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[45] **Sept. 18, 1973**

[54] **SINGLE CONDUCTOR MULTI-COIL MULTI-BEAM MICROWAVE DEVICE**

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[73] Assignee: **The United States of America as represented by the Secretary of the Army**, Washington, D.C.

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[21] Appl. No.: **279,592**

[52] **U.S. Cl.** **315/3.6**, 315/35

[51] **Int. Cl.** **H01j 25/34**

[58] **Field of Search** ..... 315/3.6, 3.5 X, 3.5

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[57] **ABSTRACT**

A traveling wave tube is provided with a low-wave, electron beam interaction means in the form of a single wire conductor coiled into at least two parallel series of aligned turns; in each series, the turns are of identical size and configuration. In one form, all the turns have rectilinear stretches of equal length that are in a common plane; an electron beam source, a collector, a sole electrode and electric and magnetic fields direct a sheet beam alongside the rectilinear stretches outside the turns. In another form, the turns of the single wire conductor are almost entirely circular and in figure-eight configuration viewed endwise; electron beams are directed through either one or both series of turns. In still other forms of the invention, the slow-wave means viewed endwise has more than two turns and the axes are coplanar or in a circular distribution.

1 Claim, 4 Drawing Figures

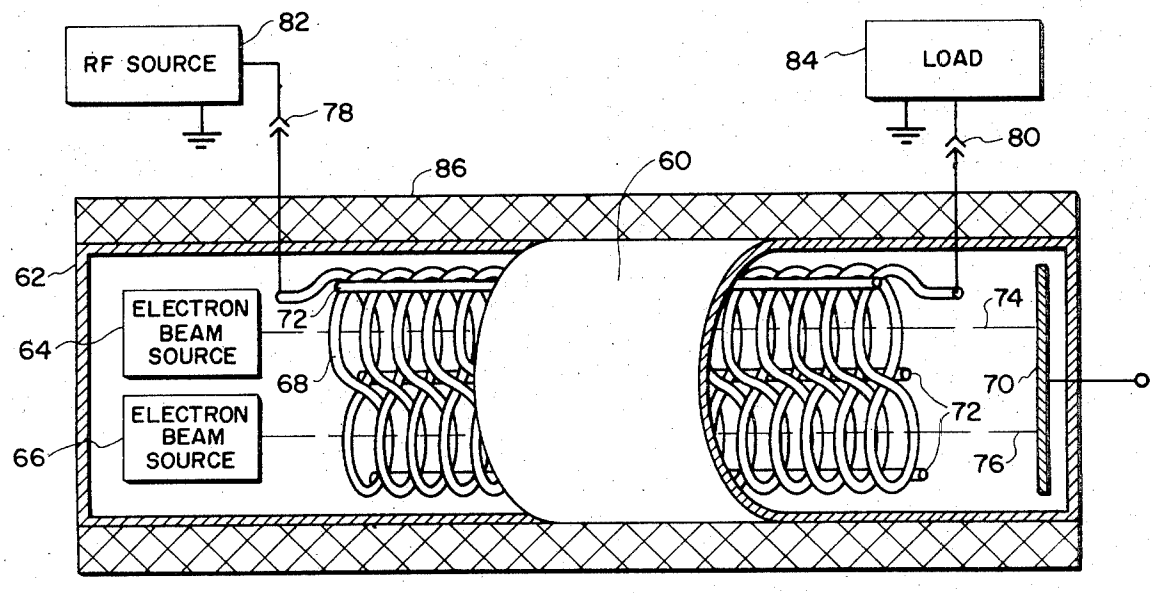


FIG. 1 (Prior Art)

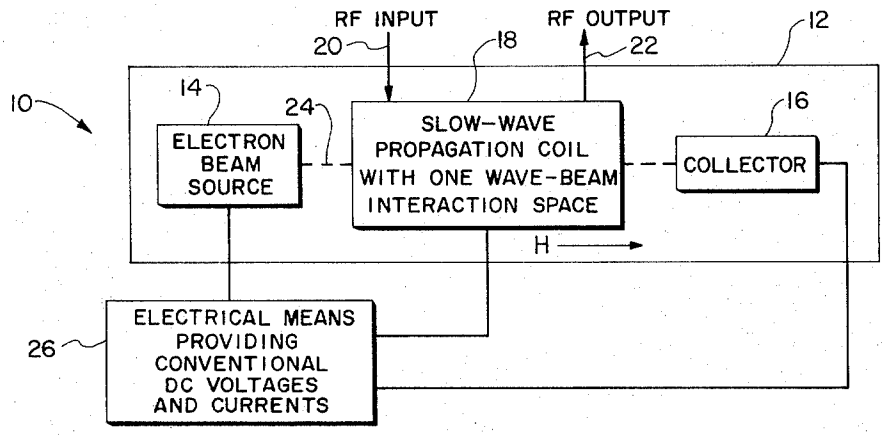


FIG. 2

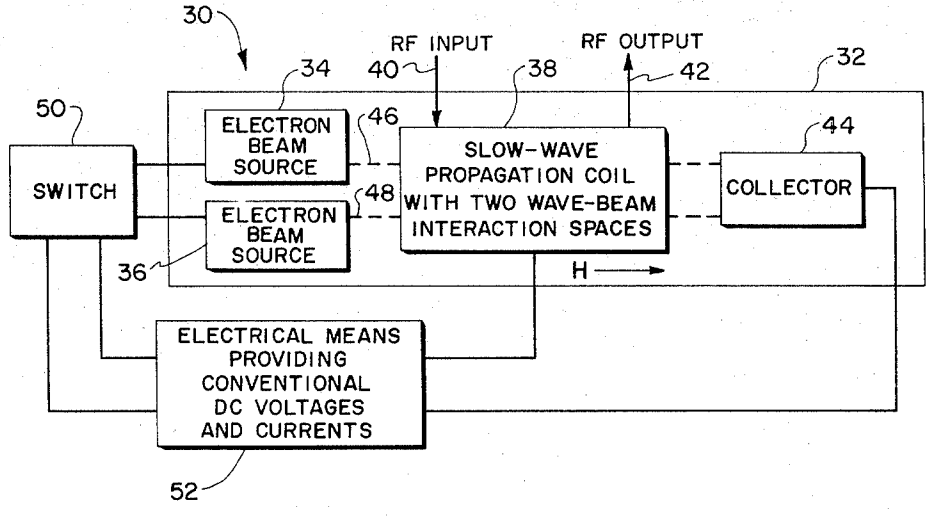
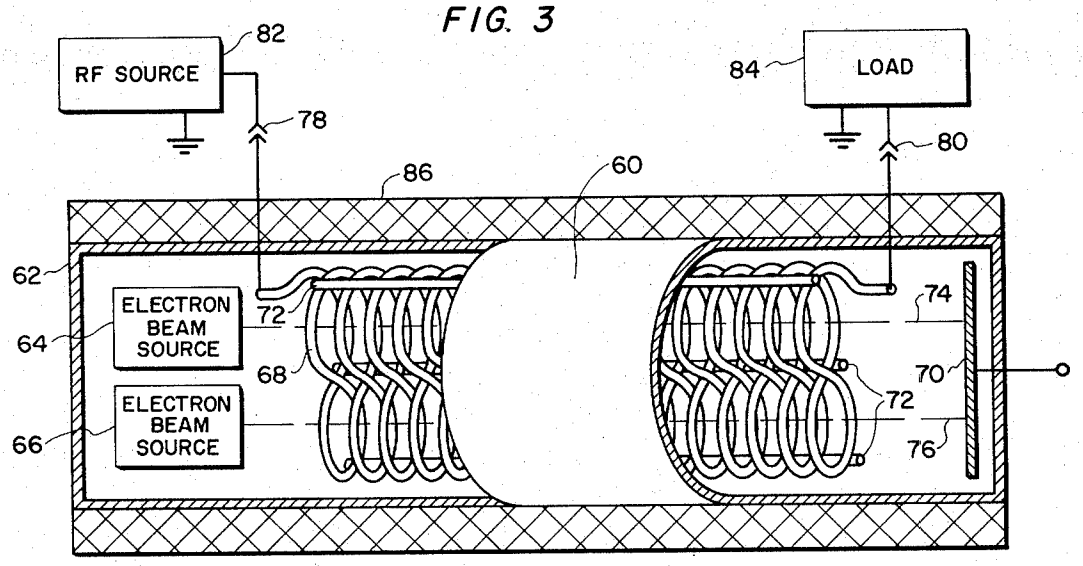


FIG. 3


RF SOURCE
82
78
84
LOAD
80
86
60
62
64
66
ELECTRON BEAM SOURCE
ELECTRON BEAM SOURCE
72
68
74
70
72
76

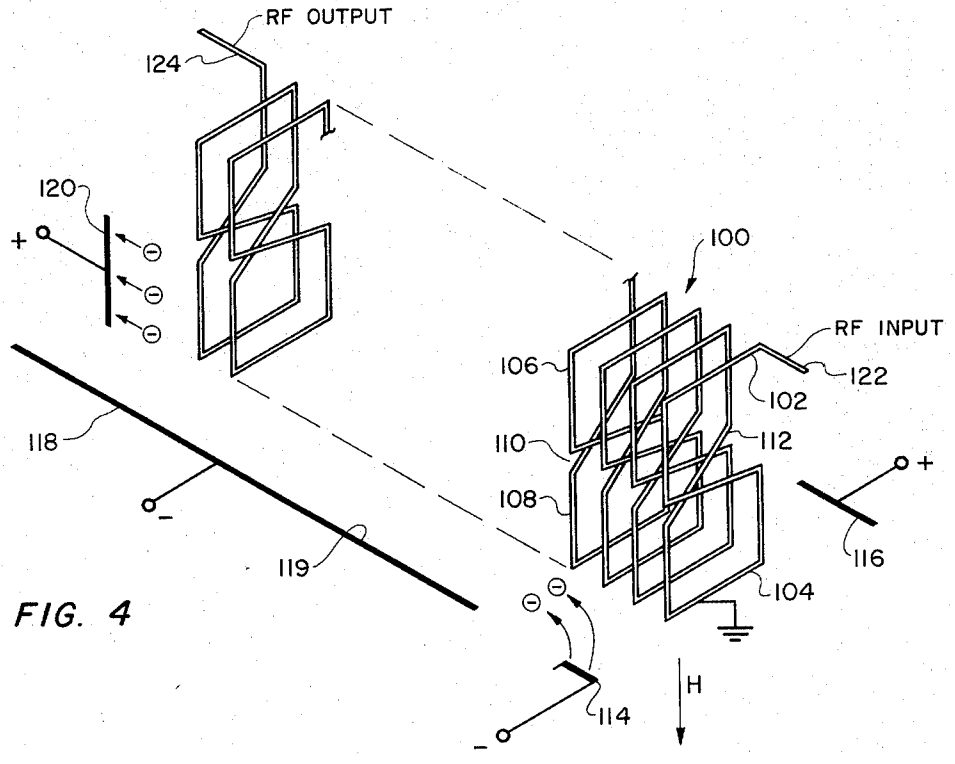

RF OUTPUT
124
120
+
100
RF INPUT
106
122
102
118
110
112
108
116
+
119
104
H
114

FIG. 4

SINGLE CONDUCTOR MULTI-COIL MULTI-BEAM MICROWAVE DEVICE

BACKGROUND OF THE INVENTION

The most common form of slow wave means for a traveling wave tube is the wire conductor coil of identical aligned turns with a constant pitch, though coils may be designed with a pitch that changes along its length to compensate for slowing of the electrons in the beam as they give up energy. The geometry of the coil as seen endwise is related to whether the traveling wave tube is designed for O-type linear operation or for M-type crossed field operation. For O-type operation, the geometry of the slow-wave means, viewed endwise is a circle; for M-type operation, the geometry of the slow-wave means viewed endwise is a loop that includes a rectilinear stretch. Regardless of the type of operation, the coil has been formed as a single series of aligned loops. In O-type operation, the electron beam is projected through the wire helix and the focusing field resists spreading of the beam eletrons laterally beyond the interaction space. In crossed field operation, a high current beam is projected and then redirected by a perpendicular magnetic field to a course that runs between a sole electrode and the coplanar rectilinear stretches of the coil for wave-beam interaction proximate to the rectilinear stretches of the coil. If the traveling wave tube is designed for as much power amplification as is practical, the beam voltage and beam current are made as high as is feasible, the focusing current is high, the wire size of the coil must be large enough to carry the amplified RF and the collector must be designed for very high heat dissipation and the electron beam source must be designed to emit the high density beam.

Phase velocity of a propagated RF wave is related to the helix design i.e. the helix diameter and pitch. In the interaction space, the electron beam must have a velocity somewhat greater than the phase velocity to transfer energy to the RF wave. The electron beam accelerating voltage level is set to impart the correct velocity to the beam electrons for interaction and energy transfer to the RF wave. Beam current may be adjusted but the DC focusing field needs to be adjusted too for the resultant change in beam current density. If the tube needs to be operated at much higher power level during one time interval compared to that during another time interval, the tube needs to be designed to operate with the higher beam current though it may be operated at the lower beam current most of the time. Also, a traveling wave tube amplifier may have to operate in continuous-wave and pulse modes sequentially. Each time mode is switched, the power level at which the tube operates needs to be switched; in order that there be no loss in data which would occur during switching, the shift in power level needs to be essentially instantaneous. However, the DC focusing field and the beam voltage cannot be switched between widely different levels of operation at a rate fast enough for widely different levels of dual power operation. One problem is that the beam current does not continue in close proximity to the helical structure during and immediately following switching; there is degradation in gain and efficiency. It is well known that a 2:1 change in power level is about the maximum that can be tolerated without adversely affecting efficiency to an unacceptable degree.

If two traveling wave tubes are connected in parallel to meet the above requirements, not only is the cost high but sophisticated phasing techniques are needed particularly for operation over a wide frequency band. If a traveling wave tube is made with two slow-wave helices connected in parallel and with two electron beam sources that can be energized singly or in combination, sophisticated phasing techniques are still required; additionally the input RF energy divides between the two parallel-mounted helices, a 3db drop prior to amplification.

SUMMARY OF THE INVENTION

Instead of providing a traveling wave tube with a slow-wave coil of one continuous wire conductor having identical turns that are coaxial, this invention provides the traveling wave tube with a slow-wave multi-coil of one continuous wire conductor that forms one complete element of the multi-coil by looping alternately clockwise and counterclockwise crossing over itself at least once to form two or more turns side-by-side, e.g. a figure-eight or a chain of three or more turns side-by-side; the looping repeats to form a series of identical such elements in line and with a predetermined pitch. The geometry of the novel multi-coil viewed endwise may be a plurality of almost circular loops; the circles are incomplete to a minor extent at the crossovers. A multi-coil with circular loops may be operated with one beam projected through one of the sub-coils or with a plurality of beams up to the number of sub-coils projected through the respective sub-coils. For crossed field operation, the loops of the novel coil include rectilinear stretches that are of equal length and coplanar. The multi-coil with the rectilinear stretches is used with a single beam source.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a block diagram of a conventional prior-art traveling wave tube and power supply;

FIG. 2 is a block diagram of a traveling wave tube and power supply, showing the primary feature of this invention;

FIG. 3 shows partly in perspective and partly in section, a traveling wave tube corresponding to FIG. 2 but with structural detail of the invention; and

FIG. 4 is a perspective showing of another embodiment of the invention in a crossed field device wherein the basic elements shown are without detail or electrical connections.

In FIG. 1 there is shown a conventional traveling wave tube **10** having an elongated evacuated envelope **12** that supports therein an electron beam source **14** near one end of the envelope **12**, a collector **16** near the other end of the envelope **12**, and a slow-wave propagation coil **18** e.g. a helix, between the beam source **14** and the collector **16**. The slow-wave coil **18** has an input **20** for RF and an output **22** for coupling amplified RF to a load. The tube **10** has one wave-beam interaction space. Input RF traversing the slow wave coil **18** is accompanied by an electromagnetic wave field having a phase velocity in the beam direction which is a very small fraction of the free space velocity of the input RF. Electron beam **24** projected by beam source **14** has an average velocity somewhat greater than the phase velocity of the propagated electromagnetic wave whereby energy is transferred from the pro-

jected stream of electrons to the electromagnetic wave. A substantially uniform longitudinal magnetic field H is provided in the envelope between the beam source and the collector by a coil, periodic permanent magnet, etc. All conventional DC voltages and DC currents required for operating the tube are provided by electrical means **26.**

In FIG. **2** there is shown a traveling wave tube **30** in an envelope **32** that differs from the prior art exemplified by FIG. **1** in that it includes two electron beam sources **34, 36** and a slow-wave propagation coil **38** with two wave-beam interaction spaces but having one RF path between input **40** and output **42** that produces the same electromagnetic wave in both ineraction spaces. One collector **44** is provided for the beams **46, 48** emitted by the two electron beam sources. If necessary, the two beams may be of different powers. A switch **50** is provided to turn on or off, separately or together, the electron beams **46** and **48.** Electrical means **52** for providing conventional DC voltages and currents is coupled to collector **44** and slow-wave coil **38** as shown in FIG. **1** and in addition is connected to electron beam sources **34** and **36** through switch **50.** In its simplest form, switch **50** is a manual switch for connecting electrical means **52** either to one or to both electron beam sources **34, 36.** While only one connection is shown extending between each electron beam source and electrical means **52** via switch **50,** each of the connections shown represent the several conductors that connect to the several elements of each electron beam source. The switch **52** may be connected so as to be operable to connect or disconnect the heater element of each electron beam source or to connect or disconnect cutoff bias to each electron beam source or to otherwise control the beams, between any current levels. Either beam **46, 48** or both beams simultaneously, interact with the wave propagated by the slow-wave means **38** to amplify the RF. One advantage realized by using this arrangement is that the RF can be raised by any one of a plurality of multipower levels depending on the magnitude of the beam currents and the number of beams used or depending upon operational requirements. There are obvious advantages in this flexibility. If a traveling wave tube is fabricated to use two beams instead of one beam of the same power as the power of the two beams, beam voltage and beam current is lower, backward wave oscillations are minimized, and design factors are generally simplified. If the tube is fabricated so that each of the two beams is of equal power to what the power of one beam would have been, high power output can be obtained by operating both beams at the same time. The latter design also lends itself to push-pull operation, e.g. by using an Eccles-Jordan type circuit for switch **50** to operate the two beams alternately. Push-pull operation avoids overheating any one of the elements.

In FIG. **3** there is shown a traveling wave tube **60** having an envelope **62** that supports therein, near one end, a pair of electron beam sources **64, 66,** a figure-eight multi-coil slow-wave circuit **68** and a collector **70** near the other end of the envelope. Dielectric ceramic rods **72** support the multi-coil in place in the conventional manner and also serve to dissipate heat during high power operation. The ends of the rods **72** are nested in or secured to support elements, not shown, that would be fixed in place in the envelope; the rods may be provided with an aquadag layer for attenuating backward wave energy. If the coil is viewed endwise, the wire of the multi-coil describes a figure-eight with identical loops almost all the way around except in the vicinity of the crossover. While it is not essential, it is preferable for the multi-coil loops to be essentially planar and for the crossovers to provide the pitch. The dominant mode supported by the figure-eight structure is characterized by large longitudinal electric fields similar to the characteristics of a TM mode. The multi-coil **68** is aligned with the two electron beam sources so that focused beams projected by the respective beam sources and represented by the broken lines **74, 76** are properly aligned with the interaction spaces of the multi-coil. The ends of the multi-coil are connected to conventional RF coupling devices **78, 80.** A source **82** of RF to be amplified is coupled to the beam source end of the coil and a load **84** is coupled to the other end of the coil. A focusing structure **86** surrounds the envelope **62.** The traveling wave tube shown in FIG. **3** requires confined focusing because the two electron beams are not axial; the coil type focusing structure in FIG. **3** needs to extend over the beam source region, even though it means greater weight, in order that the projected beams shall be in an essentially longitudinal magnetic field. Periodic permanent magnet (PPM) focusing can be employed if the entrance conditions for the electron beams are adjusted for proper focusing. Also electrostatic focusing techniques may be substituted for the focusing structure if beam current density is low.

The multi-coil **68** may be formed with three, four or more sub-coils rather than two as in the figure-eight to have the approximate appearance endwise of three-leaf or four-leaf clovers, etc. Also the sub-coils can be fabricated so that their axes are coplanar, a predetermined distance apart, or their axes can be arranged in an arcuate or circular distribution, a predetermined distance apart. The beam focusing problem is more complicated for an increased number of beams and is more complicated for smaller distances between beams.

It is within the scope of this invention for any of the described multi-coils to be formed without crossovers between adjacent turns.

In FIG. **4** there is shown a figure-eight multi-coil **100** of a single conductor wire but having different geometry than the figure-eight multi-coil shown in FIG. **3.** Each of the series of aligned loops **102** and **104** include rectilinear stretches **106** and **108** respectively that are in a common plane. Preferably the rectilinear stretches **106, 108** of consecutive pairs of loops **102** and **104** are in line and there is a minimal gap **110** between aligned stretches. The coil pitch is provided by the crossover stretches **112.** The novel coil shown in FIG. **4** is used in a crossed field device which includes the well known arrangement of electron emitter **114** and anode **116** oriented normal to and near one end of the slow-wave coil **100,** a sole electrode **118** having a planar surface **119** parallel to the plane of the rectilinear stretches **106** and **108** and coextensive therewith, and a collector **120** adjacent the other ends of the coil **100** and sole electrode **118.** A magnetic field providing means, not shown, directs a magnetic field H normal to the direction between electron emitter **114** and anode **116** to bend the paths of electrons projected by emitter **114** into the space between the sole electrode **118** and the coil **100.** The DC electric field is normal to the H field and in the sense to project the electrons toward the col-

lector. The emitted electrons move in a sheet beam parallel to but outside the figure-eight coil. With the coil **100** wound in the manner described, the electron beam interacts with an essentially symmetrical RF structure. RF is coupled into the end **122** of the coil and an RF load is coupled to the other end **124** of the coil. All DC operating parameters are omitted since they do not constitute part of the invention; one skilled in this art can readily select a set of operating voltages and currents for a particular design of the elements described.

The geometry of the coil shown in FIG. **4** requires the coplanar rectilinear stretches but the rest of each loop need not be rectilinear with corners as shown on the drawing but may be curvilinear. Ease of fabrication governs the choice of geometry; however, all the loops must have the same geometry.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

What is claimed is:

1. In a traveling wave tube amplifier a slow-wave multi-coil of a single conductor that loops alternately clockwise and counterclockwise and from the longitudinal aspect intersects and crosses over itself between loops to form a plurality of series of aligned essentially circular loops wherein the number of loops in each of the plurality of series of loops is the same, and providing an equal plurality of interaction spaces, whereby RF conducted through the wire is accompanied by an electromagnetic wave that traverses the plurality of interaction spaces in unison,

an evacuated envelope confining said coil therein,

means supporting said coil in said envelope and being operable to attenuate backward wave energy,

means for coupling one end of said wire to an RF source,

means for coupling the other end of said wire to an RF load,

electron beam source means being operable to project an electron beam through each of the plurality of series of aligned loops respectively,

switch means controlling the electron beam source means to project any one or combination of beams,

collector means for said beams, and

field means for flowing projected electrons along said coil for interaction with an electromagnetic wave traversing said coil.

* * * * *