

March 18, 1958

M. E. HINES

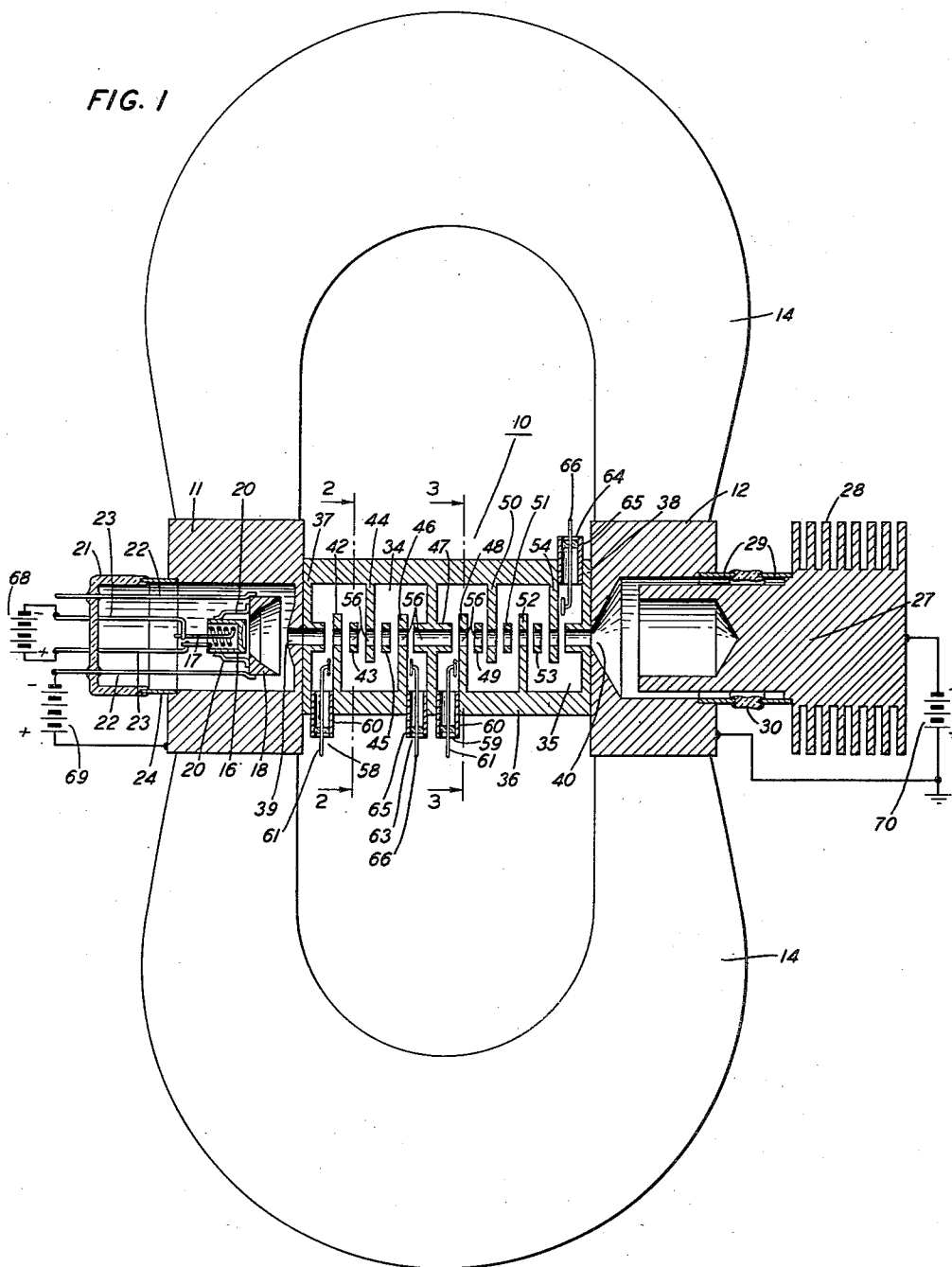
2,827,589

ELECTRON DISCHARGE DEVICE

Filed May 17, 1952

4 Sheets-Sheet 1

FIG. 1



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ELECTRON DISCHARGE DEVICE

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FIG. 2

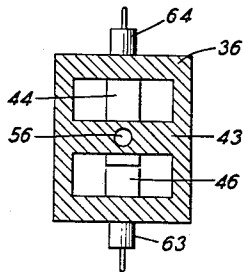


FIG. 3

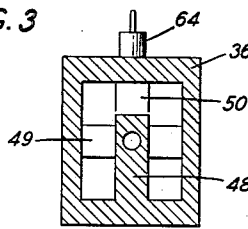


FIG. 4

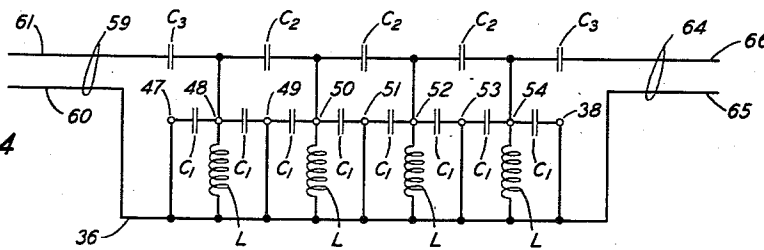
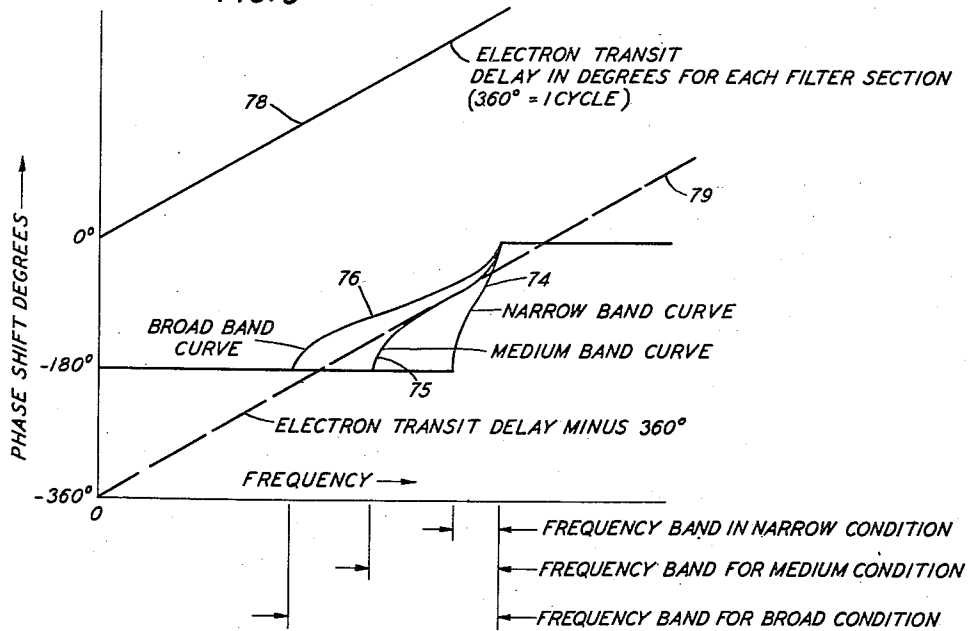


FIG. 5



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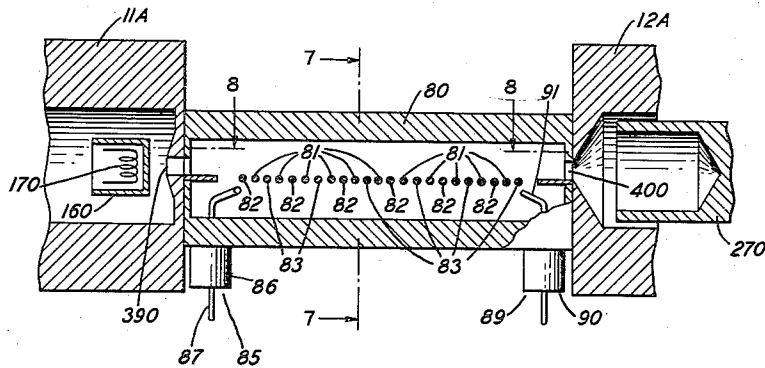
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ELECTRON DISCHARGE DEVICE

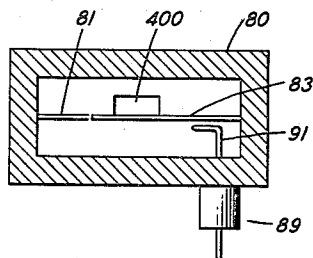
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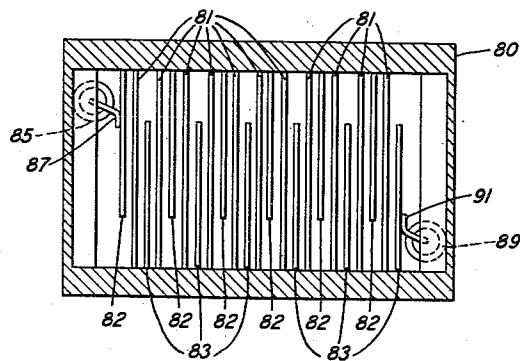
FIG. 6



**FIG. 7**



**FIG. 8**



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ELECTRON DISCHARGE DEVICE

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FIG. 9

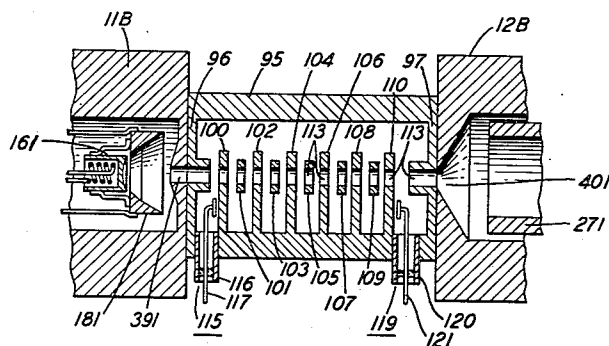


FIG. 10

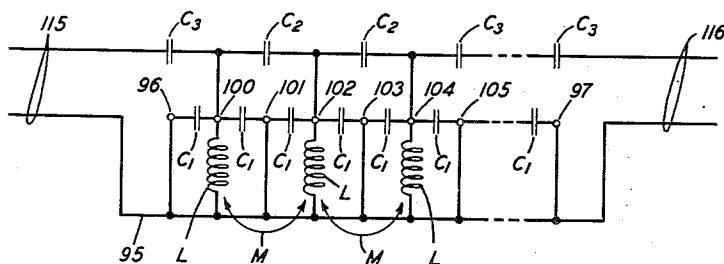
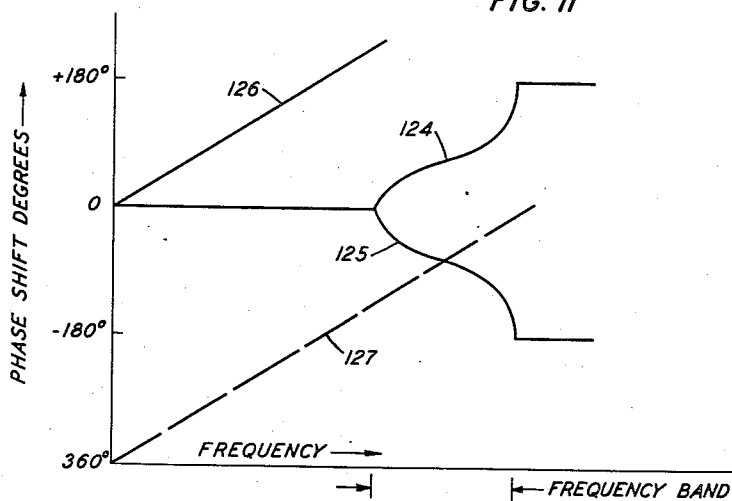


FIG. 11



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2,827,589

## ELECTRON DISCHARGE DEVICE

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Application May 17, 1952, Serial No. 288,436

13 Claims. (Cl. 315—3.5)

This invention relates to electron discharge devices and more particularly to such devices of the traveling wave tube type comprising a filter-type interaction circuit.

In traveling wave tubes of the class noted, the interaction circuit is a cascaded wave filter so arranged that the electron stream passes along certain of its elements and interacts repeatedly with the electric fields associated with propagating waves in the filter. As is known in the art, such interaction results in amplification of the wave propagating through the filter circuit, with the wave absorbing energy from the electron stream and emerging with greater power than when it entered. The electron beam, however, can only interact with the electric energy stored in the capacitance gaps adjacent which it passes. Prior filter-type traveling wave tubes have not been able to utilize fully or to maximum efficiency the stored electric field energy of the wave being propagated along the filter circuit.

It is one object of this invention to arrange most of the capacitance of the filter-type interaction circuit in the immediate vicinity of the projected electron beam. Thus it is an object of this invention to provide that a maximum of the stored energy of the tube is concentrated in those regions of the tube where interaction between the electric field energy of the propagated wave and the electron beam may occur.

A further object of this invention is to decrease the electron transit time across each energy-storage gap. The electron transit time across the capacitance or energy-storage gap should be short compared to a period of the alternating current wave. When the transit time is long, the alternating fields may reverse themselves during a single electron transit with a consequent loss in efficiency. In prior filter-type traveling wave tubes where the electron transit time has been long the circuits have been so arranged that the electron will be shielded from the electric field for a portion of the time, with a resultant decrease in the interaction region.

A still further object of this invention is to increase the frequency range of filter-type traveling wave tubes.

Further objects of this invention are to provide an improved filter-type traveling wave tube capable of dissipating a large amount of heat generated in the interaction circuit, to increase the gain in a filter-type traveling wave tube, to reduce signal distortion introduced by amplification in a filter-type traveling wave tube, and to enable the band width of the filter circuit to be facily predetermined by a simple alteration in the physical structure of the circuit.

In one specific illustrative embodiment of this invention, the filter-type circuit of a traveling wave tube comprises a hollow housing of a metallic conductor in which is situated an array of conducting strips comprising two sets alternately arranged in the array. The first set comprises a number of short cross-ground strips, both ends of which are connected to the housing. The second set comprises two groups of inductance stubs alternately arranged in the array, the stubs of the one group being con-

nected at their one end only to one side of the housing and those of the other group being connected at their one end only to the opposite side of the housing. Each of the strips is apertured and the apertures are aligned. An electron beam is projected through the aligned apertures thus traversing the energy-storage or capacity gaps defined by the strips.

In another specific illustrative embodiment of this invention, the conductive strips are coplanar wires extending in the hollow housing and an electron beam is projected along the array of wires.

In a third specific embodiment of this invention, the first set of conductive strips comprises a number of short cross-ground strips each connected at both its ends to opposite sides of the housing and the second set of conductive strips comprises a number of longer inductance stubs all connected at only one end to the same side of the housing.

In accordance with one feature of this invention, the inductance defining elements of the filter circuit have positioned closely adjacent thereto means defining ground potential. Further in accordance with this invention, the means defining ground potential is positioned between adjacent inductance defining elements of the filter circuit.

In accordance with a further feature of this invention, the electron beam is projected closely adjacent the capacitances between the inductance defining elements and the intervening ground defining elements of the filter circuit, wherein a major portion of the electric field energy of the propagating wave is stored.

It is a further feature of this invention that the electron beam be projected directly through the energy-storage gaps thus defined between the inductance elements and the intervening ground elements of the filter circuit.

A complete understanding of this invention and of the various features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a sectional view of a traveling wave tube illustrative of one specific embodiment of this invention;

Fig. 2 is a sectional view of the interaction circuit of the embodiment of Fig. 1 taken along the line 2—2 thereof;

Fig. 3 is a sectional view of the interaction circuit of the embodiment of Fig. 1 taken along the line 3—3 thereof;

Fig. 4 is an equivalent circuit schematic for the second section of the interaction circuit of the embodiment of Fig. 1;

Fig. 5 is a phase diagram showing the phase shift per filter section as a function of frequency for three different frequency bands for the embodiment of Fig. 1;

Fig. 6 is a sectional view of an interaction circuit of a traveling wave tube illustrative of another specific embodiment of this invention and to which the phase diagram of Fig. 5 is applicable;

Fig. 7 is a sectional view along the line 7—7 in Fig. 6;

Fig. 8 is a sectional view along the line 8—8 in Fig. 6;

Fig. 9 is a sectional view of the interaction circuit of a traveling wave tube illustrative of a third specific embodiment of this invention;

Fig. 10 is an equivalent circuit schematic for the interaction circuit of the embodiment of Fig. 9; and

Fig. 11 is a phase diagram showing the phase shift per filter section as a function of frequency for both the forward and backward waves for the embodiment of Fig. 9.

Referring now to the drawing, the specific embodiment illustrated in Fig. 1 comprises a traveling wave tube 10 having an electron gun pole piece member 11 and an electron collector pole piece member 12. Horseshoe magnets 14 are positioned on opposite sides of the tube 10 with the pole piece members 11 and 12 between like

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poles of the magnets; other means could of course be employed to provide the requisite magnetic field. Positioned within the pole piece member 11 is the electron gun which comprises a cup-shaped cathode 16 having a heater element 17 positioned therein and a focussing electrode 18. The focussing electrode 18 supports the cathode by short wire struts 20 and is in turn supported from a vitreous base 21 by leads 22 extending therethrough. Additional leads 23 extend through base 21 and support the heater element 17. The base 21 is sealed to the pole piece member 11 by an intermediate metallic ring 24.

Positioned within the pole piece member 12 is a collector electrode 27 advantageously having integral therewith heat radiating fins 28. A part of the collector electrode forms a portion of the envelope of the tube 10 being hermetically sealed to the pole piece member 12 by two metallic rings 29 and an intermediate glass ring 30.

Situated between the pole pieces 11 and 12 is the interaction circuit which in this embodiment comprises two isolated sections 34 and 35 with separate input and output coaxial line connections to each section. The interaction circuit comprises a hollow rectangular metallic housing 36 having apertured end plates 37 and 38, the apertures therein communicating with apertures 39 and 40 in the base of pole piece members 11 and 12 respectively. In each of the sections 34 and 35 is positioned an array of two sets of elements, the elements being arranged alternately in the array. In the first section 34 the array comprises a first set including the end plate 37 and conducting strips 43 and 45 and a center plate member 47 and a second set including the conducting strips 42, 44 and 46. In the second section 35 the first set comprises the center plate member 47, conducting strips 49, 51, 53 and end plate member 38 and the second set comprises conducting strips 48, 50, 52 and 54.

As best seen in Fig. 2 each of conducting strips 43, 45, 49, 51 and 53 comprises a short metallic member connected at both ends to the sides of the housing 36. As seen in Figs. 1 and 3 each of the conducting strips 42, 44, 46, 48, 50, 52 and 54 is a longer metallic member connected at one end only to the housing 36, the strips in each section 34 and 35 being alternately connected to the top and bottom of the housing 36. Advantageously the housing 36 may be composed of a large number of laminations, the various strips being integral portions of different laminations. As clearly seen in the drawings each of the strips has an aperture 56 therein as does the center plate member 47, the apertures 56 being aligned with the apertures 39 and 40 in the base of the pole piece members 11 and 12 respectively.

A coaxial input line 58 is provided for section 34 and a coaxial input line 59 for section 35, each line comprising an outer conductor 60 connected to the housing 36 and an inner conductor 61 capacitively connected to the strip 42 in line 58 for the first section 34 and to strip 48 in line 59 for the second section 35. Similarly, coaxial output lines 63 and 64 are associated with each section and comprise an outer conductor 65 connected in the housing 36 and an inner conductor 66 capacitively connected to the strip 46 in line 63 for the first section 34 to strip 54 in line 64 for the second section 35.

In the operation of this specific embodiment of this invention, an electron stream is projected from the electron gun, suitable voltage supplies 68 and 69 being provided for the heater element 17, cathode 16 and electrode 18. The electron stream is focussed to pass through the aperture 39 and through each of the apertures 56 under the restraint of the magnetic field provided by the magnets 14, and is collected by the collector electrode 27 to which is applied a suitable bias by a voltage supply 70. The signal to be amplified is applied to the coaxial input line 58, enters the first filter circuit section 34 where it is amplified somewhat, and emerges from the coaxial output line 63. In the process, the electron stream has become velocity modulated with variations in electron

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current and velocity, such variations having the same frequency as the applied signal. This causes a new and similar wave to appear in the second filter circuit section 35 by direct interaction with the modulated beam whether or not a signal is applied to this section from the coaxial input line 59. This signal will be further amplified in the second section and will appear at the output line 64. It is not essential to split the filter circuit into two sections in this manner, but it may be desirable to do so in order to isolate the input line from the output line and thus avoid the danger of oscillation by internal feedback of energy from the output back to the input. A similar effect can be obtained in a single section of filters by inserting some lossy material in one or more filter sections in order to attenuate backward traveling waves. The coaxial output line 63 of the first section 34 and the coaxial input line 59 of the second section 35 may be simply terminated in nonreflecting loads of some conventional variety or they may be connected in some other manner if the tube is to be used for other purposes, such as oscillation or modulation, etc. When these inner coaxial lines are simply terminated they perform the function of center attenuation and inhibit backward traveling waves.

In order to describe the action and advantages of a circuit in accordance with this invention it is convenient to develop an "equivalent circuit" composed of lumped circuit elements. As the actual circuit contains elements whose dimensions are comparable to a wavelength of the propagating waves, an exact representation of the circuit would comprise distributed parameters for which a precise analysis would present almost insurmountable difficulties. But, as is well known in the art, it is often possible to closely approximate the characteristics of a distributed circuit by deducing an equivalent lumped-element circuit which will behave in a similar manner over a restricted band of frequencies. This equivalent circuit may be then analyzed by conventional circuit theory.

The filter circuit of the specific embodiment disclosed in Fig. 1 is formed entirely of a conducting material, such as copper, with all its component parts conductively connected together. The encompassing hollow housing or shell 36 may be considered as a ground electrode. The first set of strips, comprising the end plate 37, strips 43 and 45, center plate 47, strips 49, 51 and 53, and end plate 38 are connected to the surrounding hollow housing 36 at at least their two ends so that this set of strips may be considered as essentially a portion of the ground electrode. The other set of strips, comprising the strips 42, 44, 46, 48, 50, 52 and 54 are connected to the outer housing 36 at one end only and have an appreciable length in comparison to the short grounded strips 43, 45, 49, 51 and 53. Therefore the strips of this second set may be considered to have an inductance from end to end and thus to comprise inductance stubs. It should be noted that these inductance stubs themselves comprise two groups in alternate arrangement, the strips of one group extending from one side of the housing 36 and the strips of the other group extending from the other side of the housing 36.

Because of the close proximity of the inductance stubs at their unconnected or free end to the cross-grounded strips, there exists an appreciable capacitance between these free ends and the adjacent ground. If we consider one inductance stub or strip of the second set and the two adjacent ground strips, as strip 50 and adjacent ground strips 49 and 51, the stub inductance and the capacitances between the free end of the stub and the adjacent ground strips will form a circuit, in which the capacitances between the end of the stub 50 and the adjacent grounded strips 49 and 51 will each have a certain magnitude  $C_1$  and the stub will have an inductance  $L$ . If an alternating current voltage exists on the stub 50, it will induce alternating currents in the nearby stubs

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48 and 52 also which means that a direct capacitance also exists between the elements 48 and 50 and between the elements 50 and 52. This direct capacitance between any two adjacent inductance stubs will have a certain magnitude  $C_2$ . Additionally, the inner conductors 61 and 66 of the coaxial input and output lines have a capacitance to the end stubs in each section 34 and 35, which capacitance will have a certain magnitude  $C_3$ .

Combining these elements produces the equivalent circuit shown in Fig. 4, for the second section 35. In this equivalent circuit the numerals indicating the strips of both sets in the second section have been placed at positions corresponding to the physical position of the strip itself adjacent the aligned apertures 56, and the housing 36 is indicated as ground. As the electron beam is projected through the aligned apertures 56, the electron beam may be considered in this equivalent circuit to pass in a line directly above the capacitances  $C_1$ . Therefore the numerals 47 through 54 and 38 do not, in Fig. 4, indicate that particular elements of the equivalent circuit are the actual strips but do designate the presence of the physical strip just in the vicinity of the electron beam, i. e., at the aperture 56.

The equivalent circuit of Fig. 4 is a well known type of band pass filter, composed of four simple T-sections for the case where  $C_3$  has twice the capacitance of  $C_2$ . This filter is characterized by a phase shift per section which varies from  $-180$  degrees at the lower frequency limit of the pass band to zero degrees at the upper frequency limit. Near the middle of the band the phase shift will be  $-90$  degrees and the tube most advantageously operates at or near the mid-band frequency. While only the section 35 of the interaction circuit has been shown in Fig. 4 it is to be understood that this equivalent circuit is equally valid for the first section 34 or for an interaction circuit composed of but a single section. Thus there is no significance in the particular number of filter elements in either of the two sections or in the number of sections employed in the specific embodiment illustrated. More or fewer elements or sections may be utilized as needed to obtain the amount of gain desired, the amount of gain increasing with the number of elements.

One requirement of a traveling wave tube filter-type circuit is that the electrons see a nearly constant phase of the wave as they pass from one gap to the next gap. Thus if an electron passes the center of the first gap when the electric field is at its peak opposing value, it should also find the electric field at the next gap nearly at its peak. This condition will be met in a filter-type circuit in accordance with this invention if the electrons require one-half cycle to travel from the gap between strips 47 and 48 to the gap between strips 48 and 49 and one-quarter cycle to travel from the gap between strips 49 and 50 to the gap between strips 50 and 51, etc. This condition can be met exactly at the mid-band frequency if the electron beam travels at the proper velocity and if the inductance stubs, i. e., the conducting strips of the second set, e. g., 48, 50, etc. are appreciably thicker than the ground strips, i. e., the strips of the first set. However, all the strips may advantageously be of the same thickness, as in the specific embodiment of this invention depicted in Fig. 1, and the phase difference that will exist will still be within permissive limits.

The band width of the filter may be increased or decreased by varying the capacitances between adjacent inductance stubs, i. e., by varying the capacitance  $C_2$ . Different applications to which embodiments of this invention may be put will demand various requirements as to the band width. For a broad band condition the capacitances  $C_2$  should be fairly large and for a narrower band these capacitances should be small. In accordance with this invention, these capacitances can be readily determined by the length of the inductance stub or strips of the first set that protrudes beyond the cross-ground strip of the first set. For a large band width, the inductance

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stubs should be fairly long and extend considerably beyond the aperture 56 therein, which defines the axis of alignment of the strips of both sets. When the band width is narrower and thus  $C_2$  is smaller, the image impedance of the circuit will be higher. Ordinarily the gain of a traveling wave tube will be higher for higher values of this image impedance.

As pointed out above the electron beam in passing through the aligned apertures 56 passes through the series of gaps which define the capacitances  $C_1$ . It is thus a feature of this invention that most of the capacitance in the circuit appears in the vicinity of the electron beam gaps so that most of the stored electric field energy of the propagating wave is concentrated in the useful region of the tube for intimate interaction with the electron beam. Considering the equivalent circuit of Fig. 4 again, the electron stream in accordance with this invention is projected directly adjacent the capacitance gaps  $C_1$ , and in this specific embodiment, through these gaps. In some prior filter-type interaction circuits, the electron beam has been projected directly adjacent the capacitance gaps  $C_2$ , i. e., the gaps defined by two adjacent inductance stubs. Considerably less of the energy of the electric field of the propagating wave is stored in these capacitance gaps than in the capacitance gaps between each inductance stub and the immediately adjacent ground strip. Thus in accordance with this invention the electric field at the electron stream for a given amount of energy in the circuit will be higher thereby approaching the desideratum of obtaining a maximum amount of electric field energy at the electron beam for a minimum amount of such stored energy.

Further in the operation of a filter circuit in accordance with this invention the electron transit time across each capacitance gap  $C_1$  will be short compared to a period of the alternating current wave, thereby reducing the likelihood of a reversal of the alternating fields during a single electron transit time with a consequent loss in efficiency, as may occur when the transit time is too long.

As the hollow housing 36 is advantageously of copper or other metal with high heat conductivity, as are the strips of each set, the circuit may dissipate a large amount of heat which may be generated on the various elements by ordinary resistive losses from high frequency currents or by bombardment by stray high velocity electrons. The heat so generated can be conducted outward by the conducting strips to the housing 36 and dissipated in the surrounding air.

Specific embodiments of filter-type circuits in accordance with this invention may be designed for amplification over a relatively wide frequency band as compared to prior filter-type circuits. Referring now to Fig. 5 there is shown a phase diagram depicting the phase shift per filter section, e. g., the phase difference between the voltage on adjacent inductance stubs, as a function of frequency for three different conditions. Curve 74 represents a narrow band condition where capacitance  $C_2$  in the equivalent circuit of Fig. 4 is quite small compared to capacitance  $C_1$ . Curve 75 represents the phase variation for a medium band width condition, and curve 76 for a very broad band width condition for which capacitance  $C_2$  must be successively larger in comparison with capacitance  $C_1$ . For these electronic phase curves, the transit time of electrons is expressed in degrees of phase shift such that 360 degrees would represent a transit time equal to one wave period. The electron transit delay is represented by curve 78 and appears as a straight line on the chart of Fig. 5. When the electron speed is properly adjusted, the electronic phase delay is just 360 degrees greater than the circuit phase shift at the frequency of interest. In the medium band width condition shown by curve 75, it is apparent that this phase condition may be satisfied over a considerable portion of the filter pass band where the two curves are

nearly parallel and 360 degrees apart, as shown by the line 79 which represents the electron transit delay line 78 displaced 360 degrees. This medium band width condition illustrated is one type of optimum, in that the electronic delay curve very nearly matches the circuit phase shift curve over an extended zone because the two curves 75 and 79 can be made tangent by a proper choice of filter band width and electron velocity. For a broader or narrower band filter, the curves 74 and 76 cannot be made to match the curve 79 over as broad a frequency band.

Referring now to Fig. 6 there is shown another specific embodiment of this invention wherein the traveling tube comprises a different filter-type circuit positioned between the two pole piece portions 11A and 12A having apertures 390 and 400 in their bases, respectively, a cathode 160 and heater 170 being positioned in one pole piece portion and a collector electrode 270 in the other pole piece portion as in the embodiment of Fig. 1. The filter-type circuit in accordance with this embodiment of this invention comprises an outer hollow housing 80 of substantially rectangular cross section and having a plurality of wires extending therein across the hollow section, as clearly seen in Figs. 7 and 8. These wires are arranged in a coplanar array alternately in two sets, the first set comprising wires 81 extending across the hollow housing 80, connected to the inner sides thereof at both ends, and defining ground wires corresponding to the cross-ground strips 43, 45, 49, 51, and 53 in the embodiment of Fig. 1. The second set comprises two alternate groups, a first group of wires 82 extending from one side of the hollow housing 80 and corresponding to the inductance stubs 42, 46, 48, and 52 of the embodiment of Fig. 1 and a second group of wires 83 extending from the opposite side of the hollow housing 80 and corresponding to the inductance stubs 44, 50 and 54 of the embodiment of Fig. 1. A coaxial input terminal 85 comprises an outer conductor 86 secured to the housing 80 and an inner conductor 87 capacitively connected to the first wire 82 array and a coaxial output terminal 89 similarly comprises an outer conductor 90 secured to the housing 80 and an inner conductor 91 capacitively connected to the last wire 83 of the array.

The electron stream is projected through the aperture 390 and is advantageously of the ribbon type to pass over the array of wires 81, 82 and 83 adjacent the region of their overlapping each other. The electron stream, however, may advantageously pass near the wires on either side or on both sides of the wires in the array. The method of operation of this specific embodiment is entirely similar to that of the embodiment of Fig. 1 and the equivalent circuit of Fig. 4 is equally applicable. In this embodiment the distributed inductance and capacitance of the shorter wires 82 and 83 extending alternately from opposite sides of the housing 80 correspond to the inductance  $L$  and the capacitance  $C_1$  while the direct capacitance of the shorter wires 82 and 83 to their neighboring shorter wires 82 and 83 correspond to the coupling capacitances  $C_2$ .

In contradistinction to some prior filter-type circuits which could be used only at frequencies very near the edge of the pass band where the filter characteristic induces considerable phase distortion into the signal, a filter circuit in accordance with this invention can be used in the central portion of its frequency pass band where a minimum of signal distortion will be introduced. Further by using a very narrow band structure in accordance with this invention it is possible to obtain very high circuit impedance such that the gain per filter section will be high. This permits the construction of tubes of short length and thus allows a reduction in the length of the magnetic field required to focus the electron beam.

Referring now to Fig. 9 there is illustrated a third specific embodiment of this invention comprising a slightly different filter circuit positioned between two pole piece

portions 11B and 12B having apertures 391 and 401 in their bases, respectively, a cathode 161 being positioned in the one pole piece portion and a collector electrode 271 in the other, the pole piece portions, cathode, and collector electrode being similar to those of the embodiment of Fig. 1. The interaction or filter circuit in accordance with this embodiment of the invention comprises a hollow rectangular metallic housing 95 having apertured end plates 96 and 97, the apertures therein communicating with the apertures 391 and 401 in the bases of the pole piece portions 11B and 12B, respectively. Positioned within the housing are two sets of apertured conductive strips arranged alternately in an array. The first set of strips comprises the short cross-ground strips 101, 103, 105, 107 and 109, which are connected at their both ends to opposite sides of the housing 95 and which, together with the end plates 96 and 97, can be considered as defining ground potential in the circuit. The second set of strips comprises the inductance stubs 100, 102, 104, 106, 108 and 110. Each of the strips and end plates has an aperture 113 therein, the apertures 113 being aligned with the apertures 391 and 401 for passage of the electron beam therethrough.

A coaxial line 115 comprising an outer conductor 116 secured to the housing 95 and an inner conductor 117 capacitively coupled to the first inductance stub 100 is positioned adjacent the electron gun end of the circuit and a second coaxial line 119 is positioned adjacent the electron collector end of the circuit, the coaxial line 119 similarly comprising an outer conductor 120 secured to the housing 95 and an inner conductor 121 capacitively coupled to the last inductance stub 100.

The equivalent circuit, shown in Fig. 10, for this specific embodiment of the invention is somewhat different from that for the prior two embodiments and the wave propagation characteristics differ appreciably. In this filter circuit, the capacitances  $C_1$ ,  $C_2$  and  $C_3$  are the same as in the circuit of Fig. 4, capacitance  $C_1$  being the capacitance between the end of one inductance stub and an adjacent cross-ground strip, capacitance  $C_2$  the direct capacitance between any two adjacent inductance stubs, and capacitance  $C_3$  the capacitance between end inductance stubs 100 and 110 and the inner conductors 117 and 121 of the coaxial leads 115 and 119, respectively. Similarly, each inductance stub has a certain inductance  $L$  associated therewith. As in the circuit of Fig. 4 the numerals indicating the end plates 96 and 97 and the strips of both sets have been placed at positions corresponding to the physical position of the plate or strip itself adjacent the aligned apertures 113 and the housing 95 is considered as to ground. Thus the electron beam may be again considered in the equivalent circuit to be projected to pass directly above the capacitances  $C_1$ .

The equivalent circuit of this specific embodiment differs from that of the prior embodiments, however, because of the presence of an appreciable mutual inductance  $M$  between adjacent inductance stubs. In the prior embodiments in which the inductance stubs were connected to opposite sides of the housing the adjacent long portions of the inductance stubs were separated from each other by two cross-ground strips and an inductance stub projecting from the opposite side of the housing. Therefore the mutual inductance, while present in the prior embodiments, is too small to take into consideration. However, in this specific embodiment the long portions of adjacent inductance stubs are considerably closer together so that an appreciable mutual inductance  $M$  exists between them. This mutual inductance is the dominant coupling feature between elements in the filter and causes the phase shift characteristic to be as shown in Fig. 11.

Referring now to Fig. 11 there is shown the phase diagram depicting the phase difference between the voltage on adjacent inductance stubs as a function of frequency, curve 124 representing the phase characteristic to a forward wave and curve 125 representing the phase charac-



teristic to a backward wave. The electron transit delay is indicated by the straight line 126 and one adjusted electron speed is indicated by the line 127 which represents the electron transit delay line 126 minus 360 degrees. For this specific embodiment of the invention, the phase shift between filter sections is zero degrees at the low frequency end of the pass band and 180 degrees at the high frequency end of the pass band; intermediate values of phase shift are found at frequencies within the pass band. For the electron speed indicated by line 127, it is seen that the electrons see a constant phase of the wave at each gap for a backward traveling wave on the circuit.

The specific embodiment of an interaction circuit illustrated in Fig. 1 is most advantageously operated as a traveling wave tube amplifier when the radio frequency input of the amplifier is nearest the electron gun and the radio frequency output is remote from the electron gun. However, the specific embodiment of this invention illustrated in Fig. 9 is most advantageously operated as an amplifier when the radio frequency input is adjacent the electron collector, as through coaxial terminal 119, and the radio frequency output is adjacent the electron gun, as through coaxial terminal 115, as described in application Serial No. 288,438, filed May 17, 1952, by R. Kompfner and N. J. Williams. The specific embodiment of this invention depicted in Fig. 9 may also advantageously be operated as a backward wave oscillator, one type of which is described in application Serial No. 288,509, filed May 17, 1952, by S. Millman.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An interaction circuit comprising means defining the interaction space of said circuit, said means including conducting portions, and a plurality of conducting members attached to said conducting portions of said space defining means and comprising two groups arranged alternately in an array, the members of said first group each being in electrical contact at both ends thereof with said space defining means forming a short path and the members of said second group each being in electrical contact at one end only with said space defining means forming a longer path defining an inductance, one of said second group of members being interposed between each pair of members of said first group.

2. An electron discharge device comprising a first conducting member surrounding an interaction space in said device, a plurality of conducting members attached to said first member and comprising two groups alternately arranged in an array, the members of said first group each being in electrical contact with said first member at their one end only and the members of said second group each being in electrical contact with said first member at their both ends, means for introducing an electromagnetic wave to said device for transmission along said array, and means for projecting an electron stream adjacent said conducting members for interaction with the electric field energy of said wave stored between said members of said two groups.

3. An interaction circuit for an electron discharge device comprising a metallic enclosing member, a plurality of first conducting strips each positioned within and in electrical contact with said enclosing member at their one end only and a plurality of second conducting strips in electrical contact with two sides of said enclosing member, one of said second conducting strips being interposed between each adjacent pair of first conducting strips and defining energy storage gaps therewith.

4. An electron discharge device comprising a hollow metallic housing, a plurality of first conducting strips positioned within and in electrical contact with said housing

at their one end only and comprising two groups alternately arranged in an array, the strips of the first of said groups extending from one side of said housing and the strips of the second of said groups extending from the opposite side of said housing, a second conducting strip interposed in said array between adjacent first conducting strips, said second conducting strips being in electrical contact with said housing at their both ends, means for introducing an electromagnetic wave to said device for transmission along said array, and means for projecting a stream of electrons adjacent said first and second conducting strips for interaction with the electric field energy of said wave stored between said first and second conducting strips.

5. An electron discharge device comprising a space defining base member having conductive portions, a plurality of conducting strips attached to said conductive portions of said base member and arranged in an array in said device, said strips comprising a first group each in electrical contact with said base member at their one end only and extending therefrom to define an inductance from said base member and a second group each in electrical contact with said base member only at spaced apart points on said base member to be at the potential of said base member, the strips of said groups being alternately arranged in said array, means for introducing an electromagnetic wave to said device for transmission along said array, and means for projecting a stream of electrons adjacent said array of conducting strips for interaction with the electric field energy of said wave stored in the capacitance gaps between successive first and second conducting strips.

6. An interaction circuit for an electron discharge device comprising a space defining base member having conductive portions, a plurality of first conducting members in electrical contact with said conductive portions of said base member at their one end only and comprising two groups alternately arranged in an array, the members of the first of said groups extending from one side of said base member and the members of the second of said groups extending from another side of said base member, and a plurality of second conducting members in electrical contact with two sides of said base member, one of said second conducting members being adjacent each of said first conducting members and defining an energy storage gap therewith.

7. An interaction circuit for an electron discharge device comprising a hollow conducting base member of substantially rectangular cross section, a plurality of first conducting strips positioned within and in electrical contact with said base member at their one end only and comprising two groups alternately arranged in an array, the strips of the first of said groups extending from one side of said base member and the strips of the second of said groups extending from the opposite side of said base member, and a plurality of second conducting strips positioned between said first conducting strips and in electrical contact at their both ends with said base member, said second conducting strips being at the potential of said base member and interposed between said first conducting strips.

8. An electron discharge device comprising a hollow metallic base member, a plurality of conducting strips attached to said base member, said strips comprising a first group in electrical contact at their one end only with said base member and extending therefrom and a second group in electrical contact at their both ends with said base member, the strips of said groups being alternately arranged in said array, each of said strips having an aperture therein and said apertures being aligned, means for introducing an electromagnetic wave to said device for transmission along said array, and means for projecting a stream of electrons through said aligned apertures for interaction with the electric field energy of said wave

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stored in the capacitance gaps between successive first and second conducting strips.

9. An electron discharge device comprising a hollow conducting base member, an array of conducting strips within the hollow portion of said base member, said strips comprising a plurality of first conducting strips in electrical contact at their one end only with said base member and extending therefrom and a plurality of second conducting strips in electrical contact at their both ends with said base member and extending across said hollow portion thereof, one of said second conducting strips being positioned between each adjacent pair of said first conducting strips, means for introducing an electromagnetic wave to said hollow portion for transmission along said array, means for projecting an electron stream through said hollow portion adjacent said array of conducting strips, and means for removing said wave from said hollow portion after interaction with said electron beam.

10. An electron discharge device comprising a hollow conducting base member substantially rectangular in cross section, an array of conducting strips within the hollow portion of said base member, said conducting strips comprising a plurality of first strips in electrical contact at their one end only with said base member and alternately extending from different sides of said base member and a plurality of second conducting strips in electrical contact with said base member at their both ends and extending across said hollow portion, one of said second strips being positioned between adjacent first strips in said array, means for introducing an electromagnetic wave to said hollow portion for transmission along said array, means for projecting an electron stream through said hollow portion adjacent said conducting strips for interaction with the electric field energy of said wave stored in the capacitance gaps defined between successive first and second conducting strips, and means for removing said wave from said hollow portion after interaction with said electron beam.

11. An electron discharge device comprising a hollow metallic base member substantially rectangular in cross section, an array of conducting strips within said hollow portion, said strips comprising an array of flat inductance stubs alternately in electrical contact at one end only with two opposite sides of said base member and extending therefrom and flat cross-ground strips extending across said hollow portion and in electrical contact at their both ends with the other two opposite sides of said base member, one of said cross-ground strips being positioned between adjacent inductance stubs, the length of said inductance stubs extending past the line of intersection of said crossed strips determining the direct capacitance between adjacent inductance stubs, means for introducing an electromagnetic wave to said hollow portion for transmission along said array, means for projecting a stream of electrons adjacent said line of intersection of said crossed conducting strips for interaction with the electric

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field energy of said wave stored in the capacitance gaps defined between successive inductance stubs and cross-ground strips, and means for removing said wave from said hollow portion after interaction with said electron beam.

12. An electron discharge device comprising a hollow metallic housing of substantially rectangular cross section, an array of coplanar wires positioned within said housing and extending thereacross, said wires comprising a first group in electrical contact at their one end only alternately with opposite sides of said housing and a second group in electrical contact at their both ends with said opposite sides of said housing, one wire of said second group being positioned between each pair of wires of said first group, means for introducing an electromagnetic wave to said hollow portion of said housing for transmission along said array, means for projecting a stream of electrons along said wires adjacent the region of overlapping of the alternate wires of said first group, and means for removing said wave from said hollow portion after interaction with said electron beam.

13. An electron discharge device comprising a metallic base member being rectangular in cross section and having a hollow portion, an array of conducting strips within said hollow portion, said strips comprising inductance stubs all in electrical contact at their one end only with one side of said base member and extending therefrom and cross-ground strips extending across said hollow portion and in electrical contact at their both ends with two opposite sides of said base member, one of said cross-ground strips being positioned between adjacent inductance stubs, said inductance stubs being positioned close enough together in said array to have an appreciable mutual inductance therebetween, means for introducing an electromagnetic wave to said hollow portion for transmission along said array, means for projecting a stream of electrons adjacent said array of conducting strips for interaction with the electric field energy of said wave stored in the capacitance gaps defined between successive inductance stubs and cross-ground strips, and means for removing said wave from said hollow portion after interaction with said electron beam.

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