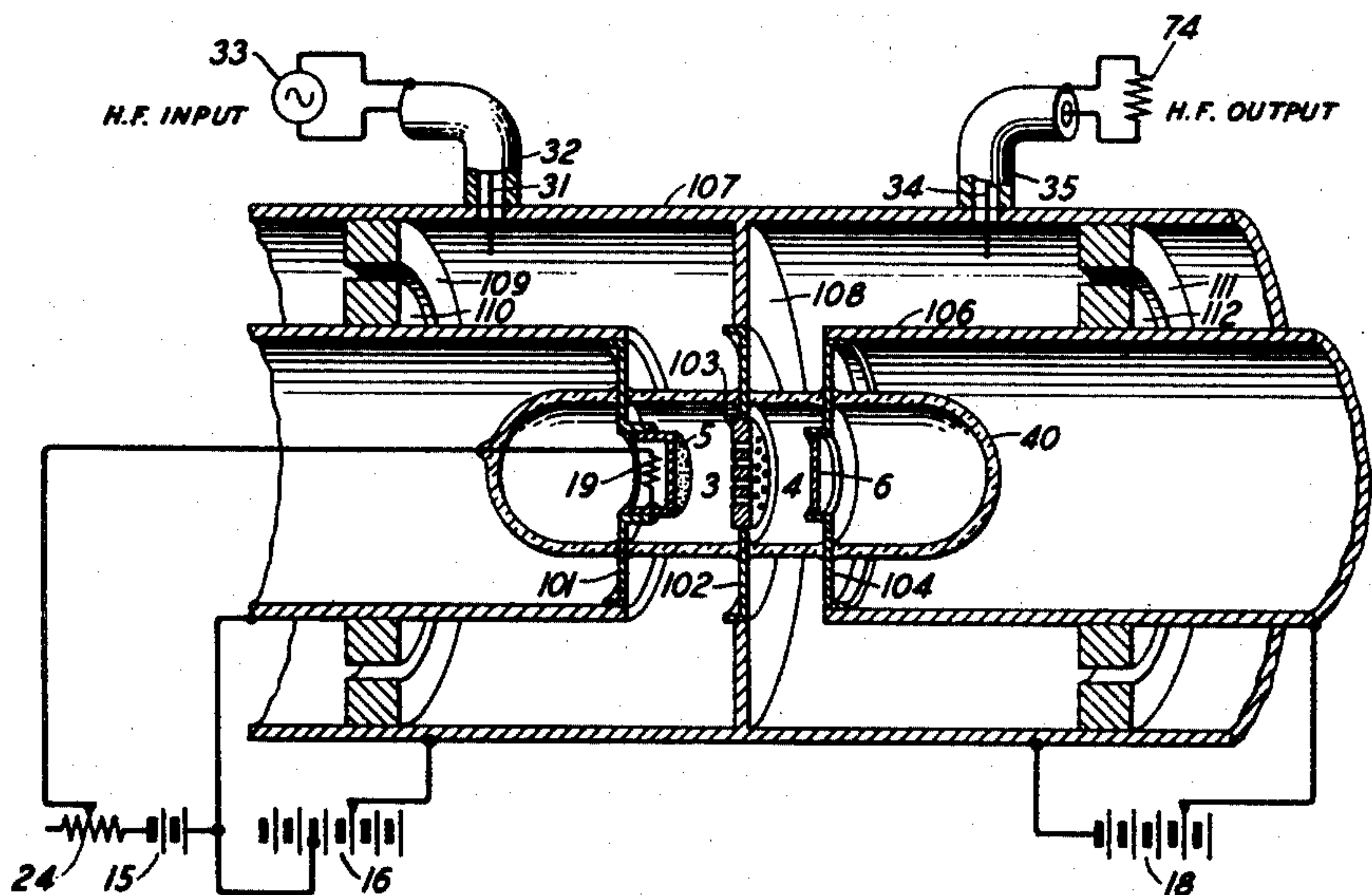
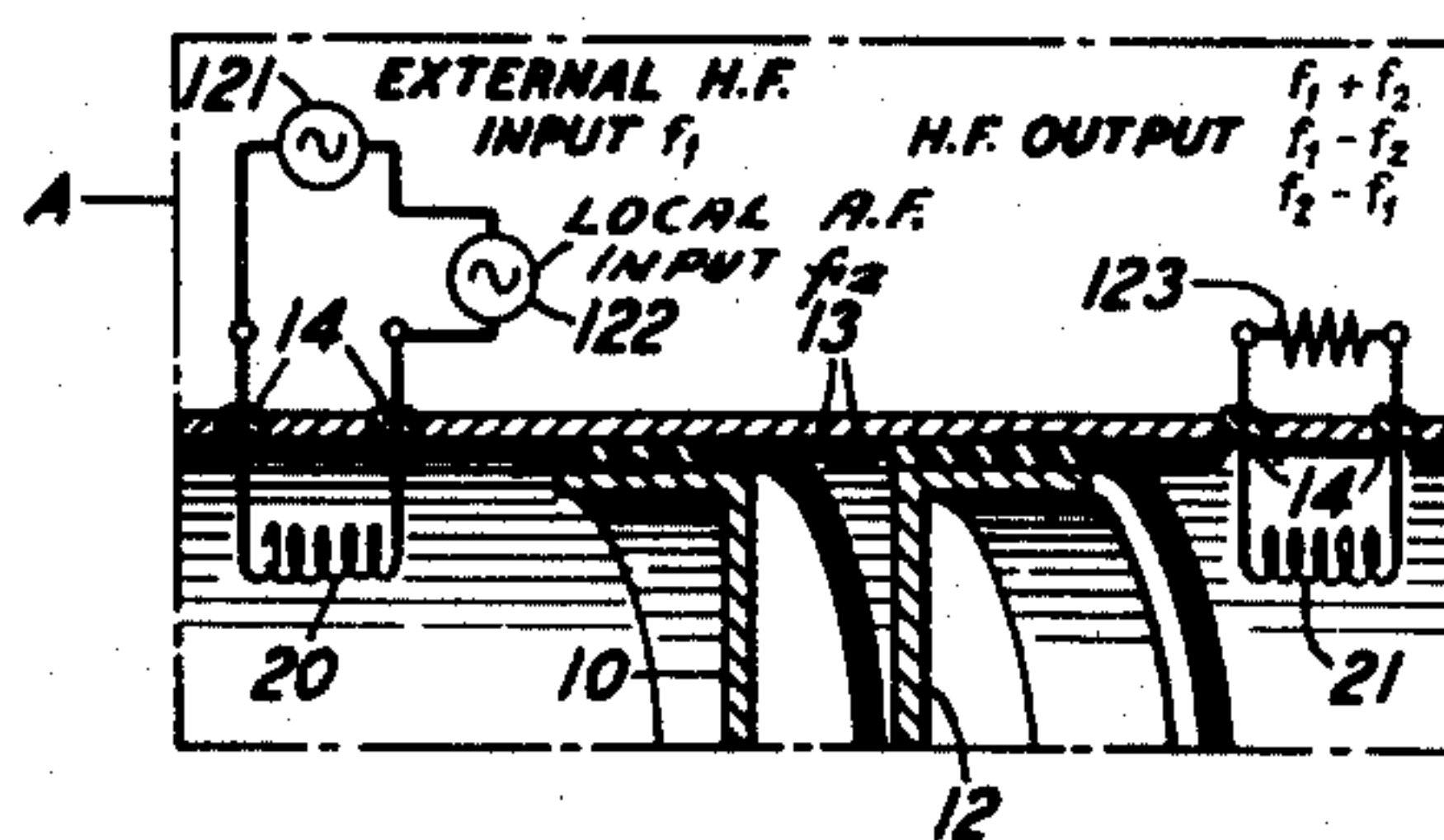


FIG. 8



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2,425,748

ELECTRON DISCHARGE DEVICE

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Application March 11, 1941, Serial No. 382,683

24 Claims. (Cl. 179—171)

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This invention relates to high frequency electronic devices for the production, amplification, or conversion of ultra-high frequency waves and particularly such devices as are characterized by critical electron transit times.

A principal object of this invention is to secure efficient amplification of ultra-high frequency waves, in the order of at least 3,000 megacycles, using moderately low voltage electron tubes.

An additional object of the invention is to produce or control oscillations of the order of 3,000 megacycles and higher in frequency with simpler discharge structures than those which are now effective for those purposes.

An additional object of the invention is to increase the available transadmittance of space charge controlled discharge devices at frequencies of the order of 3,000 megacycles and higher.

An additional object is to avoid the requirements for relatively high voltages, electron focussing and other complexities characteristic of available expedients such as devices employing "velocity variation" or "velocity modulation" as it is sometimes called.

A further object is to make available a device inherently capable of producing a degree of amplification at wave-lengths of the order of a few centimeters comparable to that heretofore attainable only at wave lengths of the order of a few meters.

Another object is to provide in such a device strictly unilateral amplification, that is, amplification where the transfer of high frequency energy shall be in only one direction, from input to output.

Efforts to operate space charge control tubes at frequencies of the order of 3,000 megacycles using the moderate electrode potentials, e. g., 200 to 400 volts, customary in lower frequency systems have met with little success. Some of the factors causing difficulty have been appreciated; for instance, the input loading at high frequencies occasioned by an effective shunting resistance between cathode and grid has been discussed at some length in various publications such as the articles "Operation of ultra-high frequency vacuum tubes," by F. B. Llewellyn, Bell System Technical Journal, October 1935, pages 632 to 665; "Analysis of the effects of space charge on grid impedance," by D. O. North, Proceedings of the Institute of Radio Engineers, January 1936, pages 108 to 136; and "The operation of electron tubes at high frequencies" by H. Rothe, Proceedings of the Institute of Radio Engineers, July 1940, pages

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325 to 331. The various theoretical studies together with the results of experimental work have led to the general conclusion that, above certain operating frequencies, barriers exist which preclude the useful operation of space charge control tubes. As a result it has been widely supposed that the transadmittance of tubes of the ordinary types decreases in magnitude as the frequency is increased thus interposing a definite barrier at frequencies even below 3,000 megacycles.

Recourse has been had to the velocity variation type of device in which the primary electron control is exercised through variation initially of electron velocities rather than of the density of the electron stream. Some success has been had with devices of this type but in general they call for the use of electrode voltages of the order of 500 to 1,000 volts or higher and accurate focussing of the electron stream and the transadmittance attained is not particularly high.

The applicant has discovered that in devices operating according to the general principles of the ordinary space charge control types of tubes to which reference has been made, the transadmittance actually does not decrease in magnitude as the frequency is increased if the tube is suitably designed and operated. The problem then becomes one of making use of that transadmittance properly. This problem has been solved in accordance with this invention by determining the conditions of operation under which the space charge control type of tube is not subject to the limitations with respect to operating frequency which heretofore have always been encountered and which, because of lack of knowledge of the means of avoiding them have hitherto been thought unavoidable.

Previous efforts to make a conventional tube such as a pentode amplify at frequencies of the order of 3,000 megacycles have uniformly failed. This was principally because such structures exhibited an inherent loss in the input circuit comprising the cathode and control grid, referred to above as input loading, of such a magnitude as to nullify the effect of the transadmittance and to conceal the fact of its existence. The solution of the problem begins with an appreciation that the magnitude of the transadmittance inherent in the electron stream may be maintained at high frequencies and that the problem is really that of making the amplifying effect of the transadmittance usefully available. A step in that direction is the further appreciation that if the cathode to grid zone of an electron discharge device

be electrically isolated from the remainder of the device, except, of course, to permit passage of the electron stream, it may be dealt with as a diode. It is possible to reduce the net resistance of a diode to any desired degree or even to make it negative by suitable design which will establish the electron transit time within the regions of 1 to $1\frac{1}{2}$ cycles or 2 to $2\frac{1}{2}$ cycles, etc., as is explained in detail in U. S. Patent 2,190,668, February 20, 1940. With the grid-cathode diode properly isolated and with its transit time such as to effectively annul the grid circuit loss a major beclouding effect is removed and the inherent transadmittance of the electron discharge device is made available. The grid may at one and the same time serve to electrically isolate the grid-cathode zone from the remainder of the device and to effectively couple the input circuit to the electron stream. Inasmuch as the transit time requirements permit a relatively wide spacing of the cathode and control grid and also permit moderate space current voltages to be used the solution of the tube design problem is greatly facilitated.

Since energy transfer by an electron discharge amplifier requires a coupling between the input circuit and the electron stream and a second coupling between the electron stream and the output circuit it is desirable to make the couplings to the electron stream as intimate and effective as possible. In the case of the output circuit a very desirable expedient is to employ a low loss closed electrically resonant shell into which the electron stream may be introduced or through which it may pass. If the stream enters the output resonator shell through a fine grid and, if passing through the shell, leaves through a similar grid, the output resonator serves to improve the electrical isolation of the input diode. The gap or transit path between the grids, or between grid and anode, of the output resonator should be short in order to maintain the transadmittance at a high magnitude at high frequencies. The magnitude of the transadmittance is substantially the same as would be produced in a low frequency tube of the same dimensions and operating voltages when the transit angle across the output gap is small. The transit time should be less than a cycle of the high frequency oscillation and preferably small with relation to a cycle.

In accordance with the principles of the invention which have been outlined, an electron discharge amplifier for very high frequencies will comprise a structure quite different from that of the usual low frequency amplifier with its container of glass or similar dielectric material through which pass wire leads for providing electrical connection between the circuit and the tube electrodes. Instead, in a preferred form, two substantially closed resonant conducting shells are provided, one of which constitutes the input circuit and the other the output circuit. Within the input circuit is a cathode spaced at a critical electrical distance, for example, $1\frac{1}{4}$ cycles transit time from a grid through which the electron stream leaves the input shell. The output shell is provided with closely spaced grids, or closely spaced grid and anode, which mark the end points of the transit of the stream through the shell. In practical application the transit angle through the output shell may be given values from the minimum readily attainable up to many hundreds of degrees but preferably less than 90 degrees at which the magnitude of the transadmittance will have decreased only about 10 per cent below its

maximum magnitude which occurs at very small transit angles. With such a structure a transadmittance of several thousand micromhos has been obtained at a frequency of 3,000 megacycles as compared with a transadmittance of a few hundred micromhos with a velocity variation type of tube.

The invention will be understood more fully from the following detailed description and the illustrative embodiments shown in the accompanying drawings.

In the drawings:

Fig. 1 shows in one form a space charge control amplifier embodying the principles of the invention;

Fig. 2 shows an amplifier arrangement operating according to certain principles of the invention;

Fig. 3 shows an alternative form of amplifier embodying the invention. Differences from the arrangement of Fig. 1 are that the electron collector is separated from the high frequency electrodes and the input and output resonant systems are physically separate;

Fig. 4 shows a tube similar in operation to that of Fig. 1 but in which the elements are cylindrical and the electron emission is radial;

Fig. 5 shows a tube embodying the invention in which both the cathode and the anode are separate from the high frequency electrodes and an additional electrode is shown as an electron accelerator for the purpose of producing a virtual cathode near the high frequency input electrodes;

Fig. 6 shows a three-stage amplifier embodying the invention and including a feedback circuit which may be used to improve the transmission characteristic;

Fig. 7 shows an embodiment of the invention wherein the electron tube utilizes only three elements, a cathode, an anode, and a single control grid of special form intended to serve effectively as a shield between the input and output circuits; and

Fig. 8 shows a modification of a portion of Fig. 1 adapting it to use as a high frequency converter.

Fig. 1 shows a cylindrical conducting shell 8 which forms portions of the amplifier input and output circuits and, being evacuated through tubulation 27, serves also as the envelope of the electron tube. The cathode, control grid, screen and anode are shown at 5, 9, 11 and 6, respectively. The sources of biasing potentials, 16, 17 and 18, may be such that the first or control grid is negative with respect to the cathode while the screen and anode are positive with the anode at a somewhat higher potential than the screen. Maintenance of the control grid negative with respect to the cathode is not important for critical transit time operation as it is for the usual low frequency type of operation so that here the potential may be either positive or negative with respect to the cathode. The cathode 5 is indirectly heated by means of the heater 19 which is energized from battery 15. The cathode temperature is preferably adjusted to secure emission only slightly in excess of that required to provide complete space charge in the electron stream. It will be noted that the cathode heater is entirely enclosed within the cathode sleeve. It is important to provide means for thermal attenuation in order to direct as much of the heat as possible to the coated surface 5 and thus avoid the introduction of the losses which occur when the high frequency conducting surfaces are oper-

ated at very high temperatures. In the figure, a simple means of heat attenuation is provided by forming the walls of the cathode sleeve with an extremely thin portion at 26 just behind the active surface thus retarding the flow of heat in the direction away from the coated surface 5.

For the high frequency, the input circuit is formed by the cavity resonator 1, where the outer shell 8 comprises the external conductor, the cathode together with its sleeve 25 forms a re-entrant member and the control grid 9 mounted in the center of an annular member 10 closes the end effectively, allowing electrons to pass through but confining nearly all of the input energy to the cavity 1. The grid 9, and also screen 11, may be of parallel wires, a wire screen, or other form of construction which provides good electrical shielding while permitting the passage of electrons. Similarly, the output circuit is a cavity resonator, 2, whose outer conductor is formed by the shell 8, while the anode 6 together with its support comprises a reentrant member and the screen 11 mounted in the center of the annular member 12 closes the end effectively, allowing the electrons to enter, but confining nearly all of the output energy to the output cavity 2. It will be noted that insulation for the polarizing potentials is provided by the insulating sleeves 13 interposed between members and flanges of sufficient area to provide capacitances of negligible impedance to the high frequency. The glass, or equivalent, seals at points 7 and points 14 provide vacuum tight means for the introduction of electrical connections through the envelope of the electron tube to members within.

The space between the control grid 9 and the screen 11 is relatively field-free and provides additional means of segregating the output cavity from the input cavity and thus eliminating mutual couplings. The two grids, 9 and 11, might be replaced by a single one providing sufficient segregation of the two cavities is obtained, or, on the other hand, additional grids might be interposed between those shown in the figure for the purpose of improving the screening, removing unwanted secondary electrons or for other purposes in the well-known manner employed at low frequencies. An example of single grid construction is shown in Fig. 7.

In operation the input signal to be amplified is introduced into the cavity 1 and the amplified output energy is extracted from the cavity 2. Many methods are available for accomplishing these results. The method shown in Fig. 1 utilizing coupling coils 20 and 21 which may be connected by the terminals shown to a suitable high frequency input source and to a high frequency load, respectively, is merely illustrative. Another method of coupling is illustrated in the feedback connection, provided by coaxial line 22, 23, where portions of conductor 23 simply project a short distance into the cavities and thus couple with the high frequency fields within.

The feedback connection shown in Fig. 1 utilizing the coaxial line composed of outer conductor 22 and inner conductor 23 is not essential to operation of the device as an amplifier. It is shown to illustrate a means of transferring energy from the output portion of the device to the input portion in a controlled manner to provide either regenerative operation, self-oscillation or inverse feedback to improve stability and reduce distortion. The amount of feedback is determined by the adjustment of the couplings and the phase may be determined, to make the feedback

regenerative or inverse in character, by adjustment of the length of the connecting line.

The operation of the arrangement of Fig. 1 may be outlined as follows: Under the influence of the biasing potentials between the cathode and the other electrodes a stream of electrons passes from the cathode 5, through the control grid 9 and the screen 11 to the anode 6. The electron stream thus passes through the gap 3 in the input cavity resonator and the gap 4 in the output cavity resonator. In each of these gaps there is a high frequency electric field when the input resonator is excited by a high frequency input and high frequency is generated in the output resonator, these resonators being constituted as previously described. The electrons flowing across gap 3 are grouped by space charge variation caused by the high frequency input which varies at high frequency the potential between the control grid 9 and the cathode 5. Thus an electron stream, the density of which varies in accordance with the input signal, passes out of gap 3 and through the space between the gaps 3 and 4. This space is relatively free of high frequency field and the degree of space charge within it may be controlled by the biasing potential on the adjoining electrodes. The density variations in the electron stream (sometimes called bunches) progress across the space without substantial decrease in amplitude, are impressed across the output circuit at gap 4 thereby inducing the desired output in resonator 2 and are collected on anode 6.

It should be noted here that the electrons enter the space between gaps 3 and 4 having been already grouped into bunches so that this space, free of the high frequency fields, through which the electrons drift, unlike the drift space in devices utilizing the so-called velocity modulation principle, is not called upon to perform the grouping function. This grouping function and other characteristics of velocity modulated tubes have been described in an article "Velocity modulated tubes," by W. C. Hahn and G. F. Metcalf in the Proceedings of The Institute of Radio Engineers, February 1939, pages 106 to 116, concerning a tube somewhat similar in appearance to Fig. 1 but different in principle and method of operation.

Another type of amplifier which superficially resembles the arrangement shown in Fig. 1 is the so-called inductive output type such as is described in the article "An ultra-high frequency power amplifier of novel design," by Andrew V. Haefl in Electronics magazine, February 1939, pages 30 to 32. In that amplifier the electron discharge is controlled by a space charge control grid and the output energy is generated in a resonant cavity much as is done in the arrangement of Fig. 1. However, there are important differences between the amplifier described by Haefl and the arrangement of Fig. 1. Very complete shielding of the electrical circuits and the electron stream is a feature of Fig. 1, and, while the Haefl amplifier utilizes high velocity electrons to minimize transit time effects in the input circuit and also between the input and output circuits, the arrangement of Fig. 1, like the arrangement of the other figures following, utilizes a transit time across the input space critically related to the operating high frequency to minimize the input loading effects and does not require a small, or even a critical, transit time in the space between input and output. This is obviously advantageous since it allows latitude in the spacing of the input electrodes and permits the use of

moderate electrode biasing voltages rather than excessively high voltages such as are required to accelerate high velocity electrons.

In one aspect the arrangement of Fig. 1 might be looked upon as a type of "grounded grid" amplifier. Such amplifiers have been used to some extent at low and moderately high frequencies and are found to have the disadvantage that the output current flows through the input energy path producing a type of feedback which does not cause oscillation but produces a low impedance at the input. The system of Fig. 1 does not operate in this fashion because with the exception of any coupling through the feedback connection through line 22, 23 which is controllable advantageously as has already been indicated, the input and output systems are completely shielded from one another so that no high frequency from the output can get back to the input circuit. The leakage through grids 9 and 11 is not sufficient to affect this condition appreciably and for even better shielding than shown in Fig. 1 an additional grid may be interposed between 9 and 11 or the distance between 9 and 11 may be lengthened. High frequency in the direct current supply leads is obviated by the shielding and adequate by-pass capacitances where the direct current leads are connected to the enclosed high frequency systems. Thus the bunched, or variable current flowing inside the tube is entirely smoothed out for external leads by the flow of displacement current.

It has been mentioned that a feature of the invention is the reduction of input loading by operating with the input electron transit time critically related to the operating frequency. It has been shown in applicant's Patent 2,190,668, dated February 20, 1940, which will be referred to later, that when the duration of electron transit time between two electrodes, such as across gap 3 between cathode 5 and control grid 9, lies between 1 and $1\frac{1}{2}$ or between 2 and $2\frac{1}{2}$, etc., cycles of the operating high frequency, the loading resistance produced by the electron stream is negative in sign. When the electron current is not sufficiently large to cause this negative resistance to exceed the positive resistance of the resonant input system and connected circuits, no singing oscillations can occur and the negative input loading resistance can, therefore, be used to compensate for the extra losses in the input system caused by the presence of the hot cathode surface 5.

The production of negative loading resistance, rather than positive, by operating with critically related electron transit time across the input electrodes in this amplifier arrangement is similar to the production of negative resistance in diodes as described in the before-mentioned applicant's Patent 2,190,668, dated February 20, 1940. Reference may be made to that patent wherein an equation is developed relating the resistance of an electron stream and the electron transit time and a curve of the equation is plotted (Fig. 3 of said Patent 2,190,668) showing the regions where the resistance is negative. This figure shows that, as previously stated, the resistance is negative when the transit time is between the periods of 1 and $1\frac{1}{2}$ or between 2 and $2\frac{1}{2}$ or between 3 and $3\frac{1}{2}$, etc., cycles of the operating high frequency. The greatest negative values of resistance occur when the transit time is substantially the period of $1\frac{1}{4}$, $2\frac{1}{4}$, $3\frac{1}{4}$, etc., cycles of the operating high frequency.

In applicant's copending application, Serial No. 75

319,414, filed February 17, 1940, now Patent No. 2,308,523, dated January 19, 1943, is described the use of a diode operated in this manner to compensate for high frequency circuit resistance.

The principle, the production of negative resistance by critical adjustment of input electron transit time, is utilized in this invention to compensate for and thus effectively eliminate input loading in high frequency amplifiers and the like. In Fig. 1, for example, the input electron transit time is the time required for an electron to traverse the gap 3 between the cathode 5 and the control grid 9 and its duration is determined by the spacing of the tube electrodes and the polarizing voltages employed. The usual, though not essential procedure to obtain the proper input transit time is to fix appropriately the anode potential by source 18, the screen potential by source 17 and make the final adjustment that of the control grid potential by source 16. The anode 6 must, of course, be positive with respect to the cathode. The screen 11 and control grid 9 may be either positive or negative with respect to the cathode.

As has been previously mentioned, the length of gap 4, between the grid 11 and the anode 6, and the biasing potentials are so related that the output electron transit time, across gap 4, is made short, preferably less than a cycle of the high frequency, to maintain the transadmittance at a high magnitude.

It is noteworthy that when the input electron transit time is the period of several cycles, rather than only 1 or 2, the tendency for the electron stream to produce input loading gradually decreases with further increase in the number of cycles required as is indicated by the decreasing amplitude of the curve of Fig. 3, Patent 2,190,668, previously referred to. Thus at the extremely high frequencies electrons may be allowed to consume a good many cycles in their transit across the input space, and the adjustment called for by the requirement of a whole number of cycles plus a quarter for the transit time becomes less critical as the number of cycles becomes larger. It is true that there will then be less negative resistance available to compensate for circuit losses, but on the other hand, neither will there be severe loading in case the adjustment for producing the desired transit time should change for any reason. It follows that the tolerances to which the biasing potentials must be held for the purpose of maintaining proper electron transit time do not become impractically severe at the higher frequencies where the input transit time may be made to extend over several cycles as for convenience in construction.

Proper electron transit time adjustment must be supplemented by suitable physical structures in order to achieve substantial high frequency amplification, and space charge control tubes constructed as in the past for low frequency applications are not at all well adapted to use in amplifiers for 10 or 20 centimeter waves. Thus, important features of this invention are the physical embodiments which conform to the conditions under which amplification is possible at these high frequencies, and under tube operating conditions comparable to those usual in operation at lower frequencies. The possibilities attainable are indicated by the results of tests on preliminary designs of tubes and circuits based on the invention. In one such test an amplifier employing the principles described above and illustrated by Fig. 1, but without a feedback arrangement such as line 22, 23 and with inherent regen-

eration reduced to an inappreciable amount by care in the reduction of stray coupling between input and output, gave a gain of 9.5 decibels at a wave-length of 18 centimeters when the total cathode emission was only 18 milliamperes and when the highest potential employed was not more than 400 volts on the anode. In the particular tube used, the cathode-grid separation was about 0.015 inch. The grid-screen separation was 0.125 inch and the screen-anode separation was 0.015 inch. The cathode diameter was $\frac{3}{8}$ inch and the whole of its flat end-surface was coated with thermionic emitting material. The grid was operated at a positive potential to secure the desired emission with an input electron transit time (between the cathode and the grid) the period of about $1\frac{1}{4}$ cycles of the operating high frequency. In order to reduce the effect of secondary emission from the screen, its bias was made approximately the same as that of the grid. It may be noted that on account of the various electrode biasing potentials the electron velocity may be different over different portions of the electron path so that the relative electron transit times through the input and output gaps are not necessarily proportional to the relative physical lengths of those gaps. Thus in the input gap the electrons may be traveling relatively slowly while in the output gap the potentials are such that their velocity is much greater and in practice the lengths of the gaps may be equal.

Fig. 2 shows a tube and circuit arrangement which was one of the first to be tested according to the principles of the invention. The structure is not ideal and embraces compromises which are avoided in preferred arrangements illustrated in other figures. Designation numbers which are the same as on Fig. 1 indicate similar elements in the two figures. In Fig. 2 the vacuum tube elements are enclosed in an evacuated envelope 40 and the output resonant cavity 2 enclosed by the conducting shell 42 is attached to two rings 43 and 44 sealed into the envelope. The openings in the rings 43 and 44 within the tube are closed with mesh grids 11 and 30 thereby enclosing between them a portion of the output cavity 2 and the gap 4 corresponding to the output gap 4 in Fig. 1. The flanges 37 and 38 were added as shown simply to add capacitative loading to decrease the resonant frequency of the output system to correspond to what could be introduced into the input of the tube. This expedient was necessary only because of the somewhat unsatisfactory structure of the input portion of this particular tube. The supporting structures and leads for the cathode and the adjacent control grid were of such nature that they acted as a filter for frequencies above 430 megacycles. The input frequency employed was, therefore, selected as 384 megacycles which was supplied through the input system shown, requiring, however, loading the output system with the flanges 37 and 38. The anode 6 is independent of the high frequency electrodes 11 and 30 and resistor 36 is inserted in the lead to 6 to prevent spurious oscillations. The input system 1 is of the coaxial type comprising the outer conductor 41 and inner conductor 39. The high frequency input voltage is applied to these conductors through the input line 31, 32. The high frequency voltage between conductors 39 and 41 is applied between the cathode 5 and the space charge control grid 9 by leads 45 and 46, respectively. The tube operates as explained in connection with Fig. 1. Space charge control of the electron stream is exerted

by the high frequency input voltage across the input gap 3 between cathode 5 and control grid 9. The grouped electrons then proceed to grid 11 and cross the output gap 4 between the grids 11 and 30 delivering energy to the output resonant system 2. High frequency output is taken off through the coaxial line 34, 35 which is coupled to the high frequency field in the space 2 as shown. As previously explained, the electron transit time across the input gap 3 is adjusted to minimize the input loading and the electron transit time across the output gap 4 is made short to maintain the gain at high frequencies. While this tube, the most appropriate available at the time, did not have the best type of input connections for high frequency operation it produced amplification at 384 megacycles (wave-length approximately 78 centimeters) consistent with its trans-conductance measured at low frequencies. Such performance, together with the results of later tests at shorter wave-lengths with more suitable tube structures as referred to previously, under operating conditions according to the teachings of this invention show the soundness of the principles involved and indicate that, within the limitations of physical structure, amplifier performance essentially equivalent to that at low frequencies may be had at very high frequencies.

During the course of the experiments with the arrangement of Fig. 2, it was found that by adjusting the input to sufficient amplitude and tuning the output resonant system to the harmonic frequency three times that of the input by removing the capacitance loading of flanges 37 and 38, an output at the higher frequency was obtained. Thus with an input at 240 megacycles, output power at 720 megacycles was obtained.

Fig. 3 shows an arrangement differing from Fig. 1 in that an evacuated glass envelope is employed, no feedback is shown, and the anode is separate from the high frequency output electrodes. In another aspect Fig. 3 may be considered similar to Fig. 2 except that a more suitable input system is substituted for that of Fig. 2. In this figure, as in the others, designation numbers carried over from earlier figures indicate elements similar to those bearing the same numbers in the earlier figures. The input resonant cavity 1 is enclosed by cathode 5, conducting members 25, 41 and 50, and control grid 9. The output resonant cavity 2 is enclosed by screen 11, conducting members 43, 42 and 44, and screen 30. Members 50, 43 and 44 are rings sealed into the glass envelope. The openings in these rings within the envelope are covered with the mesh screens 9, 11 and 30 which allow the passage of electrons from cathode 5 to anode 6 but are substantial barriers to the escape of the high frequency electric fields within the resonant cavities. Thus the input and output electric fields are well shielded from each other and from the electron stream except where it passes through the input field in the gap 3 between the cathode 5 and the control grid 9 and where it passes through the output field in the gap 4 between the screens 11 and 30. A high frequency input is connected to the terminals of the coupling coil 29 for excitation of the input resonant system and the high frequency load is connected to the terminals of coupling coil 21 for extraction of energy from the output resonant system. The input and output circuits may be connected together for feedback or regeneration as illustrated in Fig. 5. The operation of this circuit is the same as ex-

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plained in connection with Fig. 1, the electron stream being space charge controlled in gap 3 and delivering energy to the output circuit in gap 4, the electron transit times being adjusted as previously described.

Two useful features of Fig. 3 result from the separate position of the anode 6. First, the anode may be operated at a lower potential than the screens 11 and 30 and hence the small output transit time may be maintained at the same time that the power efficiency of the system is increased. Second, by adjustment of biasing potentials secondary electrons from the plate may be timed to return through the output gap 4 between screens 11 and 30 in the proper phase to add to the output energy. In such operation the anode should be coated with a good secondary emitting surface as indicated at 51.

Fig. 4 illustrates a modification employing a cylindrical form of structure. Various components in the drawing are numbered to correspond with similar components of previous Figs. 1, 2 and 3. The evacuated enclosure for the tube elements comprises conducting shells 66, 67, 68 and 69, and the seals of glass or other insulating material designated 7. The cathode 5 emits electrons radially in all directions through the space charge control grid 9 and the screen 11 to the anode which is the conducting member 69. In this instance, therefore, the electron path extends in all radial directions from the cylindrical cathode and the intercepting members 9, 11 and 69 are in the shape of curved surfaces of cylinders. The input resonant cavity 1 is enclosed by the cathode 5, members 66, 70, 60, 71 and 67, and the control grid 9. It will be noted that this is a coaxial system closed at one end by the flanges 62 and 63 and at the other end by the member 60. The annular space between 60 and 71 and the insulating disc between flanges 62 and 63, designated 13, provide insulation for biasing potentials and are of sufficient area to provide low impedance by-pass capacitances for the high frequency. The output resonant cavity is enclosed by the screen 4, and members 68, 69, 73, 61 and 72. This also is a coaxial system closed at one end by flanges 64 and 65 and at the other end by member 61. The insulating disc between two flanges 64 and 65, designated 13, and the annular space between members 73 and 61 separate the biasing voltages and provide low impedance by-pass capacitances for the high frequency. The input resonant system is shown energized through the coaxial line 31, 32, from a high frequency source 33 and a high frequency load is represented at 74 coupled to the output resonant system through the coaxial line 34, 35. This tube and circuit, illustrated in Fig. 4, operates as has already been described in connection with Fig. 1. The electron stream is space charge controlled and the electrons are grouped immediately in the input gap 3, between the cathode 5 and control grid 9. The grouped electrons then pass through the gap 4, between the screen 11 and the adjacent portion of member 69 which serves as the anode, delivering high frequency energy to the output system in accordance with the high frequency input from 33. The electron transit times across the gaps 3 and 4 are adjusted for optimum performance as previously described. The cylindrical structure has the inherent disadvantage that the output circuit consists of a coaxial line whose geometrical relations are such that it is difficult to make the ratio of inner and outer conductors large enough to secure as high output impedances

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as may be procured with other structures such as that of Fig. 1. However, in broad band applications where extremely high output impedance is not desirable the structure of Fig. 4 may be advantageous.

Fig. 5 illustrates another modification in which the cathode is removed entirely from the high frequency field and a space charge grid is interposed between it and the input gaps to accelerate the electrons and, if desired, to form a virtual cathode very close to the input gap. The output resonant system is the same as that of Fig. 3. The input resonant system differs from that of Fig. 3 in that the conducting enclosure does not include the cathode and its supporting member 25 but includes instead a ring 83 and screen 82 such that the input gap 3 is between the screen 82 and the space charge control grid 9 rather than between the cathode 5 and the control grid 9 as in Fig. 3. The grid 80 mounted in the sealed-in ring 81 is operated at a positive potential with respect to the cathode to draw electrons from the cathode while the screen 82 is maintained at a potential very nearly the same as that of the cathode. Potential adjustments may be such that the grid 80 serves simply to assist in the drawing of electrons from the cathode or such that a virtual cathode is formed very close to the screen 82. In either case the flow of electrons through the input gap 3 between screen 82 and grid 9 is governed by the space charge control of grid 9 due to the high frequency input voltage between it and screen 82. The electrons are immediately grouped in the gap 3 and thereafter deliver energy to the output system in passing through the output gap 4 between screens 11 and 30, finally being collected at the anode 6. Operation is thus the same as that of the previously described figures. As mentioned in connection with Fig. 3, the anode may be provided with a secondary electron emitting surface 51 and potential adjustments made so that the secondary electrons pass through the gap 4 at the proper time to contribute to the output. The input-output connection through coaxial line 22, 23 is not essential to operation but may be used to provide regeneration or feedback as explained in connection with Fig. 1. The insulating disc 13 between the flanges 85 and 86 separates the biasing voltages on the conducting shells 41 and 42 of the input and output resonant systems. The high frequency path through the outer conductor 22 of the feedback line is maintained through the capacitance between the flanges 85 and 86.

Fig. 6 illustrates a three-stage amplifier in which each stage is similar to the arrangement of Fig. 1 with the exception that glass envelopes enclose the vacuum tube elements. The elements of the three tubes which are connected in cascade are enclosed in the envelopes 90, 91 and 92. The elements in the three tubes are similar and are similarly designated, as in Fig. 1. It will be observed that the type of structure illustrated is practically identical with that of Fig. 1. The cylindrical conducting shell 8 which bounds all of the resonant cavities does not, however, serve as the evacuated envelope in Fig. 6 as it does in Fig. 1. The resonant systems are separated from each other by the flanged rings 95, 96, 97, 98, 99 and 100 in which are mounted the control grids 9 and the screens 11. These rings are shown sealed into the glass envelopes. An alternative and possibly preferable construction is to attach them externally to the envelopes to other rings which are sealed into the envelopes, such as ring

50 in Fig. 3. The insulating sleeves 13, as in the earlier figures, function to insulate the polarizing voltages but by virtue of the capacitances between the conductors which they separate they provide low impedance paths for high frequency currents.

The input resonant system 1 of the amplifier and the first tube is energized from a high frequency source connected to the input coaxial line 31, 32. The output resonant system 2 of the amplifier and the last tube is coupled to an output coaxial line 34, 35 which is connected to a high frequency load. Each of the intermediate resonant systems 93 and 94 serves as the output circuit of the preceding tube and the input circuit of the following tube. Each intermediate cavity 93 and 94 is electrically and physically longer than the terminal resonant systems 1 and 2 so that a node in the standing wave of the high frequency field exists midway between the bounding rings, 96 and 97, and 98 and 99. Thus each system, 93 and 94, functions somewhat as if separated into two parts by a conducting plane passed through the center perpendicular to the axis but with the two parts coupled together electrically. The leads for energizing the cathode heaters and for biasing the anodes are carried through the space in the resonant systems 93 and 94 in the positions of the nodes in the high frequency fields to minimize the coupling between these leads and the fields. As an added precaution it may be found desirable to shield these leads and provide high frequency by-pass capacitances where the leads leave the shell 8. The coaxial line 22, 23 shown coupling the input and output resonant systems may be used if desired to provide either regeneration or negative feedback. As mentioned in connection with Fig. 1, the amount of regeneration or feedback may be varied by changing the degree of coupling between the line and the resonant systems and the phase may be varied by changing the length of line between the two systems.

It is the usual practice to make the input and output resonant systems of the amplifiers such as have been described resonant at the same frequency, that of the input which is to be amplified. However, for certain purposes it may be desirable to tune them to different frequencies. For instance, as was indicated in connection with Fig. 2, the output system may be tuned to a harmonic of the input frequency to obtain an output at a frequency harmonically related to that of the input. Also, where a band of frequencies is to be amplified the input and output systems may be tuned to somewhat different frequencies to equalize transmission over the band and particularly the resonant systems in a multistage amplifier such as that of Fig. 6 may be made resonant at such neighboring frequencies as are desirable to transmit a band of frequencies. Such frequency bands would not ordinarily be so wide as to interfere with satisfactory adjustment of the electron transit times.

Fig. 7 illustrates a single-stage amplifier arrangement similar in electrical arrangement to Fig. 1 or each stage of Fig. 6 in that the cathode and anode of the electron tube form portions of the boundaries of the input and output resonant cavities. Here, however, a single grid electrode 103 is interposed between the cathode and anode rather than two, as 9 and 11 shown in Figs. 1 and 6. This single grid is of conducting material, relatively thick, with small holes through it in the direction of the electron flow to permit free

passage of electrons from cathode to anode through the gaps 3 and 4 in the input and output cavities. The relatively long, small diameter holes through the thick grid electrode, while permitting the passage of electrons, effectively prevent the transmission of high frequency energy and consequent intermingling of the high frequency fields on either side of the grid in the input and output cavities. An alternative method of constructing the grid electrode, not shown, is to use what is in effect a thick member with narrow slits rather than holes so that the structure consists of a series of slats much like those of a window shutter with the slats in the open, or horizontal, position. With such an electrode the relatively long passage between the slats from one side of the electrode to the other isolates the input and output high frequency fields.

The cathode 5, control grid 103 and anode 4 are supported by the ring members 101, 102 and 104, respectively, which are sealed into the glass envelope 40. The input resonant cavity 1, which is energized from the high frequency source 33 through the coaxial line 31, 32 is bounded by the coaxial cylindrical members 105 and 107, the separating member 108, grid electrode supporting member 102, grid electrode 103, cathode 5, cathode supporting member 101, and closure members 109 and 110. The output resonant cavity 2, from which the amplified high frequency energy is transferred to load 74 by coaxial line 34, 35, is bounded by the coaxial cylindrical members 106 and 107, the separating member 108, grid electrode supporting member 102, grid electrode 103, anode 6, anode supporting member 104, and closure members 111 and 112. The closure members 109, 110, 111 and 112 are annular conducting rings which are movable axially to adjust the sizes of the resonant cavities. Rings 109 and 111 fit closely to cylindrical member 107 while rings 110 and 112 fit closely to cylindrical members 105 and 106, respectively. The gaps between rings 109 and 110 and between rings 111 and 112 are short and the ring surface areas facing each other across the gaps are of sufficient area to provide a low impedance capacitive path for high frequencies and to effectively close, to high frequency fields, the cavities 1 and 2 while serving to isolate the biasing voltages connected to the tube electrodes.

The operation of the Fig. 7 device is the same as that of Fig. 1 considering that the single grid electrode 103 takes the place of the two grids 9 and 11 shown in Fig. 1. A feedback connection may be added to the Fig. 7 showing to provide regenerative or oscillatory action such as the coaxial line 22, 23 of Fig. 1 or any other suitable means.

Fig. 7 illustrates more strikingly, perhaps, than the other figures a reason why, as previously mentioned, the necessity for focussing the electron stream may be avoided in this type of tube. The reason is that the electron path is not long. For instance, in one particular tube constructed, the distance from the cathode to the anode is $\frac{1}{8}$ inch with a cathode diameter of $\frac{3}{8}$ inch. Therefore, it can be seen that an accelerating voltage will produce practically linear electron flow whereas with alternative high frequency amplifier tubes the distance from cathode to anode is comparable or large compared with the diameter of the electron stream requiring external means to keep the electron flow parallel.

It has been stated that a device according to this invention is adaptable to the conversion of

high frequency waves. One such application is where two different frequencies are applied to the input of a device and a frequency equal either to the sum or difference of the two input frequencies is derived from the output as in the production of the intermediate frequency in a heterodyne radio receiver. In this use, as a converter, the device which has been described is operated with the input circuit tuned to respond to the input frequencies and the output circuit tuned to the desired sum or difference output frequency. As an example of use as a converter, Fig. 8 shows a schematic diagram of the connections for the different frequencies applied to the device illustrated in Fig. 1 and also shows elimination of the feedback connection 22, 23. Fig. 8 is a modified drawing of the portion of Fig. 1 included within the dashed line A. It should be understood that the representation of Fig. 1 in Fig. 8 might equally well be the representation of any of the other figures since the distinctive features of Fig. 8 are the use of different frequencies and the corresponding differently tuned input and output circuits. In such cases, an over-all feedback connection cannot be used directly since the input and output frequencies differ.

Fig. 8 illustrates, therefore, the changes in Fig. 1 to adapt it to frequency conversion. The input is from two sources, 121 representing the input at one frequency f_1 which may be an incoming high frequency signal from an external source, and 122 representing the input at another frequency f_2 which may be from any other source such as a local high frequency oscillator. The output into load 123, which may be of any suitable type, resistive, reactive, or a tuned circuit, may be any sum or difference frequency of f_1 and f_2 to which the output resonant circuit in the device is tuned. Thus the output frequency may be either $f_1 + f_2$, $f_1 - f_2$ or $f_2 - f_1$. In practice, it would usually be one of the latter two difference frequencies rather than the first-mentioned sum frequency.

The two input frequencies are applied simultaneously to the input of the device and therefore the input resonant circuit must be tuned to respond to both frequencies, f_1 and f_2 and consequently be capable of supporting electric fields corresponding to those two frequencies. For the purpose of minimizing input loading a number of adjustments of input electron transit time are possible. When the input frequencies are relatively close together, the input transit time may be made so that it is substantially the same number of cycles for both, that is, approximately $1\frac{1}{4}$ or $2\frac{1}{4}$ or $3\frac{1}{4}$, etc., cycles for both frequencies. If the frequencies are quite different the input transit time may be made so that it is approximately $1\frac{1}{4}$ or $2\frac{1}{4}$ or $3\frac{1}{4}$, etc., cycles for one of the frequencies and at the same time approximately a different number of cycles, either $2\frac{1}{4}$ or $3\frac{1}{4}$, etc., cycles for the other frequency. Thus, the input loading may be minimized for both frequencies. When one of the two frequencies, as f_2 for example, is supplied by a source such as a local oscillator whose power output is ample enough to make considerations of losses unimportant, then there would be no need to adjust the input transit time to minimize loading on the frequency f_2 . The only adjustment necessary would then be one to insure that the loading for the signal frequency f_1 , is minimized; that is, to insure that the input transit time is approximately $1\frac{1}{4}$, $2\frac{1}{4}$, etc., cycles for the frequency f_1 .

In the case of a multistage device such as that

of Fig. 6, any stage may be made the one in which frequency conversion takes place with preceding or following stages acting as amplifiers of the input and output frequencies, respectively. In such an arrangement the input amplifier stages and the input circuit of the converter stage would be tuned to the input frequencies and the input electron transit time would be adjusted in one of the ways indicated above, while the output circuit of the converter stage and the circuits of the following amplifier stages would be tuned to the output frequency, and the input electron transit time in the output amplifier stages would be adjusted to approximately $1\frac{1}{4}$ or $2\frac{1}{4}$ or $3\frac{1}{4}$, etc., cycles of the output frequency to minimize the input loading in those stages.

In a converter embodiment such as has just been described, it is evident that the tuning of the output and input systems to different frequencies allows a somewhat less elaborate mechanical structure to be used for shielding the output from the input, while maintaining the same high degree of electrical shielding. Thus in use as a converter, the single grid of Fig. 7 may be made less elaborate than when the same tube is to be employed as an amplifier, and in fact, the grid may then approximate the form of any one of the grids described in connection with Fig. 1.

In regard to ground connections, none of which has been indicated in the figures, any part of the external circuit may be connected to earth to form a direct current ground for the application of biasing voltages. As far as the high frequency is concerned each cavity resonator is a substantially complete system in itself and the potential of a point in one of them cannot be uniquely referred to the potential of a point located in another. This property of cavity resonators is well appreciated by those who have worked with them and with high frequency field analysis treated by the usual retarded potential solution of Maxwell's field equations.

The illustrative embodiments presented have pictured desirable physical structures which avoid long high frequency leads and inefficient circuit elements and provide the shielding and the types of circuits which make possible the operating conditions under which benefits of the essential electron transit time adjustments may be had. First, the input transit time must lie within the range where input loading is compensated for by the negative resistance of the electron stream as has been defined. Second, the output transit time must be short so that the gain of the system is maintained at high frequencies. Third, the input and output resonant systems must be constructed so as to couple directly to the electron stream, must have low high-frequency losses, and must be thoroughly shielded from each other to prevent unwanted stray couplings from being present. The interdependence of these factors has not heretofore been appreciated and the studied combinations disclosed herein make possible types of performance not heretofore obtainable.

The invention may be exemplified in forms other than the typical ones shown and it is not intended that the invention be construed as limited to these but only as defined by the appended claims.

What is claimed is:

1. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a

high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and electron path lengths through the high frequency fields in the input and output closed systems being such that the electron transit time through the input high frequency field lies between the period of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle and the electron transit time through the output high frequency field is less than the period of one cycle of the field.

2. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and the electron path length through the high frequency field in the input closed system being such that the electron transit time through the input high frequency field is approximately the period of any whole number of cycles of the high frequency field and that number increased by one-fourth cycle.

3. A high frequency device comprising an electron discharge tube containing an electron emitting cathode, an anode and a space charge control electrode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit, comprising a substantially closed electrical resonant system enclosing a high frequency electric field and connected to the space charge control electrode to effect space charge control of the electron stream, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and electron path lengths through the high frequency fields in the input and output closed systems being such that the electron transit time through the input high frequency field ranges from that of any whole number of cycles of the high frequency field to one-half cycle more than that number and the electron transit time through the output high frequency field is less than the period of one cycle of the field.

4. A high frequency device comprising an electron discharge tube containing an electron emit-

ting cathode, an anode and a space charge control electrode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field and connected to the space charge control electrode to effect space charge control of the electron stream, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and the electron path length through the high frequency field in the input closed system being such that the electron transit time through the input high frequency field is approximately the period of any whole number of cycles of the high frequency field and that number increased by one-fourth cycle.

5. A high frequency device comprising an electron discharge tube containing an electron emitting cathode, an anode, a space charge control electrode therebetween adjacent to the cathode and an output electrode adjacent to the anode between the anode and the space charge control electrode, electrical potential means for causing a flow of electrons over a path from the cathode to the anode including the control electrode and the output electrode, a substantially closed electrical resonant system attached to the cathode and the space charge control electrode to include the space between the cathode and the control electrode, means for energizing at high frequency the said resonant system whereby variations are impressed upon the electron stream and a second substantially closed electrical resonant system attached to the said output electrode and the anode to include the space between the output electrode and the anode whereby high frequency energy may be generated in the said second resonant system by the passage of electrons between the output electrode and the anode, the said closed resonant systems being joined to their respective electrodes so as to include the necessary openings to permit the passage of electrons through the interelectrode spaces while maintaining substantially closed electrical boundaries for the resonant frequency except for coupling means for high frequency excitation and output energies, the said electrical potential means and the spacing of the electrodes being such that the electron transit time between the cathode and the space charge control electrode is a period between that of any whole number of cycles of the energizing high frequency and the period of that number increased by one-half cycle and the electron transit time between the said output electrode and the anode is less than the period of one cycle of the high frequency.

6. A high frequency device comprising an electron discharge tube containing an electron emitting cathode, an anode, a space charge control electrode therebetween adjacent to the cathode and an output electrode adjacent to the anode between the anode and the space charge control electrode, electrical potential means for causing a flow of electrons over a path from the cathode to the anode including the control electrode and the output electrode, a substantially closed electrical resonant system attached to the cathode and the

space charge control electrode to include the space between the cathode and the control electrode, means for energizing at high frequency the said resonant system whereby variations are impressed upon the electron stream, a second substantially closed electrical resonant system attached to the said output electrode and the anode to include the space between the output electrode and the anode whereby high frequency energy may be generated in the said second resonant system by the passage of electrons between the output electrode and the anode, the said closed resonant systems being joined to their respective electrodes so as to include the necessary openings to permit the passage of electrons through the inter-electrode spaces while maintaining substantially closed electrical boundaries for the resonant frequency except for coupling means for high frequency excitation and output energies, and a feedback circuit connecting the two closed resonant systems whereby high frequency energy may be introduced into the first-mentioned system from the second-mentioned system, the said electrical potential means and the spacing of the electrodes being such that the electron transit time between the cathode and the space charge control electrode is a period between that of any whole number of cycles of the energizing high frequency and the period of that number increased by one-half cycle and the electron transit time between the said output electrode and the anode is less than the period of one cycle of the high frequency.

7. A high frequency device according to claim 6 in which the energization of the first-mentioned resonant system is entirely by means of the feedback connection from the second-mentioned resonant system.

8. A high frequency device according to claim 6 in which the feedback connection is such that the energy introduced by it into the first-mentioned resonant system is in opposite phase to the energy introduced into that system by the first-mentioned energizing means, whereby the gain is stabilized and the distortion reduced.

9. A high frequency device comprising a plurality of electron discharge tubes operating in tandem, each tube containing an electron emitting cathode, an anode, a space charge control electrode therebetween adjacent to the cathode and an output electrode adjacent to the anode between the anode and the space charge control electrode, electrical potential means for causing electrons to flow from the cathodes to the anodes over paths including the respective control and output electrodes, each tube having a substantially closed electrical resonant system attached to the cathode and space charge control electrode to include the space between the cathode and the space charge control electrode and a substantially closed electrical resonant system attached to the said output electrode and the anode to include the space between the output electrode and the anode, the said closed resonant systems being joined to their respective electrodes so as to include the necessary openings to permit the passage of electrons through the interelectrode spaces while maintaining substantially closed electrical boundaries for the resonant frequency except for coupling means for high frequency excitation and output energies, means for energizing at high frequency the resonant system attached to the space charge control electrode of the first of the series of tubes whereby variations are impressed upon the electron stream, means whereby the

resonant system attached to the space charge control element of each tube following the first tube of the series is energized from the output energy of the preceding tube, the electrical potential means and the electron path lengths between the electrodes of the tubes being such that the electron transit time between each cathode and the adjacent space charge control element is a period between that of any whole number of cycles of the energizing high frequency and the period of that number increased by one-half cycle.

10. A high frequency device comprising a plurality of electron discharge tubes operating in tandem, each tube containing an electron emitting cathode, an anode, a space charge control electrode therebetween adjacent to the cathode and an output electrode adjacent to the anode between the anode and the space charge control electrode, electrical potential means for causing electrons to flow from the cathodes to the anodes over paths including the respective control and output electrodes, each tube having a substantially closed electrical resonant system attached to the cathode and space charge control electrode to include the space between the cathode and the space charge control electrode and a substantially closed electrical resonant system attached to the said output electrode and the anode to include the space between the output electrode and the anode, the said closed resonant systems being joined to their respective electrodes so as to include the necessary openings to permit the passage of electrons through the interelectrode spaces while maintaining substantially closed electrical boundaries for the resonant frequency except for coupling means for high frequency excitation and output energies, means for energizing at high frequency the resonant system attached to the space charge control electrode of the first of the series of tubes whereby variations are impressed upon the electron stream, means whereby the resonant system attached to the space charge control element of each tube following the first tube of the series is energized from the output energy of the preceding tube, and a feedback circuit connecting one of the closed resonant systems attached to an output electrode with a preceding closed resonant system attached to a space charge control element, the electrical potential means and the electron path lengths between the electrodes of the tubes being such that the electron transit time between each cathode and the adjacent space charge control element is a period between that of any whole number of cycles of the energizing high frequency and the period of that number increased by one-half cycle.

11. A high frequency device comprising a plurality of electron discharge tubes operating in tandem, each tube containing an electron emitting cathode, an anode, a space charge control electrode therebetween adjacent to the cathode and an output electrode adjacent to the anode between the anode and the space charge control electrode, electrical potential means for causing electrons to flow from the cathodes to the anodes over paths including the respective control and output electrodes, each tube having a substantially closed electrical resonant system attached to the cathode and space charge control electrode to include the space between the cathode and the space charge control electrode and a substantially closed electrical resonant system attached to the said output electrode and the anode to include the space between the output electrode and the

anode, the said closed resonant systems being joined to their respective electrodes so as to include the necessary openings to permit the passage of electrons through the interelectrode spaces while maintaining substantially closed electrical boundaries for the resonant frequency except for coupling means for high frequency excitation and output energies, means for energizing at high frequency the resonant system attached to the space charge control electrode of the first of the series of tubes whereby variations are impressed upon the electron stream, means whereby the resonant system attached to the space charge control element of each tube following the first tube of the series is energized from the output energy of the preceding tube, and a feedback circuit connecting one of the closed resonant systems attached to an output electrode with a preceding closed resonant system attached to a space charge control element, the electrical potential means and the electron path lengths between the electrodes of the tubes being such that the electron transit time between each cathode and the adjacent space charge control element is a period between that of any whole number of cycles of the energizing high frequency and the period of that number increased by one-half cycle, and the electron transit time between each anode and the adjacent output electrode is less than the period of one cycle of the high frequency.

12. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, and means for producing a virtual cathode at a point along the electron path close to where the electrons enter the high frequency input system, the electrical potential means and electron path lengths through the high frequency fields in the input and output closed systems being such that the electron transit time through the input high frequency field is a period between that of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle and the electron transit time through the output high frequency field is less than the period of one cycle of the field.

13. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant system being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output

high frequency energies, and a feedback circuit connecting the two closed resonant systems whereby high frequency energy may be introduced into the first-mentioned system from the second-mentioned system, the electrical potential means and the electron path lengths through the high frequency fields in the input and output closed systems being such that the electron transit time through the input high frequency field is a period between that of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle and the electron transit time through the output high frequency field is less than the period of one cycle of the field.

14. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, and a control electrode in the path of the electron stream between the cathode and the entrance to the resonant system comprising the input circuit, the electrical potential means and the electron path length through the high frequency field in the input closed system being such that the electron transit time through the input high frequency field is a period between that of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle.

15. A high frequency device comprising an electron discharge tube containing an electron emitting cathode, an anode and a space charge control element therebetween, electrical potential means for causing a stream of electrons to flow from the cathode to the anode through the space charge control element, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field and including space traversed by the electron stream between the cathode and the space charge control element, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field and including space traversed by the electron stream between the space charge control element and the anode, the electrical potential means and the electron path lengths being such that the electron transit time through the high frequency field in the input closed system lies between the period of any whole number of cycles of the high frequency field and the period of that number increased by one-half cycle.

16. A device according to claim 2 characterized in that the two electrical resonant systems are resonant at the same frequency.

17. A device according to claim 2 characterized in that the two electrical resonant systems are resonant at different frequencies.

18. A device according to claim 11 characterized in that the several electrical resonant systems are resonant at the same frequency.

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19. A device according to claim 11 characterized in that the several electrical resonant systems are resonant at frequencies not one and the same.

20. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode with a surface coating adapted to emit secondary electrons, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and the electron path length through the high frequency field in the input closed system being such that the electron transit time through the input high frequency field is approximately the period of any whole number of cycles of the high frequency field and that number increased by one-fourth cycle.

21. A high frequency device comprising an electron discharge tube containing an electron emitting cathode and an anode, electrical potential means for causing a stream of electrons to flow over a path from the cathode to the anode, a high frequency input circuit comprising a substantially closed electrical resonant system enclosing at least two high frequency electric fields of different frequencies, a high frequency output circuit comprising a substantially closed electrical resonant system enclosing a high frequency electric field, the resonant systems being aligned

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with openings intercepting the electron path to allow the said electron stream to pass through both systems in series without preventing thorough shielding of the input and output high frequency energies, the electrical potential means and the electron path length through the high frequency fields in the input closed system being such that the electron transit time through the input high frequency fields is approximately the period of any whole number of cycles of the fields and that number increased by one-fourth cycle.

22. A device according to claim 21 characterized in that the electron transit time through the input high frequency fields is approximately the period of the same whole number of cycles of each field and that number increased by one-fourth cycle.

23. A device according to claim 21 characterized in that the electron transit time through the input high frequency fields is approximately the period of a different whole number of cycles of the different fields and those numbers increased by one-fourth cycle.

24. A device according to claim 21 characterized in that the electron transit time through the input high frequency fields is approximately the period of any whole number of cycles of at least one of the fields and that number increased by one-fourth cycle.

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