June 9, 1959 E. C. DENCH 2,890,384

TRAVELING WAVE ELECTRONIC DEVICES

Filed Sept. 24, 1953 2 Sheets-Sheet 1

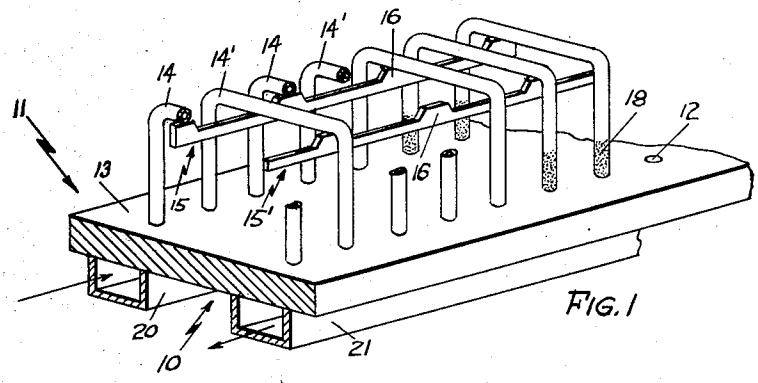


FIG. 1

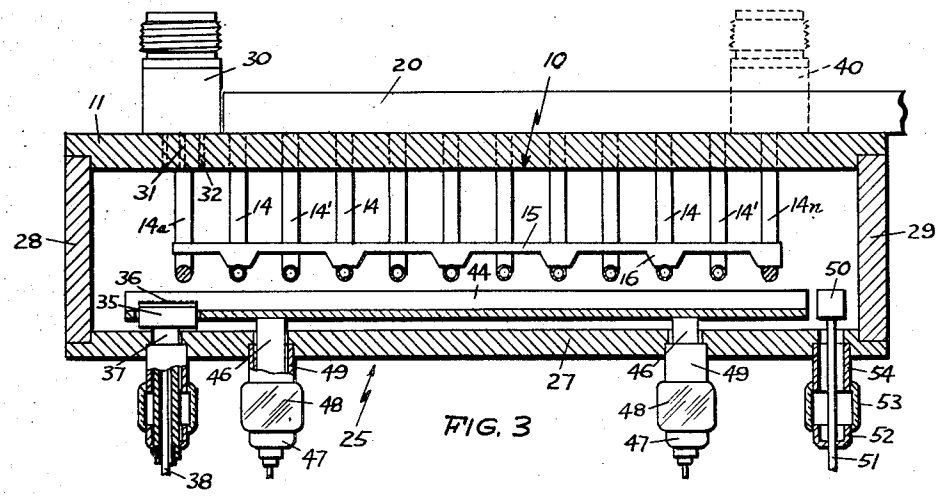


FIG. 3

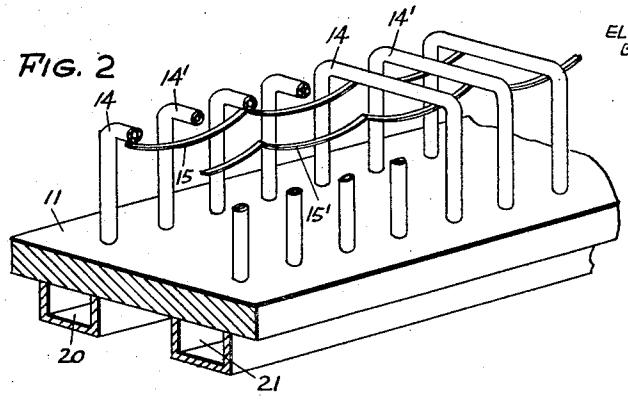


FIG. 2

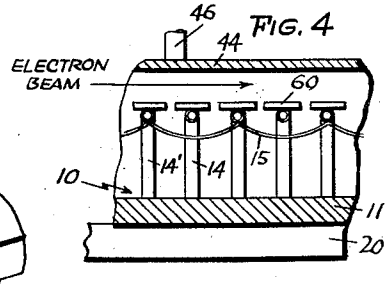


FIG. 4

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TRAVELING WAVE ELECTRONIC DEVICES

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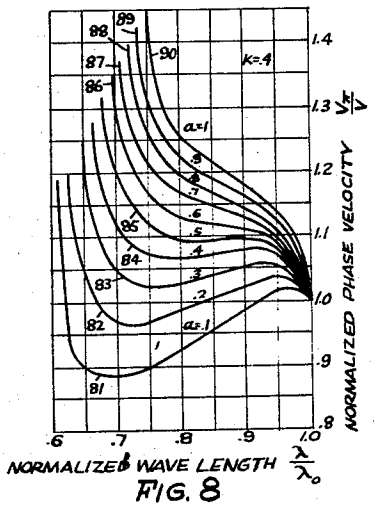


FIG. 8

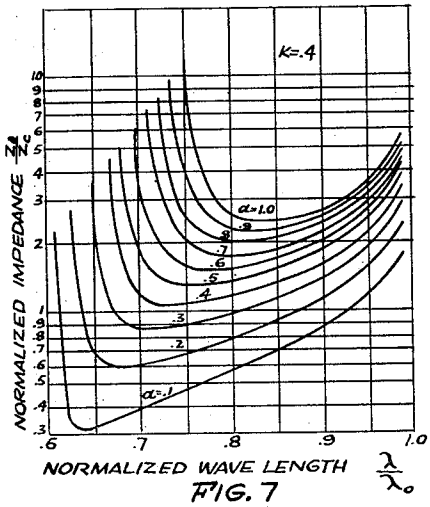


FIG. 7

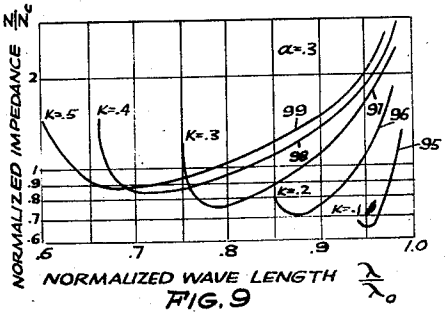


FIG. 9

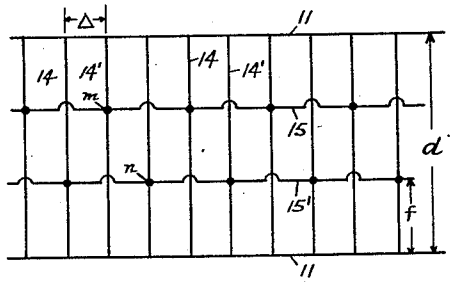


FIG. 5

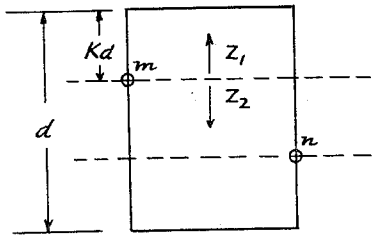


FIG. 6

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2,890,384

TRAVELING WAVE ELECTRONIC DEVICES

Edward C. Dench, Needham, Mass., assignor to Raytheon Manufacturing Company, Newton, Mass., a corporation of Delaware

Application September 24, 1953, Serial No. 382,133

30 Claims. (Cl. 315—39.3)

This invention relates to an improved periodic delay line of the fluid-cooled type suitable for use in high power traveling wave tubes and to traveling wave tubes using said delay line.

One of the commonly employed anode structures forming the signal wave transmission network of a traveling wave tube is the strapped solid vane structure exemplified in an application by Edward C. Dench, for United States Letters Patent, Serial No. 268,097, filed January 24, 1952, now United States Patent 2,850,671, issued September 2, 1958. This anode network includes an electrically conductive supporting plate, to which a plurality of equally spaced substantially rectangular planar members or vanes positioned substantially normal to the supporting plate are attached. At points on the edges of alternate vanes near the free ends thereof are connected two pairs of conductive straps which extend longitudinally along the structure. This anode structure is enclosed within an evacuated envelope of a traveling wave tube which includes a negative electrode, collector electrode, means for producing an electron beam and necessary connections.

All other things being equal, it is desirable that the characteristic impedance of a periodic anode network for use in a traveling wave tube amplifier or oscillator be as high as possible.

The characteristic impedance Z_o normalized with respect to the characteristic impedance Z_c of each cavity or network section formed between two adjacent anode network vanes is a function of a design parameter α. For the strapped vane structure, α is defined as

$$\alpha=\frac{\omega^o L_s}{Z_c} \qquad (1)$$

where

ω_o is the cutoff frequency
L_s is the strap inductance per network section
Z_c is the characteristic impedance of the parallel conductor network section or cavity formed by two adjacent vanes.

As pointed out, however, in the aforesaid Patent No. 2,850,671, it is not practically feasible to increase the impedance by increasing α indefinitely. A value of α must be selected and maintained, for a particular periodic delay network, which will permit that network to transmit waves at all frequencies within the pass band at phase velocities which are less than the phase velocity $V_{p\pi}$ of the lower cutoff or π mode frequency.

The ratio of Z_o to Z_c is a constant, for a given value of α and wavelength. In order to increase the characteristic impedance Z_o, therefore, it is necessary to increase Z_c also.

For the strapped vane network, Z_c is given by

$$Z_c=k\frac{s}{h} \qquad (2)$$

where
s is the spacing between vanes and
h is the height of the vanes.

Since the separation of the vanes (pitch) determines the velocity at cutoff and, hence, the velocity everywhere in the operating range, the amount of separation is dictated by operating voltage considerations. It is undesirable to increase Z_c by increasing s since this increases the phase velocity and voltage of the amplifier. If h is reduced, on the other hand, the surface of the network presented to the electron beam is narrowed, and it is difficult to obtain the desired beam current.

In accordance with the subject invention, the central portion of the vanes is eliminated and the network elements are reduced to U-shaped loops. In this way the impedance of the delay line is increased without changing the pitch or width. In order to overcome the problem of heat dissipation resulting from the smaller surface area of the vanes, the latter are made in the form of U-shaped tubular loops through which a cooling fluid may be circulated. Although the straps may be located externally or internally near the ends of the loops, it is preferable to use a single pair of spaced straps located near the center of the loops.

The decreased area of the opposing faces of adjacent loops can be achieved by reducing the loop dimensions within limits compatible with physical strength and efficient internal flow of cooling fluid.

A further improvement of the periodic delay network of the subject invention, when used as an anode in traveling wave tubes, may be effected by providing flat surfaces on the outer surface of the loop cross arms, that is, along the surface of the loop facing the electron stream.

From Equation 2 it is evident that if the value of α is to remain constant, the strap inductance L_s or the cutoff frequency ω_o must be increased. Usually it is not feasible to vary the cutoff frequency so that it is necessary to increase the value of L_s. This may be accomplished in at least two ways. The number of straps may be reduced from four, as used in the periodic structure of the aforesaid Patent No. 2,850,671, to a single strapped pair. The size of the straps may be decreased to achieve the desired increase in L_s. In addition, the strap inductance may be increased by keeping the straps as far away from the loops as possible except at the points of connection. In the case of linear straps, slotted portions may exist therein over which the portion of the loop not connected thereto may pass; the loops may also be bent to achieve the same result.

Other and further objects and advantages of this invention will be apparent as the description thereof progresses, reference being had to the accompanying drawings wherein:

Fig. 1 is a fragmentary isometric view of an improved periodic delay network according to the invention;

Fig. 2 is a view showing a modification of the strapping of the network of Fig. 1;

Fig. 3 is a longitudinal cross-sectional view of a traveling wave tube discharge device utilizing the periodic network of Fig. 1 as the anode;

Fig. 4 is a view illustrating a modification of the periodic anode network of Figs. 1 and 2;

Fig. 5 is a schematic view showing the equivalent circuit of the periodic network of Fig. 1;

Fig. 6 is a schematic view showing the equivalent circuit of a single network section of the network of Fig. 5;

Fig. 7 is a graph illustrating the relationship between the impedance of a periodic network, such as shown in Fig. 1, and the wave length for various values of the design parameter α;

Fig. 8 is a graph illustrating the relationship between the phase velocity of a wave traveling along a periodic transmission network of the type shown in Fig. 1 and the wave length, for various values of the design parameter α; and

Fig. 9 is a graph indicating the effect of the constant k upon the wave length for a periodic structure such as shown in Fig. 1.

Referring to Fig. 1, the periodic transmission network **10** includes an electrically conductive base **11** having a major surface **13** and containing two rows of aligned circular apertures **12** positioned adjacent opposite sides of the base and extending clear through the same. A plurality of electrically conductive tubular U-shaped loops **14** and **14'** are disposed longitudinally along the base. The pitch or spacing between adjacent loops is preferably uniform throughout the length of the structure. The ends of each loop are inserted in oppositely disposed apertures in the base in a manner clearly shown in Fig. 1.

A pair of spaced straps **15** and **15'** are located near the center of each loop and are attached to alternately arranged loops **14** and **14'**, respectively. These loops are preferably constructed of strap metal having a high thermal and electrical conductivity. Each strap contains a plurality of spaced projecting portions **16** whose spacing between centers is substantially equal to the pitch of the network. The portions of the strap between adjacent projecting portions will be referred to as slotted portions. The straps are connected to the transmission loops at the projecting portions, as by soldering. In order to couple together the odd numbered loops with one strap and the even numbered loops with the other strap, the projecting portions of one strap fall opposite the slotted portion of the other, as shown in Fig. 1. The straps **15** and **15'**, alternately, may be in the form of loops of metal strip, as shown in Fig. 2. The center of each strap loop of Fig. 2 or the slotted portion of the straps of Fig. 1, as the case may be, is thus separated from the U-shaped network loops **14** or **14'**, as the case may be, by a relatively large amount, whereby the strap inductance is substantially increased.

Attenuation may be introduced into network **10** by means of a metallic attenuating coating **18**, such as graphite, which may be deposited near the ends of some of the transmission loops. Instead of resorting to an attenuative coating, the loops themselves may be constructed of a material, such as iron, having a high attenuation factor.

A pair of trough-shaped headers **20** and **21** are secured in substantial alignment with the opposite ends of the network loops **12** and **12'** to the under side of base **11**, as by soldering, so as to form a fluid-tight seal. One end of each header is closed, while the other end is connected to a fluid circulating pump, not shown. The cooling fluid passes along one header, through each loop in parallel and back along the other header.

Although the periodic network **10** has been shown as linear, it should be understood that the network may also be circular to conform to the usual practice in magnetron design.

In Fig. 3, a traveling wave tube amplifier **25** is shown which includes as its anode the periodic network **10**, previously described.

The periodic structure serving as the anode of the traveling wave amplifier comprises a base **11** which forms one of the walls of an evacuated envelope further including an oppositely disposed wall **27**, end walls **28** and **29**, and a pair of side walls, not shown. Base **11** may be fastened to the contiguous walls of the envelope by soldering or by means of fastening devices such as screws.

The inner conductor **31** of a coaxial input coupling device **30** extends through an aperture **32** in wall **11** and is attached, as by soldering, to one end of the first loop **14***a* at the input end of the anode structure. This loop, as well as the loop **14***n* at the other end of the structure, is solid as contrasted with the tubular loops in between. An output coupling device **40** is similarly attached to one end of a loop **14***n* at the output end of the anode structure, as shown in Fig. 3.

Positioned adjacent the input end of the anode **10** is a cathode structure **35** having an electron-emissive surface **36**. Cathode **36** is supported by a hollow supporting cylinder **37** extending through an aperture in wall **27** of the tube envelope. Cylinder **37** surrounds a central conductor **38** which is connected to one end of a heater coil, not shown, positioned in thermal proximity to cathode-emissive surface **36**. The details of this cathode are set forth more specifically in an application for United States Letters Patent, Serial No. 255,499 of Edward C. Dench, filed November 8, 1951, now United States Patent No. 2,809,328, issued October 8, 1957.

An auxiliary electrode **44** is positioned substantially parallel to the anode structure and spaced therefrom, as shown in Fig. 3. Electrode **44**, which is otherwise referred to as a "sole," is a U-shaped member whose bottom surface is positioned somewhat lower than the electron-emissive surface **36** of the cathode. Sole **44** is supported relative to the remainder of the tube envelope by means of a pair of supporting rods **46** rigidly attached to the sole. These rods are insulatedly supported with respect to wall **27** by means of metallic members **47** sealed, in turn, to ceramic seals **48**. The latter are connected to an electrically conductive cylinder **49** which surround rods **46** and are, in turn, attached to recesses in wall **27** surrounding the apertures through which rods **46** pass.

Positioned beyond the opposite end of sole **44** and in substantial alignment therewith is a collector electrode **50** rigidly supported by means of a lead-in rod **51** extending through an aperture in wall **27** and spaced therefrom. Rod **51** is supported relative to wall **27** by means of a conductive cup **52**, a ceramic cylinder **53**, and a metallic cylinder **54** surrounding rod **51** and sealed together like the sole-supporting device previously described.

A direct current electric field may be established between the anode and the sole by connecting a source of direct current voltage, not shown, therebetween. The cathode **35** is negative with respect to the anode but may or may not be at the same potential as the sole.

A transverse magnetic field is produced in the space between the periodic anode structure and the sole in a direction normal to the electric field, or in a direction perpendicular to the plane of the paper. By proper adjustment of the magnetic field, the electrons emitted from the cathode will be directed along a path adjacent the loops of the anode structure. Interaction of the electron beam with a wave traversing the anode structure will result in amplification within the traveling wave tube.

It is possible to eliminate the transverse magnetic field and to operate the traveling wave tube as a non-magnetic amplifier.

The cathode-sole assembly shown in Fig. 3 may be replaced by a continuous cathode extending the length of the tube and similar to that described in an application for United States Letters Patent of William C. Brown, Serial Number 210,896, filed February 14, 1951, now United States Patent No. 2,651,001, issued September 1, 1953. This is true regardless of whether or not the tube utilizes a transverse magnetic field.

An improvement in the periodic structure of Figs. 1 to 3 is shown in Fig. 4, in which flat plates **60** are attached as by brazing to the outer edge of the cross arms of a corresponding transmission loop, as shown in Fig. 4, that is, along the surface of the tubular loops facing the electron stream. These plates are substantially rectangular, and may be approximately the length of the loop cross arm. The tubes may alternately be formed with flat surfaces instead of having flat pieces attached thereto. For example, the surface of the tubular loops facing the electron stream may be filed or machined down flat, provided, of course, that the wall thickness of the loops is sufficiently large. A composite surface of the periodic structure formed by the several plates **60** which is presented to the interaction space of the travel-

ing wave tube is substantially flat, rather than a series of rounded surfaces, and the gap between adjacent plates is quite small compared to the average distance between the rounded surfaces of adjacent tubular loops of Figs. 1 to 3. Since this composite surface approaches a solid plane substantially equidistant at all points from the sole of the traveling wave tube, the direct current electric field in the interaction space is comparatively uniform. Because of this uniform direct current field, a more uniform electron beam is attained.

An analysis of the strapped loop periodic structure of Figs. 1 to 3 may be had by constructing a linear array of said loops which have been straightened out, as schematically illustrated in Fig. 5. The length of the loops included between the two points of connection to base **11** is designated as d, while the distance of the straps from the ends of the loop is designated as f. The ratio of f to d, which is a measure of the strap separation, is designated as k. For example, if both straps were located at the center of the loops, the value of k would be 0.5.

A single network section is shown schematically in Fig. 6 and may be considered to be a parallel-conductor shorted transmission line of characteristic impedance Z_c. It is divided into two parallel paths by the dotted line through point m at which the strap **15** is connected to loop **14**. The impedances looking in both directions away from m are Z_1 and Z_2. The impedance Z between point m and point n, the point of connection of strap **15'** to loop **14'**, is equal to the parallel combination of impedances Z_1 and Z_2, where

$$Z_1=jZ_c \tan \frac{2\pi kd}{\lambda} \tag{3}$$

and

$$Z_2=jZ_c \tan \frac{2\pi(1-kd)}{\lambda} \tag{4}$$

the impedance Z thus becomes

$$Z=\frac{jZ_c\left(\tan \frac{2\pi kd}{\lambda}\right)\left(\tan \frac{2\pi(1-kd)}{\lambda}\right)}{\left(\tan \frac{2\pi kd}{\lambda}\right)+\left(\tan \frac{2\pi(1-kd)}{\lambda}\right)} \tag{5}$$

The effect of the network design parameter α on the normalized impedance

$$\frac{Z}{Z_c}$$

of the periodic network of Fig. 1, for a given wave length, normalized with respect to the upper cutoff wave length λ_0 is shown in the graph of Fig. 7. The network impedance is increased as α is increased from 0.1 to 1. For example, at a normalized wave length of 0.9, the normalized impedance increases from about 0.9 when α=.1 to approximately 2.7 when α=1. This graph represents a periodic network having a value k=4, as will be shown later. The shape of the curves of Fig. 7 will be changed somewhat as the strap separation, or value k, changes, as will be evident from inspection of Fig. 9, to be described later.

This dispersion curve of the spaced harmonic of the traveling wave suitable for amplification, that is, the relationship between the wave length and the phase velocity of the first harmonic of a wave traveling along the periodic network **10** of the traveling wave tube of Fig. 3 is shown in Fig. 8 for various values of α. The portion of the dispersion curve representative of the component of the traveling wave suitable for operation of the traveling wave tube as an oscillator is not shown in Fig. 8 but, as more fully described in a copending application of Edward C. Dench for United States Letters Patent, Serial No. 382,025, filed September 24, 1953, the two portions of the dispersion curve representative of the fundamental and first space harmonic are symmetrically located about a line passing through the origin

$$\left(\frac{V_\pi}{V}=0 \text{ and } \frac{\lambda}{\lambda 0}=0\right)$$

of the curve and unity on the normalized phase velocity axis and having a slope equal to the reciprocal of twice the pitch of the periodic network.

As shown in Fig. 8, the curves **81** and **82** for respective values of α of .1 and .2 are relatively flat over a wide range. However, the required phase velocity for most of the wave lengths in the pass band is greater than that necessary for π mode oscillations so that undesirable oscillations may be set up in the traveling wave tube. For high values of α, for example, for values of the order of 0.6 to 1, the curves **86** to **90** are not flat over any substantial portion thereof and the gain of an amplifier tube operating on these curves, even assuming that oscillations will not occur, will vary considerably with operating wave lengths. For values of α in the range of 0.3 and 0.5, the curves are relatively flat over a wide range of wave lengths, for example, between the normalized wave lengths of approximately .75 and .95, as shown in curves **83** to **85**. Hence, the degree of interaction between the electron beam and the waves propagating along the anode structure, and consequently the gain of the traveling wave tube when used as an amplifier, remain substantially constant over a wide band of frequencies when curves **83** to **85** obtain. In practice, this means that the desired gain may be accomplished over a wide band of frequencies using the same anode voltage or the same magnetic field strength, if the tube utilizes a transverse magnetic field.

A value of α equal to about 0.4 or 0.5 is satisfactory for the periodic network represented in Fig. 8.

As evidenced by Equation 5, infra, the factor k of the strapped loop periodic network has an effect upon the impedance level of the network. The effect of k on the impedance is shown in Fig. 9 in which graphs of normalized impedance versus normalized wave length for various values of k from 0.1 to 0.5 are shown by curves **95** and **99**, respectively, when α is held constant. The curves of Fig. 9 indicate that the impedance level of the system is reduced when k is reduced. Since the value of k, as well as the value of α, affects the shape of the curves, suitable values of k and α should be chosen simultaneously in order to secure desirable network characteristics.

Although the traveling wave tube shown in Fig. 3 is of linear configuration, this invention may be applied to other than linear traveling wave tubes. For example, a circular tube of the type shown in application for United States Letters Patent of Edward C. Dench, Serial No. 382,025, filed September 24, 1953, may be used.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is, accordingly, desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member having a single major surface and a plurality of spaced circuit elements uniformly disposed along the length thereof, said elements including a first portion spaced from and disposed substantially parallel to said major surface of said member and at least one portion extending from said first portion toward said major surface of said member and having at least one end thereof electrically connected to the major surface of said member, said elements cooperating with said member to form a series of network sections.

2. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive mem-

ber having a single major surface and a plurality of shorted transmission loops attached to said major surface of said member at the ends thereof, said loops cooperating with said member to form a series of network sections, and a pair of electrically-conductive straps attached to alternate ones of said loops.

3. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member and a plurality of hollow circuit elements uniformly disposed along said member, said elements including a first portion spaced from and disposed substantially parallel to said member and a portion extending from said first portion toward said member and shorted at the ends thereof by said member, said elements cooperating with said member to form a series of network sections, and means for circulating a cooling fluid through said circuit elements.

4. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member and a plurality of hollow circuit elements uniformly disposed along said member, said elements including a first portion spaced from and disposed substantially parallel to said member and a portion extending from said first portion toward said member and shorted at the ends thereof by said member, said elements cooperating with said member to form a series of network sections, and a pair of electrically-conductive straps each having alternately arranged projecting portions and slotted portions, said projecting portions attached to a first alternate set of said elements and said slotted portions spaced from a second alternate set of said elements, and means for circulating a cooling fluid through said circuit elements.

5. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member having a single major surface and a plurality of circuit elements uniformly disposed along said member, said elements including a first portion spaced from and disposed substantially parallel to said member and a portion extending from said first portion toward said member and having the ends thereof electrically connected to the major surface of said member, said elements cooperating with said member to form a series of network sections, said elements each having a flat portion associated therewith for presenting a substantially planar surface parallel to the major surface of said member.

6. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member having a single major surface and a plurality of circuit elements having the ends thereof electrically connected to the major surface of said member and uniformly disposed along the length thereof, said elements cooperating with said member to form a series of network sections, said elements having a flat portion formed thereon for presenting a substantially planar surface parallel to the major surface of said member.

7. A periodic network for propagating electromagnetic wave energy comprising an electrically-conductive member and a plurality of hollow circuit elements uniformly disposed along said member, said elements including a first portion spaced from and disposed substantially parallel to said member and a portion extending from said first portion toward said member and shorted at the ends thereof by said member, said elements cooperating with said member to form a series of network sections, and means for circulating a cooling fluid through said circuit elements, said elements each including a portion associated therewith for presenting a substantially continuous surface approximately equidistant from a given portion of said member.

8. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member including a single major surface and a plurality of uniformly disposed circuit elements having at least one portion attached to the major surface of said member and a major portion disposed substantially parallel to the major surface of said member, said elements cooperating with said member to form a series of network sections, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy.

9. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member having a single major surface and a plurality of shorted transmission loops attached to said major surface of said member at the ends thereof and uniformly disposed along said member, said loops cooperating with said member to form a series of network sections, and a pair of electrically-conductive straps attached to alternate ones of said elements, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy.

10. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member and a plurality of hollow circuit elements uniformly disposed along said member, said elements including a first portion spaced from and disposed substantially parallel to said member and a portion extending from said first portion toward said member and shorted at the ends thereof by said member, said elements cooperating with said member to form a series of network sections, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, and means for circulating a cooling fluid through said circuit elements.

11. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member and a plurality of hollow circuit elements shorted at the ends thereof by said member and uniformly disposed along said member, said elements cooperating with said member to form a series of network sections, and a pair of electrically-conductive straps each having alternately arranged projecting portions and slotted portions, said projecting portions attached to a first alternate set of said elements and said slotted portions spaced from a second alternate set of said elements, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, and means for circulating a cooling fluid through said circuit elements.

12. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member having a single major surface and a plurality of circuit elements having the ends thereof electrically connected to the major surface of said member, said elements cooperating with said member to form a series of network sections, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, said elements each having a flat portion associated therewith for presenting a substantially planar surface parallel to the major surface of said member.

13. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member having a single major surface

and a plurality of circuit elements having the ends thereof electrically connected to the major surface of said member and uniformly disposed along said member, said elements cooperating with said member to form a series of network sections, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, said elements having a flat portion formed thereon for presenting a substantially planar surface parallel to the major surface of said member.

14. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically-conductive member and a plurality of hollow tubular circuit elements shorted at the ends thereof by said member and uniformly disposed along the longitudinal axis thereof, said elements cooperating with said member to form a series of network sections, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, and means for circulating a cooling fluid through said circuit elements, said elements each including a flat portion associated therewith for presenting a substantially planar surface parallel to the longitudinal axis of said device.

15. A periodic network for propagating electromagnetic wave energy comprising a solid electrically conductive member having a single major surface and a plurality of uniformly disposed circuit elements each having at least a portion thereof attached to the major surface of said member and a major portion thereof disposed substantially parallel to the major surface of said member, said elements cooperating with said member to form a series of network sections.

16. A periodic network for propagating electromagnetic wave energy comprising a solid electrically conductive member having a single major surface and a plurality of uniformly disposed transmission loops each having at least a portion thereof attached to the major surface of said member and a major portion thereof disposed substantially parallel to the major surface of said member, said loops cooperating with said member to form a series of network sections, and a pair of electrically conductive straps attached to alternate ones of said loops.

17. A periodic network for propagating electromagnetic wave energy comprising a solid electrically conductive member having a major surface and a plurality of uniformly disposed hollow transmission loops each having at least a portion thereof attached to said member and a major portion thereof disposed substantially parallel to said member, said loops cooperating with said member to form a series of network sections, a pair of electrically conductive straps attached to alternate ones of said loops, and means for circulating a cooling fluid through said circuit elements.

18. A periodic network propagating electromagnetic wave energy comprising an electrically conductive member having a single major surface and a plurality of uniformly disposed circuit elements having at least one end thereof electrically connected to the major surface of said member, said elements cooperating with said member to form a series of network sections, said elements having a portion associated therewith which presents a substantially continuous surface approximately equidistant from said major surface of said member.

19. A periodic network for propagating electromagnetic wave energy comprising an electrically conductive member having a major surface and a plurality of uniformly disposed hollow circuit elements, said elements including a first portion spaced from and disposed substantially parallel to said member and portions extending from said first portion toward said member and shorted at the ends thereof by said member, said elements cooperating with said member to form a series of network sections, said elements having a portion associated therewith which presents a substantially continuous surface approximately equidistant from said major surface of said member, and means for circulating a coolant through said circuit elements.

20. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, an electrically conductive electrode arranged coextensive with said periodic network, said periodic network including an electrically conductive member having a single major surface and a plurality of uniformly disposed circuit elements having the ends thereof electrically connected to the major surface of said member, said elements cooperating with said member to form a series of network sections, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, said elements each having a portion thereof which presents a substantially continuous surface approximately equally spaced from said electrode.

21. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, an electrically conductive electrode arranged coextensive with said periodic network, said periodic network including an electrically conductive member having a single major surface and a plurality of circuit elements having at least one portion attached to said member and a major portion arranged substantially parallel to said electrode, said elements cooperating with said member to form a series of network sections, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, said elements each including a portion which presents a substantially continuous surface approximately parallel to said electrode.

22. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, an electrically conductive principal electrode arranged coextensive with said periodic network, said periodic network including an electrically conductive member having a major surface and a plurality of hollow circuit elements having at least one portion attached to said member and a major portion arranged substantially parallel to said principal electrode, said elements cooperating with said member to form a series of network sections, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, and means for circulating a cooling fluid through said circuit elements, said elements each including a portion which presents a substantially continuous surface approximately parallel to said principal electrode.

23. A periodic network for propagating electromagnetic wave energy comprising an electrically conductive uniplanar member and a plurality of circuit elements spaced along said member, said elements including a first portion spaced from and disposed substantially parallel to the major surface of said member and at least one portion extending from said first portion toward the major surface of said member, said elements cooperating with said member to form a series of network sections, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element.

24. A periodic network for propagating electromagnetic wave energy comprising an electrically conductive member and a plurality of hollow circuit elements spaced along said member, said elements cooperating with said member to form a series of network sections, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries

of each element, and means for circulating a cooling fluid through said circuit elements.

25. A periodic network for propagating electromagnetic wave energy comprising an electrically conductive member having a single major surface and a plurality of circuit elements spaced along said member, said elements including a first portion spaced from and disposed substantially parallel to the major surface of said member and at least one portion extending from said first portion toward the major surface of said member, said elements cooperating with said member to form a series of network sections, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element, said elements each including a portion which presents a substantially continuous surface disposed approximately parallel to said major surface of said member.

26. A periodic network for propagating electromagnetic wave energy comprising an electrically conductive member and a plurality of hollow circuit elements spaced along said member, said elements cooperating with said member to form a series of network sections, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element, and means for circulating a cooling fluid through said circuit elements, said elements each including a portion which presents a substantially continuous surface disposed approximately parallel to the major surface of said member.

27. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically conductive member having a single major surface and a plurality of uniformly disposed circuit elements cooperating with said member to form a series of network sections, said elements including a first portion spaced from and disposed substantially parallel to the major surface of said member and at least one portion extending from said first portion toward the major surface of said member, a pair of electrically conductive straps attached to alternate ones of said elements, a principal electrode arranged coextensive with and spaced from said periodic network, a source of electrons, and means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element.

28. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically conductive member and a plurality of uniformly disposed hollow circuit elements cooperating with said member to form a series of network sections, a pair of electrically conductive straps attached to alternate ones of said elements, a principal electrode arranged coextensive with and spaced from said periodic network, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element, and means for circulating a cooling fluid through said circuit elements.

29. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically conductive member having a single major surface and a plurality of uniformly disposed circuit elements cooperating with said member to form a series of network sections, said elements including a first portion spaced from and disposed substantially parallel to the major surface of said member and at least one portion extending from said first portion toward the major surface of said member, a pair of electrically conductive straps attached to alternate ones of said elements, a principal electrode arranged coextensive with and spaced from said periodic network, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element, said elements each including a portion which presents a substantially continuous surface disposed approximately parallel to said principal electrode.

30. A traveling wave electron discharge device comprising an evacuated envelope, a periodic network mounted within said envelope for propagating electromagnetic wave energy, said periodic network including an electrically conductive member and a plurality of uniformly disposed hollow circuit elements cooperating with said member to form a series of network sections, a pair of electrically conductive straps attached to alternate ones of said elements, a principal electrode arranged coextensive with and spaced from said periodic network, a source of electrons, means for directing said electrons along a path adjacent said periodic network and in energy interacting relationship with said wave energy, the area of opposing adjacent elements being substantially less than the area contained within the external boundaries of each element, said elements each including a portion which presents a substantially continuous surface disposed approximately parallel to said principal electrode, and means for circulating a cooling fluid through said circuit elements.

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UNITED STATES PATENT OFFICE

Certificate of Correction

June 9, 1959

Patent No. 2,890,384

Edward C. Dench

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 45, for that portion of the formula reading

$\omega^o L_s$ read $\omega_o L_s$

column 5, line 61, for "This" read —The—; column 7, line 3, after "thereof", and before the comma, insert —and uniformly disposed along said member—.

Signed and sealed this 9th day of February 1960.

[SEAL]

Attest:
KARL H. AXLINE,
Attesting Officer.

ROBERT C. WATSON,
Commissioner of Patents.