July 5, 1938. R. K. POTTER 2,122,538

WAVE AMPLIFIER

Filed Jan. 22, 1935 2 Sheets-Sheet 1

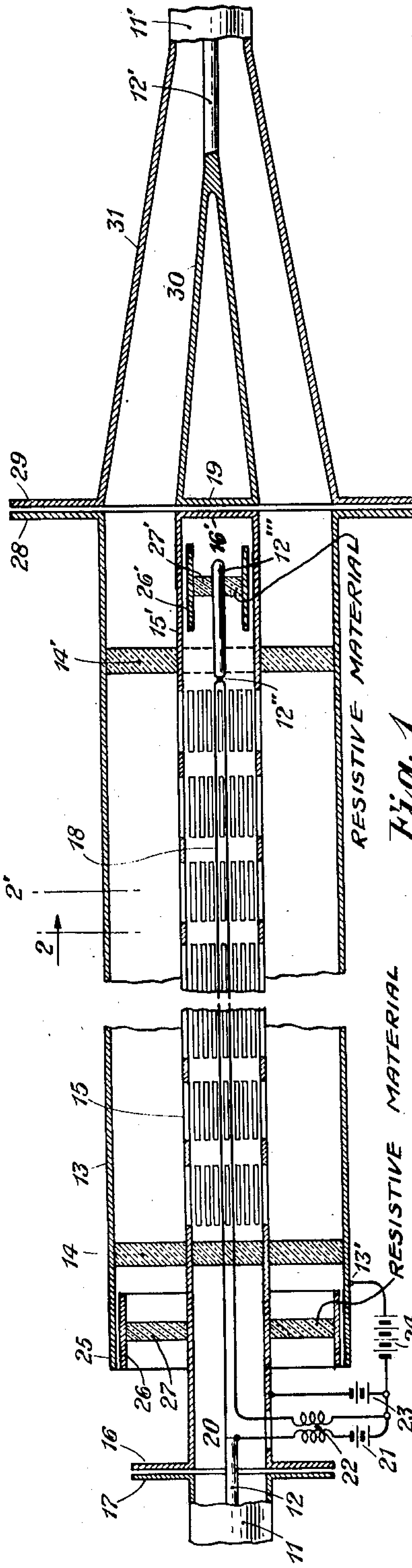

Fig. 1

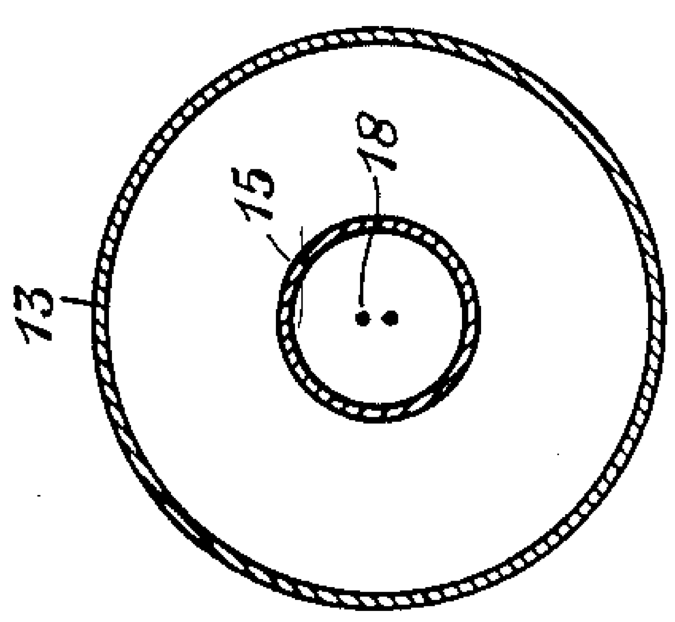

Fig. 2

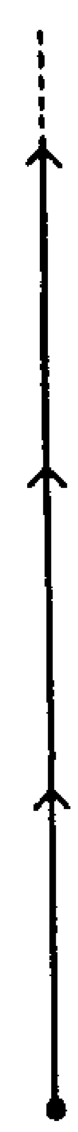

Fig. 3

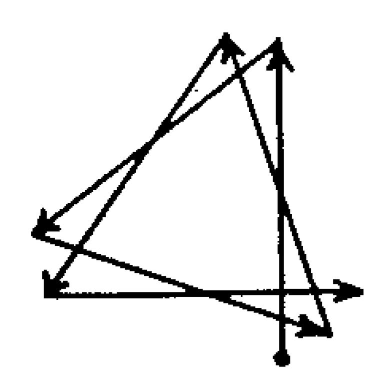

Fig. 4

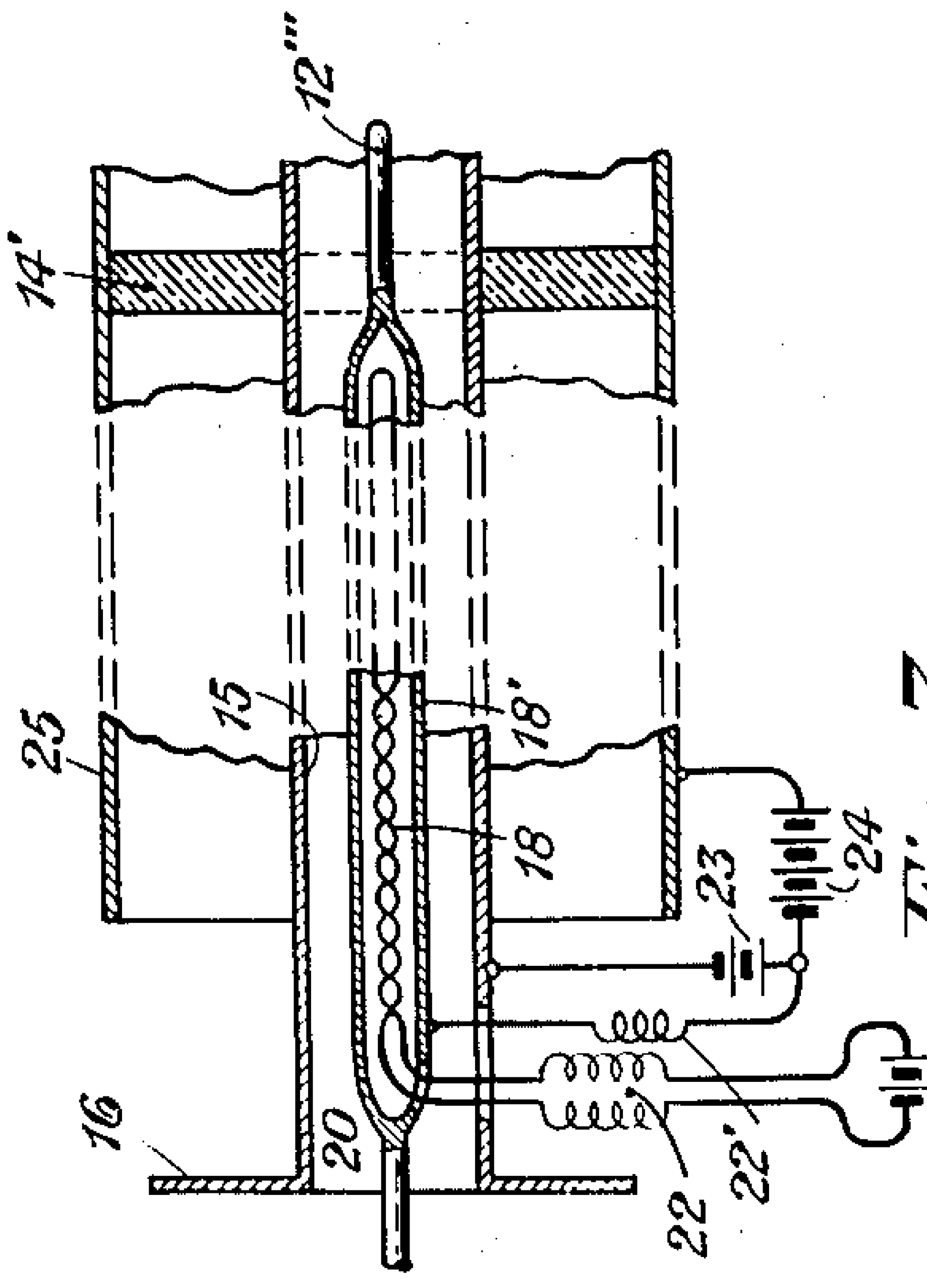

Fig 7

INVENTOR
R. K. Potter

BY [signature]
ATTORNEY

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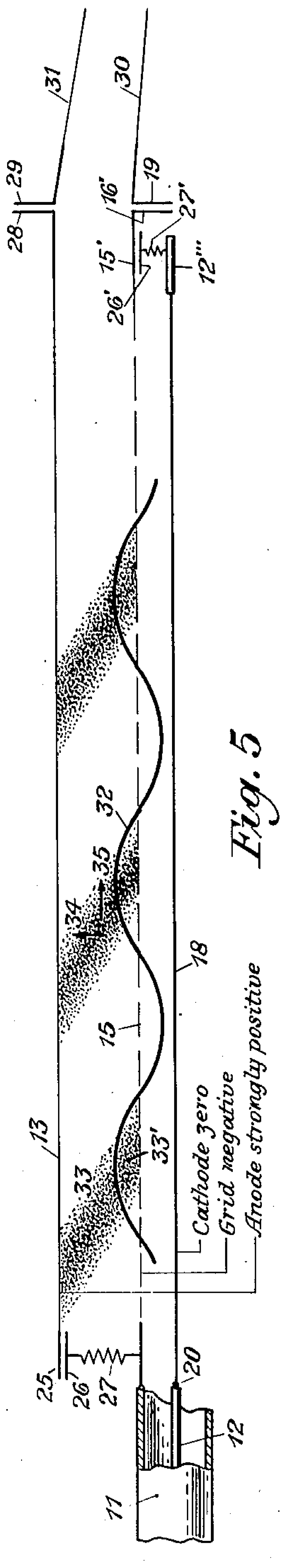

Fig. 5

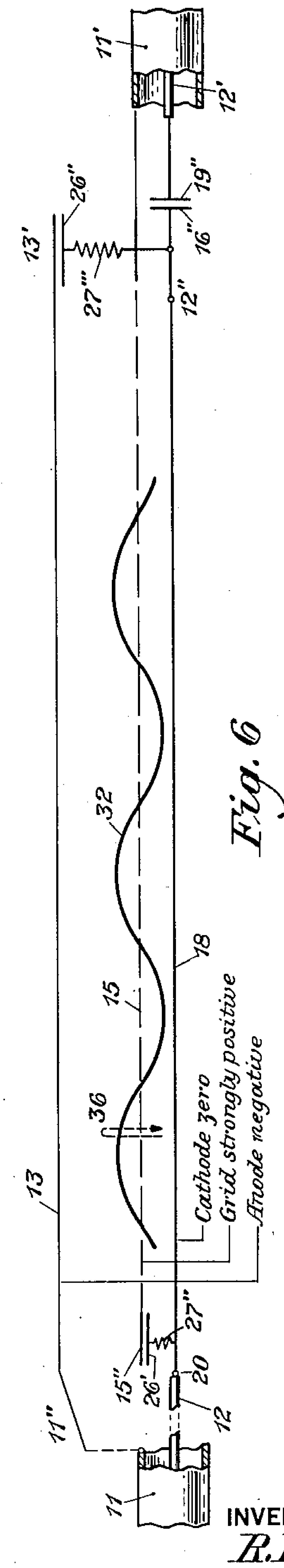

Fig. 6

INVENTOR
R.K. Potter

BY [signature]
ATTORNEY

Patented July 5, 1938 **2,122,538**

UNITED STATES PATENT OFFICE

2,122,538

WAVE AMPLIFIER

Ralph K. Potter, Madison, N. J., assignor to American Telephone and Telegraph Company, a corporation of New York

Application January 22, 1935, Serial No. 2,968

20 Claims. (Cl. 179—171)

An object of my invention is to provide new and improved apparatus and method for the amplification of electromagnetic waves. Another object is to provide for the amplification of waves of high frequency. In one aspect my invention is an amplifier of considerable length in the direction of transmission, this length being in some cases several wave lengths. The fact that the electrodes of the amplifier extend along its length for one or more wave lengths enables the amplifier to gather the incoming wave energy along its length and gradually build up amplified outgoing wave energy along its length. Such an amplifier as contemplated herein may be well adapted to be interposed in a high frequency concentric conductor system.

The foregoing objects and aspects of my invention will become more readily apparent on consideration of a limited number of specific examples of the invention which I have chosen for disclosure in the following specification. It will be understood that this specification relates principally to these particular embodiments of the invention, and that the scope of the invention will be indicated in the accompanying claims.

Referring to the drawings, Figure 1 is a diagrammatic longitudinal section of a three-electrode vacuum tube interposed in a concentric conductor system and exemplifying my invention; Fig. 2 is a cross-section taken on the line 2 in Fig. 1; Figs. 3 and 4 are vector diagrams which will be referred to in discussing the principles involved in the practice of my invention; Figs. 5 and 6 are highly diagrammatic longitudinal sections showing wave forms which will be referred to in explaining the principles involved in my invention; and Fig. 7 is a detail longitudinal section showing certain changes for an indirectly heated cathode instead of the directly heated cathode of Fig. 1.

Referring to Fig. 1, the concentric conductor system comprising the axial conductor 12 and the outer conductor or shell 11 is adapted for transmitting high frequency currents from left to right. The outgoing members of this conductor system are indicated at 11′ and 12′ on the right.

A three-electrode vacuum tube has the outer metallic shell or anode 13 closed at the left by the glass seal 14 and at the right by the glass seal 14′ and the end wall 16′. Coaxially disposed therein is a grid 15 stamped with comparatively long closely spaced longitudinal slots. On the left this grid 15 is turned out in a plane annular flange 16 opposite a similar flange 17 on the end of the concentric conductor shell 11. These two flanges 16 and 17 may be regarded as the plates of a condenser so that by virtue of displacement currents between them there is electrical continuity between the shell 11 and the grid 15.

Lying close to the axis of the tube is a hairpin cathode-filament 18, its two ends being on the left and its return bend being at 12″ on the right. At its right-hand end the grid 15 is extended beyond the glass seal 14′ as an unperforated shell 15′ and closed across by the end wall 16′. A disk 19 is placed parallel with the end wall 16′, and from its edge the conical conductor 30 tapers down to the right and merges into the axial conductor 12′ of the concentric conductor system on the right. The cross walls 16′ and 19 are the plates of a condenser and afford virtual electrical continuity from the grid 15 to the axial conductor 12′.

The circuit of the cathode battery 21 supplying heating current through the inductance 22 for the filament-cathode 18, is readily apparent. The axial conductor 12 incoming on the left is conductively connected to the axial filament-cathode 18 at 20. The anode circuit battery 24 is connected to the filament-cathode through the inductance 22 and to the anode at 13′. Also, there is a grid biasing battery 23 connected in the usual way.

At the left end, the tube shell or anode 13 ends in the part 25. Just within this is a short cylindrical shell 26 spaced slightly from 25. This shell 26 is connected to the grid 15 by an annulus 27 of resistance material. The members 25 and 26 are the plates of a condenser. With the resistance disc 27 they afford a capacity-resistance connection across between the grid 15 and the anode shell 13 at the left.

On the right a short axial conductor rod 12‴ is electrically connected at 12″ to the bent end of the hair pin filament 18. Within the terminal part 15′ of the grid 15 and around this extension conductor 12‴ is the short cylindrical shell 26′ spaced slightly from 15′ so that the two members 15′ and 26′ may be regarded as the plates of a condenser. The annulus 27′ of resistance material connects the extension conductor 12‴ to the condenser plate 26′. Thus the elements 15′, 26′, 27′ and 12‴ constitute a capacity-resistance bridge across between the grid 15 and the filament-cathode 18 at their right-hand ends.

On the right the anode shell 13 has an outwardly directed plane annular flange 28: closely opposed to this is a similar annulus 29 with a connected conical tapering shell 31 extending to the right from its inner edge and merging into the outer shell 11' of the concentric conductor system on the right.

The length of the tube 13 between the glass seals 14 and 14' is considerable as compared to the longest wave to be amplified in the concentric conductor system. In some cases the length of the glass tube may be several wave lengths. This permits of a cumulative or additive effect of the wave as it is propagated along the length of the electrode of the tube. If the electrodes are more than one wave long, corresponding elements of successive waves propagated along the electrodes are superposed upon each other to increase the amplification of the wave. The wave entering the tube at the left may be thought of as represented by radial lines of force with their inner ends on the axial conductor 12 and their outer ends on the inner face of the cylindrical shell 11, these lines of force being alternately directed outwardly and inwardly as one goes along the length of the conductor system at one instant, but all moving with the speed of transmission from left to right. There is virtually a continuous electrical connection from the shell 11 through the condenser 17—16 to the grid 15 so that these waves of lines of force continue their progress within the vacuum tube, their inner ends traveling on the filament-cathode 18 and their outer ends on the grid 15. If we consider a short length of the vacuum tube such as that between the lines 2 and 2' in Fig. 1, it may be looked upon as, in principle, a complete ordinary vacuum tube, provided the section of tube is so short as compared with a wave length that there is no variation in potential along the length of any electrode within the section. In the absence of any incoming waves there will be a steady stream of electrons from the filament-cathode 18 through the openings in the grid 15 to the plate 13. When waves come along to the segment 2—2', the density of this electron stream will be increased or diminished according to the direction of the lines of force of those waves. Thus the incoming waves will determine amplified outgoing waves in the concentric conductor system whose axial conductor is the grid 15 and whose surrounding shell conductor is the anode 13. These outgoing waves will pass from the conductors 15 and 13 through the capacity connections 16'—19 and 28—29 to the conically tapered pair of conductors 30 and 31, and thence to the normal size axial conductor 12' and shell conductor 11' of the outgoing concentric conductor system on the right.

Any elemental change in the anode current in the tube segment 2—2' will tend to create a wave disturbance going both right and left therefrom. At any particular point on the right, the wave elements arriving from the left will tend to add as vectors, as shown in Fig. 3. On the other hand, at any particular point on the left, the wave elements will tend to add as vectors, as indicated by the diagram in Fig. 4. This is in accordance with ordinary well-known wave transmission theory. Hence in great measure if not entirely, the incoming waves from the left will determine very little wave disturbance going to the left but will be amplified substantially going to the right. The capacity connection 25—26 and the resistance 27 interposed in series to each other as a bridge at the left between the conductors 15 and 13, will be designed to afford a proper impedance termination, so that, in so far as there is set up a wave transmission to the left, it will be substantially absorbed by this bridging connection.

For an applied wave of a given length the electrodes must be at least one wave length long in order that the vectors representing propagation of energy back towards the impedance 27 will add up algebraically to zero. Under these conditions there is no propagation of energy in this direction. The same will hold true when the electrode length is a multiple of the applied wave length. For any electrode length less than one wave length or for an electrode length intermediate between the successive whole multiples of the applied wave length some energy will be propagated in the direction towards the impedance 27. The ratio of the energy so propagated to that propagated towards the output becomes increasingly small as the electrode length is increased. This is because the vectors add algebraically in the same phase relation for propagation in the direction of the output, thereby producing a total energy which increases with electrode length while in the reverse direction the vectors cannot combine algebraically to a value greater than would be the case if the electrodes were one-half wave length long. That an electrode length equal to one-half wave length will produce the greatest transfer of energy towards the impedance 27 will be apparent when it is considered that up to one-half wave length all of the vectors will add together in the same linear direction regardless of their angular displacement while vectors beyond one-half wave length all add up in the opposite linear direction regardless of their angular displacement and hence oppose the vectors of the first half-wave.

As the incoming wave from the left travels along with its radial lines of force extending between the filament-cathode 18 and the grid 15, its energy will gradually be absorbed in the reaction which it encounters by which the anode current is varied to give an amplified reproduction. Whatever energy the incoming wave may retain when it reaches the right-hand end of the tube will be impressed upon the bridge consisting of the condenser 15'—26' and the resistance 27'. These are designed to afford a proper impedance termination so that such residual input wave energy will be absorbed and not reflected.

Fig. 5 is a highly diagrammatic representation of Fig. 1, the identification of the corresponding parts being made apparent by the use of the same reference numerals. In Fig. 5 the grid and the anode are shown only at one side of the cathode instead of at both sides, as in Fig. 1. The sinusoidal line 32 on the grid line 15 as axis represents the incoming waves of electromotive force between the cathode 18 and the grid 15. At the crests of these waves in the line 32 the normal radial electron flow from the cathode 18 through the grid 15 is increased. This is indicated by the stippling 33' under each such crest. As the wave moves on to the right, the cloud of electrons moves out radially so that behind each wave crest there will be trailing an inclined cloud 33 of electrons, the individual electrons moving radially as indicated by the arrow 34 but the region of increased density, that is the cloud 33, moving to the right, as indicated by the arrow 35.

In the apparatus of Figs. 1 and 5 the motion of the individual electrons is not purely oscillatory. There is a continuous radial drift of electrons imposed by the plate battery 24. This continuous radial motion consists of a steady intensity determined by the plate battery and a superposed oscillatory intensity determined by the incoming waves. The resultant is a fluctuating intensity. Although the radial drift of the electrons occurs no farther to the right than the glass seal 14', its fluctuations to that point produce electromagnetic waves which are continued to the right between the conductors 30 and 31 and thence between the conductors 12' and 11'.

The tube may be operated in a somewhat different manner, as indicated in Fig. 6. Whereas in Figs. 1 and 5 the grid is moderately negative and the anode is strongly positive, in Fig. 6 the grid is made strongly positive and the anode moderately negative. At the input end on the left the inner and outer concentric conductors are connected to the cathode 18 at 20 and to the anode 13 at 11'', respectively and an impedance bridge of capacity 15''—26' and resistance 27'' is placed across the left end of the cathode 18 and grid 15. At the right end the grid 15 is connected to the outer concentric conductor 11' and the cathode 18 is connected through a condenser 16''—19'' to the inner conductor 12'. An impedance of capacity 13'—26'' and resistance 27''' is bridged across the cathode 18' and anode 13 at the right. With no input waves applied at the left end of the amplifier to affect the normal potential of the anode 13 and the filament 18, many electron paths will be as indicated by the arrow 36; that is, electrons emitted by the cathode 18 will be accelerated by the positive grid 15 and will pass through the grid openings into the grid-anode space. The energy acquired by these electrons during acceleration will cause them to travel a considerable distance in the grid-anode space, against the attraction of the positive grid 15 and the repulsion of the negative anode 13, before coming to rest and starting back toward the grid. By suitably adjusting the grid and anode potentials this turning point of the electrons can be brought very close to the anode. The cloud of momentarily stationary electrons thus formed becomes a virtual cathode from which electrons may be readily drawn to the anode. Owing to the close proximity of anode and virtual cathode, a comparatively small increase of anode potential in the positive direction will draw a relatively large number of electrons from the virtual cathode.

With no input to the amplifier, all the electrons emitted by the cathode eventually reach the grid, assuming that the grid is sufficiently positive to prevent the formation of space charge in the grid-cathode region. Thus for no input there is a constant flow of electrons from cathode to grid. When an input wave is applied at the left between anode and cathode, many electrons are drawn from the virtual cathode to the anode, the number of these electrons fluctuating in accordance with the variations of the anode potential. Consequently the number of electrons remaining, which are drawn to the grid, also fluctuates in accordance with the anode potential variations, the number reaching the grid decreasing as the anode potential increases in the positive direction. The result of this action is an amplified wave between grid and cathode, which, as it is propagated along the length of the electrodes, undergoes the same building-up as described in the negative grid amplifier of Fig. 5.

Figs. 1 and 5 show a directly heated cathode. For an indirectly heated cathode suitable modification is indicated in Fig. 7, as will readily be apparent.

As has been mentioned heretofore, a short section of the elongated vacuum tube described herein may, in effect, be considered as equivalent to a conventional three-element vacuum tube. Additional grids or elements for shielding or other purposes recognized in conventional vacuum tube practice may be employed in this elongated type of tube.

I claim:

1. Apparatus for amplifying the energy of a high frequency wave train comprising a vacuum tube having cathode, anode and control electrodes lying in the direction of propagation and each having a length several times that of the wave length of said frequency so that the wave propagated in one direction is greater than that in the reverse direction, an input connection to apply said wave train to certain of said electrodes at one end of the tube for propagation along said electrodes, and an output connection to at least one different electrode at the other end of the tube to take off a wave propagated along said different electrode.

2. Apparatus for amplifying the energy of a train of high frequency waves comprising a plurality of electrodes paralleling each other over a distance of more than one wave length of said frequency in the direction of propagation so that the wave propagated in one direction is greater than that in the reverse direction, means to impress the wave configuration on one pair of said electrodes for propagation along said electrodes, output connections to a different pair of said electrodes, and operating potentials so applied to said electrodes as to produce on said different pair of said electrodes an amplified copy of the wave configuration applied to said first pair.

3. In combination, a pair of conductors for the transmission of high frequency waves, a vacuum tube having more than two electrodes at least two of which extend over a distance of more than one wave length of said frequency substantially in the same direction and respectively in continuation of said pair of conductors so that the wave propagated in one direction is greater than that in the reverse direction, and another pair of conductors similar to said first mentioned pair extending on in substantially the same direction from a different pair of electrodes of said vacuum tube.

4. A vacuum tube amplifier for high frequency waves having a plurality of electrodes extending parallel to each other over a distance of more than one wave length of said frequency in one and the same direction so that the wave propagated in one direction is greater than that in the reverse direction, means to apply an input high frequency electromotive force to a pair of said electrodes at one end of said tube so that said electromotive force may be propagated along the length of said electrodes, and operating voltages applied to certain of said electrodes so as to gradually build up in response to said propagation a corresponding amplified output electromotive force propagated along another pair of electrodes toward and to the other end of the tube.

5. In combination, a long vacuum tube having electrodes extending along the length of the tube a distance of more than one wave length of an applied wave so that the wave propagated in one direction is greater than that in the reverse direction, input conductors connected at one end to two of these electrodes and output conductors

connected at the other end to a different pair of these electrodes.

6. In combination, a pair of conductors for the transmission of high frequency waves, a vacuum tube having a plurality of electrodes, two of these extending substantially parallel with each other in the same direction and respectively in continuation of said two conductors, at least one other electrode substantially parallel with said two electrodes, said electrodes extending for a distance of more than one wave length of the applied wave so that the wave propagated in one direction is greater than that in the reverse direction, and two more conductors similar to the first pair extending on in substantially the same direction and respectively in continuation of a pair of said electrodes, this pair having at least one member different from the members of the first mentioned pair.

7. In combination, a vacuum tube including a pair of input electrodes and including a pair of output electrodes, said electrodes extending coaxially a distance of more than one wave length of an applied wave in the direction of wave propagation so that the wave propagated in one direction is greater than that in the reverse direction, a concentric conductor pair coaxial with the tube and connected at one end of the tube to said input coaxial electrodes, and a like conductor pair also coaxial with the tube and connected at the other end of the tube to said output coaxial electrodes so that transmission may take place through the tube from one concentric conductor pair to the other.

8. In combination, a long vacuum tube having three electrodes in which the rate of electron emission to the anode varies sinusoidally over the length of said anode and the phase of this sinusoidal variation changes progressively in one direction along the anode, a concentric conductor system extending in the same direction and having its two conductors connected respectively at one end of said tube to two of its electrodes, a similar concentric conductor system extending in the same direction at the other end of the tube and having its two conductors connected at that end to two electrodes of the tube, the connections at one end being tapered with the proper ratio of radii so as to bring the concentric conductor system to the same dimensions on both the input and the output ends of the tube.

9. In combination, a concentric conductor system, a three-electrode vacuum tube interposed therein having its electrodes extending through the tube a distance of more than one wave length of an applied wave and disposed symmetrically around a common axis with the concentric conductor system so that the wave propagated in one direction is greater than that in the reverse direction, certain of said electrodes and certain of the conductors of said concentric conductor system having terminating portions lying adjacent each other to form capacity connections between certain tube electrodes and certain conductors of said concentric conductor system.

10. A cylindrical vacuum tube with axial cathode, coaxial outer cylindrical anode, and coaxial intermediate cylindrical grid, said electrodes extending through said tube a distance of more than one wave length of an applied wave so that the wave propagated in one direction is greater than that in the reverse direction, a pair of input conductors connected to the cathode and grid at one end, a pair of output conductors connected to the anode and one of the other electrodes at the other end, one of the input conductors having a flange adjacent a corresponding flange on one of said electrodes to constitute closely spaced condenser plates on respective sides of a gap, thus forming a capacitative connection, and an output conductor similarly capacitatively connected to another electrode.

11. In combination, a long vacuum tube having a plurality of electrodes extending through the tube a distance of more than one wave length of an applied wave and disposed symmetrically around a common axis so that the wave propagated in one direction is greater than that in the reverse direction, input conductors connected to certain of said electrodes at one end, output conductors connected to a different pair of electrodes at the opposite end, and an impedance matching termination bridged across two electrodes of the tube at one end thereof.

12. A cylindrical vacuum tube with axial cathode, coaxial outer cylindrical anode, and coaxial intermediate cylindrical grid, said electrode extending through the tube over a distance of more than one wave length of the applied wave so that the wave propagated in one direction is greater than that in the reverse direction, a pair of input conductors connected to the cathode and another electrode at one end, a pair of output conductors connected to the cathode and yet another electrode at the other end, an annular condenser and a resistance in series bridged across between an electrode connected to an input conductor and an unconnected electrode at the input end of the tube, and a like bridging combination across between a different pair of electrodes at the output end.

13. The method of amplifying high frequency waves which consists in propagating a wave from point to point for a distance of more than a wave length along a conductive path in an evacuated space, producing at each point by the electromotive force of the wave thus propagated along the path a corresponding change in each element of the field along the corresponding length of another path in said evacuated space, and in said latter path effectively adding to each other elements of the wave propagated in the direction of transmission.

14. The method of amplifying high frequency waves which consists in propagating a wave from point to point for a distance of more than a wave length along a conductive path in an evacuated space, producing at each point by the electromotive force of the wave thus propagated along the path a corresponding change in each element of the field along the corresponding length of another path in said evacuated space, and in said latter path effectively adding to each other elements of the wave propagated in the direction of transmission while effectively balancing out elements of the wave propagated in the reverse direction.

15. The method of amplification of a wave train which consists in cumulatively amplifying the energy of the wave train at successive points distributed continuously along a conductive path in an evacuated space extending over several wave lengths of the wave train.

16. The method of amplification of a wave train which consists in cumulatively amplifying the energy of the wave train at successive points distributed continuously along a conductive path in an evacuated space extending in the direction of propagation over a distance of as much as one wave length.

17. The method of amplifying high frequency electric waves which consists in propagating a wave along a path formed in an evacuated space between a cathode and a parallel control electrode extending over a distance of at least a wave length, varying the rate of electron flow from the extended cathode element over the cathode length in accordance with the instantaneous distribution of force in the electric waves traveling in the direction in which said cathode extends and in the region between said cathode and the parallel control electrode, producing corresponding changes in the field along a third electrode which add cumulatively in the direction of transmission, and taking off the amplified energy which is thereby determined in the region between said third electrode and another electrode.

18. The method of amplifying high frequency waves which consists in propagating a wave along a conductive path in an evacuated space for a distance of at least a wave length, amplifying each element of said wave at each of a number of successive points along the length of said path in the direction of propagation, and cumulating the resultant amplified components propagated along the length of the path in that same direction.

19. The method of amplifying high frequency waves between a pair of conductors which consists in propagating a wave along said conductors in an evacuated space for a distance of at least a wave length so that the wave component propagated in one direction is greater than the component in the reverse direction, emitting electrons within said space along the length of one conductor with the electron paths transverse thereto, controlling the electron discharge current at each point along said conductor within said space in accordance with the incoming wave of electromotive force propagated along the pair of conductors within the space, thereby producing a corresponding amplified wave.

20. The method of amplifying high frequency waves between a pair of conductors which consists in propagating a wave along said conductors in an evacuated space for a distance of at least a wave length so that the wave component propagated in one direction is greater than the component in the reverse direction, emitting electrons along the length of one of said conductors within said space, varying the discharge density of said electrons at each point along said pair of conductors within said space in accordance with the impressed wave, thereby producing an amplified electron discharge current from point to point along the emitting conductor, and taking this current off on a pair of conductors in substantial alignment with the first pair.

RALPH K. POTTER.