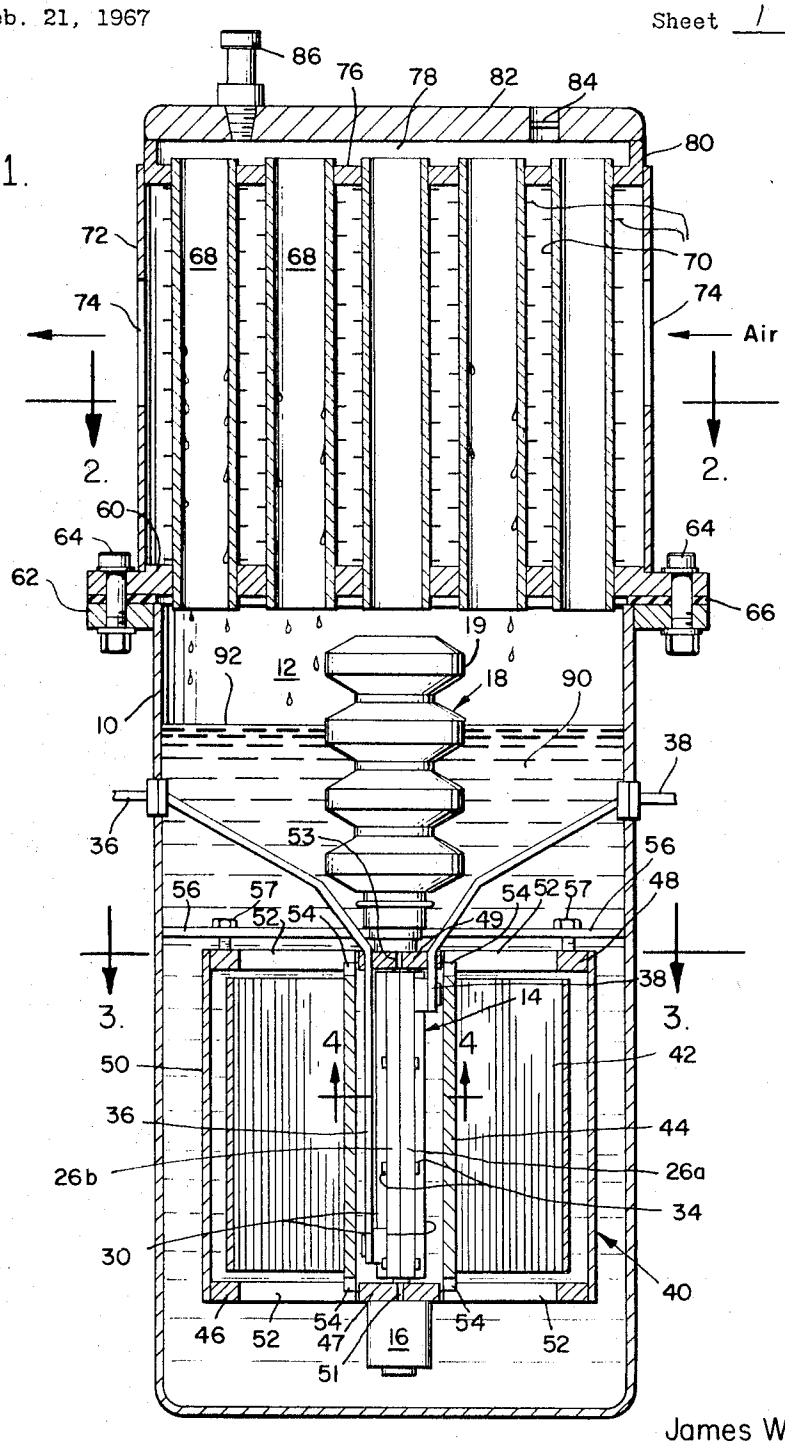
May 13, 1969 J. W. HANSEN ET AL 3,444,419

EVAPORATIVELY COOLED TRAVELING-WAVE TUBE

Filed Feb. 21, 1967 Sheet 1 of 2

Fig. 1.

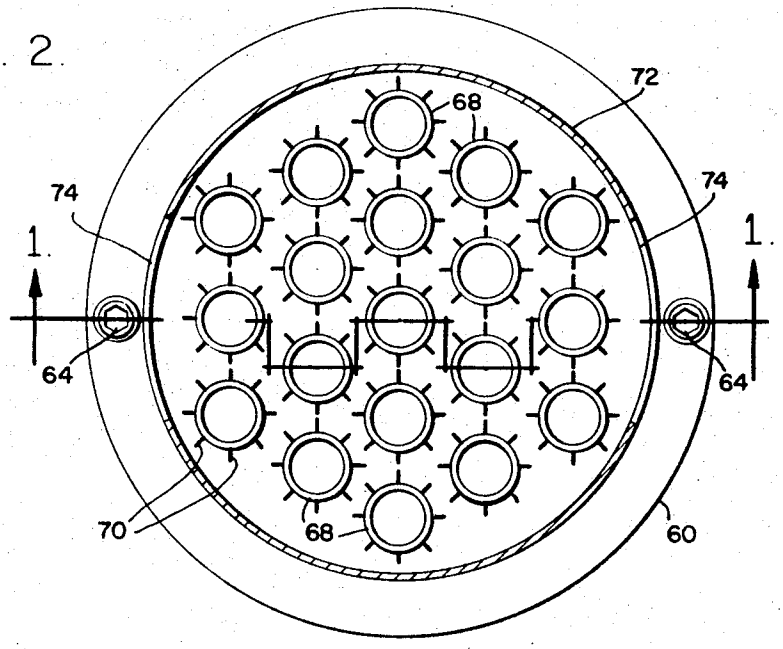


James W. Hansen,
Leonard T. King,
INVENTORS.
BY.
Paul M. Cobbe
ATTORNEY.

EVAPORATIVELY COOLED TRAVELING-WAVE TUBE

Filed Feb. 21, 1967

Fig. 2.



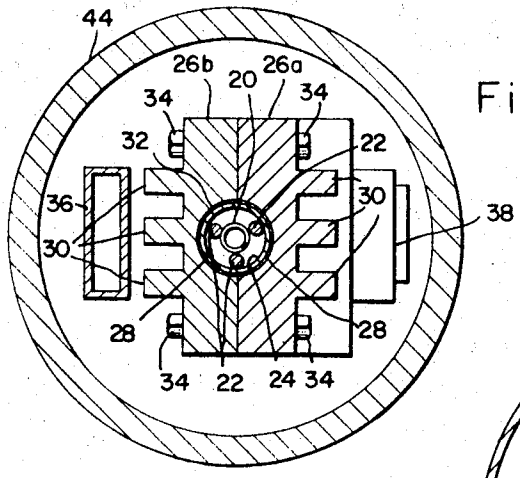


Fig. 4.

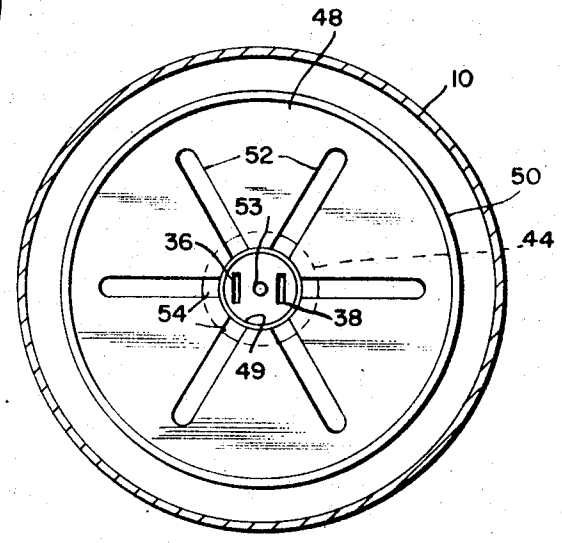


Fig. 3.

United States Patent Office 3,444,419 Patented May 13, 1969

3,444,419

EVAPORATIVELY COOLED TRAVELING-WAVE TUBE

James W. Hansen, Los Angeles, and Leonard T. King, Hermosa Beach, Calif., assignors to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Filed Feb. 21, 1967, Ser. No. 617,684
Int. Cl. H01j 25/34
U.S. Cl. 315—3.5 10 Claims

ABSTRACT OF THE DISCLOSURE

The disclosed assembly includes a hermetically sealed chamber in which a traveling-wave tube is vertically mounted, with a fluid coolant normally existing in the liquid state disposed in the chamber in contact with the electron gun, collector, focusing arrangement, and extended outer surface of an aligning and heat-conveying encasing assembly for the slow-wave structure of the tube. Boiling of the liquid coolant due to heat generated by the tube, causing coolant movement along tube surfaces, and subsequent condensation of the evaporated coolant in a plurality of air-cooled condenser tubes extending upwardly from the chamber enables heat removal from the tube.

BACKGROUND OF THE INVENTION

This invention relates to electron beam tubes, and more particularly relates to a traveling-wave tube assembly including an evaporative cooling arrangement.

In traveling-wave tubes a stream of electrons is caused to interact with a propagating electromagnetic wave in a manner which amplifies the electromagnetic energy. In order to achieve such interaction the electromagnetic wave is propagated along a slow-wave structure which is disposed along and about the electron stream path. The slow-wave structure provides a path of propagation for the electromagentic wave which is considerably longer than the axial length of the structure, and hence, the traveling-wave may be made to effectively propagate at nearly the velocity of the electron stream. Interactions between electrons in the stream and the traveling-wave cause velocity modulation and bunching of the stream electrons, the net result being a transfer of energy from the electron stream to the wave traveling along the slow-wave structure.

In the design of traveling-wave tubes numerous considerations are involved such as power level, center frequency, bandwidth, operating efficiency, and tube life, for example. For a particular application, one or more of these considerations are emphasized, although optimization of certain design requirements is usually incompatible with optimization of certain other considerations. For example, when designing a tube for wideband operation, it is difficult to maintain a substantially constant gain and high efficiency over the entire bandwidth; or, when designing a tube for high power operation, it is difficult to maintain long tube life and high reliability.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a traveling-wave tube which is capable of operating with a substantially constant gain throughout a relatively wide bandwidth at frequencies near the upper end of the microwave spectrum, and at the same time is able to operate at substantially higher power levels than prior art tubes of comparable frequencies and bandwidths.

It is a further object of the invention to provide a traveling-wave tube which, in addition to possessing the foregoing advantages, also has a long life and high reliability.

A traveling-wave tube assembly in accordance with the invention includes a hermetically sealed housing defining a chamber and a plurality of spaced conduits communicating with and extending upwardly from the chamber, with a plurality of cooling fins extending outwardly from the outer surface of each conduit.

A traveling-wave tube subassembly including an electron gun which launches a stream of electrons along an axial path toward a collector is disposed in the chamber in an orientation such that the electron stream travels vertically upwardly. A slow-wave structure is coaxially disposed about the electron stream path between the electron gun and the collector. An encasing arrangement having an extended outer surface is disposed about the slow-wave structure in order to maintain the slow-wave structure in precise coaxial alignment with the electron stream path and in order to convey heat outwardly from the slow-wave structure. A focusing arrangement substantially coextensive with the slow-wave structure is disposed about the slow-wave structure in order to focus the electron stream traveling axially within the slow-wave srtucture, the inner surface of the focusing arrangement being spaced from the extended outer surface of the slow-wave structure encasing arrangement.

A cooling fluid is disposed in at least the lower portion of the chamber in contact with the electron gun, the collector, the slow-wave structure encasing arrangement and the focusing arrangement. The cooling fluid and the pressure within the hermetically sealed housing are selected such that the fluid exists in the liquid state under quiescent conditions but is capable of being vaporized by heat generated by the traveling-wave tube subassembly during operation thereof.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawing:

FIG. 1 is a longitudinal sectional view of a traveling-wave tube assembly in accordance with the present invention;

FIG. 2 is a cross-sectional view taken along line 2—2 of FIG. 1;

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 1; and

FIG. 4 is an enlarged cross-sectional view taken along line 4—4 of FIG. 1 and illustrating a portion of the assembly including the slow-type structure and its encasing arrangement.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIG. 1 with greater particularity, a traveling-wave tube assembly according to the invention may be seen to include a housing **10**, of aluminum for example, which defines a cylindrical chamber **12** in which a traveling-wave tube subassembly **14** is located. The traveling-wave tube subassembly **14** includes an electron gun **16**, which may be of a conventional construction well-known in the art, which functions to launch a stream of electrons along an axial path through the subassembly toward a collector **18**. The collector **18** may also be of conventional construction and may include a plurality of outwardly extending flanges **19** to provide an extended coolant contact surface area. The subassembly **14** is oriented such that the electron gun **16** is located in the lower portion of the chamber **12** and the collector **18** in the upper portion. Thus, the electrons travel vertically upwardly from the gun **16** to the collector **18**.

As may be seen from FIG. 4, the subassembly **14** also includes a slow-wave structure **20**, such as an electrically conductive helix of copper-plated molybdenum for example, which is coaxially disposed about the electron stream between the electron gun **16** and the collector **18**.

The slow-wave structure **20** is supported by a plurality of longitudinally extending rods **22**, of a dielectric material such as berryllia, equally circumferentially disposed about the slow-wave structure **20**. The slow-wave structure **20** and its support rods **22** are mounted within an encasing barrell **24**, of copper-plated stainless steel for example. The rods **22** and the slow-wave structure **20** may be held in a rigid clamped relationship within the barrel **24** by employing a barrel triangulating and slow-wave structure assembling technique such as that disclosed in U.S. Patent No. 2,943,228 to Bernard Kleinman.

In order to ensure precise coaxial alignment of the slow-wave structure **20** with the electron stream path and also to be better facilitate heat removal from the slow-wave structure, additional encasing means are provided externally of the barrel **24**. This additional encasing means includes a pair of like elongated blocks **26***a* and **26***b* of a material having both high mechanical strength and a high thermal conductivity. Examples of suitable block materials are stainless steel, beryllium-copper, and brass, although brass is preferred on account of its ease of fabrication. Each block **26** defines a longitudinally extending semi-cylindrical groove **28** having a radius slightly greater than the outer radius of the barrel **24**. When the blocks **26***a* and **26***b* are in the desired assembled relationship as shown, the semi-cylindrical grooves **28** face one another in aligned relationship so as to provide a cylindrical space for receiving the barrel **24**. Each block **26** also definies a plurality of longitudinally extending ridges **30** which project outwardly from the block surfaces opposite to the surfaces defining the grooves **28** so as to provide an extended coolant contact surface area.

The blocks **26** are soldered to the barrel **24** by means of a layer **32** of a suitable solder disposed between the outer circumferential surface of the barrel **24** and the grooves **28**. Although other solder materials may be used, indium is preferred on account of its relatively low melting point and its desirable thermal expansion properties. In addition to being soldered to the barrel **24**, the blocks **26***a* and **26***b* are mechanically fastened together in a rigid arrangement, for example by means of screws **34**.

Mounted adjacent the outer surface of block **26***b* is a waveguide **36** which extends parallel to the block **26***b* throughout substantially its entire length. Appropriate apertures and microwave couplings well-known in the art (but not shown) are provided through the block **26***b* and the barrel **24** at the end of the waveguide **36** adjacent the electron gun **16** to apply input microwave energy from the waveguide **36** to the electron gun end of the slow-wave structure **20**. Similar apertures and microwave couplings are provided through barrel **24** and block **26***a* adjacent the collector end of the slow-wave structure **20** in order to couple microwave energy from the collector end of the slow-wave structure **20** to a waveguide **38** mounted adjacent the outer surface of block **26***a* and extending parallel to the block **26***a* for only a very small portion of its length. The waveguides **36** and **38** both extend upwardly and outwardly from the collector end of the blocks **26** and through the housing **10** for connection to external circuitry (not shown).

In order to focus the electrons traveling from the gun **16** to the collector **18** into a well-collimated beam, an elongated annular focusing arrangement **40** is coaxially disposed about the slow-wave structure **20** for generating a magnetic field along the slow-wave structure axis. The focusing arrangement **40** may include a solenoid **42** in which an electrically conductive foil or tape is wound about a tubular bobbin **44** which is coaxially disposed about the slow-wave structure encasing arrangement so as to leave substantial space between the outer surfaces of blocks **26** and the inner surface of the bobbin **44**. The wound tape **42** extends throughout most of the length of the bobbin **44**, although short circumferential portions of the bobbin **44** remain exposed at each end. Successive turns of the electrically conductive tape are insulated from one another by an electrically insulating tape which is also wound about the bobbin **44** between successive windings of the conductive tape.

A pair of disk-like annular pole pieces **46** and **48** of ferromagnetic material are disposed at the respective ends of the bobbin **44** and are secured to the bobbin **44**, by brazing for example. The ferromagnetic disks **46** and **48** extend radially outwardly from the bobbin **44** beyond the foil solenoid **42**. A ferromagnetic tubular member **50** is mounted on and is secured to the outer circumferential surfaces of the pole pieces **46** and **48** to provide an outer return path for the magnetic field generated by the solenoid **42**.

In order to bring the magnetic field inwardly to the vicinity of the electron beam, a second pair of disk-like annular ferromagnetic pole pieces **47** and **49** are disposed radially inwardly of the respective pole pieces **46** and **48**. The inner pole pieces **47** and **49** are secured, for example by brazing, to opposite ends of the barrel **24** which extend slightly beyond the ends of the blocks **26**. The pole pieces **47** and **39** define cylindrical apertures **51** and **53**, respectively, in their central regions for passage of the electron beam, the pole piece **49** also being provided with rectangular apertures to accommodate the waveguides **36** and **38**.

As may be seen from FIGS. 1 and 3, each outer pole piece **46** and **48** defines a plurality of radially extending slots **52** which register with a like plurality of notches **54** provided in the ends of the bobbin **44**. The slots **52** permit cooling fluid to enter and leave the space between the solenoid **42** and the surrounding ferromagnetic members **46**, **48** and **50**; while the slots **52** in conjunction with the notches **54** permit cooling fluid to enter and leave the space between the blocks **26** and the bobbin **44**.

The traveling-wave tube subassembly **14** is supported within the chamber **12** by means of a plurality of bars **56** which are attached to and which extend radially inwardly from the housing **10** in locations not overlapping the slots **52**. The inner ends of the bars **56** are secured to the lower portion of the collector **18** which in turn supports the slow-wave structure **20** and its encasing arrangement. The focusing arrangement **40** (except for the inner pole pieces **47** and **49** which are supported by the slow-wave structure assembly) is supported by means of bolts **57** extending downwardly from the bars **56**, the electron gun **16** being supported by the lower inner pole piece **47**.

The upper wall for the chamber **12** is defined by a relatively thick plate **60**, of aluminum for example, which is secured to an outwardly extending flange **62** of the housing **10** by means of bolts **64** or the like. A sealing ring **66**, of rubber for example, is disposed between the flange **62** and the plate **60** in order to provide a hermetic seal for the chamber **12**. A plurality of condenser tubes **68** having their longitudinal axes disposed parallel to the longitudinal axis of the cylinder housing **10** and having their lower ends communicating with the chamber **12** extend upwardly from the chamber **12** through the plate **60**. A plurality of cooling fins, which may take the form of bristle-like elements **70**, extend radially outwardly from the outer circumferential surface of each of the tubes **68** in order to provide an extended surface for the transfer of heat away from the tubes **68**. Both the condenser tubes **68** and the cooling fins **70** may be of aluminum, for example.

A tubular housing **72**, of aluminum for example, extends upwardly from the plate **60** and surrounds the condenser tubes **68**. Enlarged diametrically opposite apertures **74** are provided in the housing **72** so that a coolant, such as air, may be directed through the space between the outer surfaces of the tubes **68**, as shown by the arrows in FIG. 1, in order to facilitate heat removal from the assembly. The coolant may be furnished from a fan or pump (not

shown) located externally of the assembly adjacent one of the apertures **74**, for example.

A plate **76**, of aluminum for example, is secured to the upper end of the housing **72** in order to provide a lower wall for an upper chamber **78**. The upper ends of the tubes **68** extend through the plate **76** and communicate with the chamber **78** so as to interconnect the chambers **12** and **78**. An annular flange **80** extending upwardly from the outer edge of the plate **76** provides a lateral wall for the cham- **78**, while a relatively thick plate **82**, also of aluminum for example, is secured to the upper edge of the flange **80** in order to provide an upper wall for the chamber **12**. A diaphram safety valve **84** is disposed in an aperture in the wall **82** in order to provide an automatic gas escape path from the chamber **78** in the event the gas pressure within the chambers **78** and **12** exceeds a predetermined level. Also, a manually operable pressure valve **86** is provided through another aperture in the wall **82** to control the gas pressure within the chambers **78** and **12**.

Disposed in the lower chamber **12** is a cooling fluid **90**, such as a fluorinated hydrocarbon, which at room temperatures fills the chamber **12** to a level **92** slightly below the top of the collector **18**. The particular cooling fluid to be used is selected in conjunction with the pressure within the hermetically sealed chambers **12** and **78** such that the fluid exists in the liquid state under quiescent conditions, but is capable of being vaporized by heat generated by the traveling-wave tube subassembly **14** during operation thereof. An example of a particular cooling fluid which appears desirable on account of its electrically insulating and chemically inert properties is an FC–75 fluorinated hydrocarbon sold by Minnesota Mining and Manufacturing Co., St. Paul, Minn.

In preparing the assembly of the present invention for operation, after the traveling-wave tube subassembly **14** has been mounted within the chamber **12**, cooling liquid **90** is poured into the chamber **12** up to the level **92**. The plate **60** is then placed on and secured to the flange **62** in sealing relationship. The manually operable pressure valve **86** is opened, and the traveling-wave subassembly **14** is energized by applying operating potentials to the electron gun **16**, the slow-wave structure **20**, the collector **18**, and the solenoid **42**. After a few minutes the valve **86** is closed, thereby rendering the assembly of the invention in the desired operating condition.

Heat generated by the electron gun **16**, the collector **18**, and the solenoid **42** is transferred directly to the liquid coolant **90** which is in contact with the outer surface of the electron gun **16** and the collector **18**, as well as with both the outer and inner circumferential surfaces and the upper and lower end surfaces of the solenoid **42**. Heat generated by the slow-wave structure **20** is conveyed via rods **22**, barrel **24**, indium layer **28** and blocks **26** to portions of the liquid coolant **90** which contact the extended outer surface of the blocks **26**.

As heat is transferred from the traveling-wave tube subassembly **14** to the liquid **90**, boiling of the liquid occurs adjacent the heated surfaces of the traveling-wave tube subassembly **14**. The resultant vapor bubbles travel to the surface **92** of the liquid enabling fresh liquid to come into contact with the surfaces of the traveling-wave tube subassembly **14** which are exposed to the coolant **90**, thereby continually conveying heat away from these surfaces. The vapor escaping from the liquid surface **92** travels upwardly to the condenser tubes **68** where it is cooled by the air passing over the outer surfaces of the tubes **68** and the cooling fins **70**. The vapor then condenses on the inner surfaces of the tubes **68**, as shown, and returns by gravity to the lower chamber **12**.

The assembly of the present invention enables traveling-wave tube operation with a substantially constant gain throughout a relatively wide bandwidth at frequencies near the upper end of the microwave spectrum, and at substantially higher power levels than prior art tubes of comparable frequencies and bandwidths. For example, a traveling-wave tube assembly according to the invention has been operated over an 8.7% bandwidth at K-band frequencies at a power level as high as 250 watts. On the other hand, the highest power level generally achieved with prior art traveling-wave tubes operating at comparable frequencies and bandwidths is around 25 watts.

Although the present invention has been shown and described with reference to a particular embodiment, nevertheless, various changes and modificatons obvious to a person skilled in the art to which the invention pertains are deemed to lie within the spirit, scope and contemplations of the invention.

What is claimed it:

1. An evaporatively cooled traveling-wave tube assembly comprising:

a hermetically sealed housing defining a chamber and a plurality of spaced conduits extending upwardly from said chamber and each having one end communicating with said chamber, a plurality of cooling fins extending outwardly from the outer surface of each of said conduits;

a traveling-wave tube subassembly disposed in said chamber and comprising: electron gun means disposed at one end of said subassembly for launching an electron stream along an axial path, collector means disposed at the other end of said subassembly for intercepting electrons of said stream, a slow-wave structure coaxially disposed about said axial path between said electron gun means and said collector means, encasing means having an extended outer surface disposed about said slow-wave structure for maintaining said slow-wave structure in precise coaxial alignment with said electron stream path and for conveying heat outwardly from said slow-wave structure, focusing means disposed about and substantially coextensive with said slow-wave structure for focusing said electron stream, the inner surface of said focusing means being spaced from said extended outer surface of said encasing means;

means for supporting said subassembly in said chamber in an orientation such that said electron stream travels vertically upwardly;

and a cooling fluid disposed in at least the lower portion of said chamber in contact with said electron gun means, said collector means, said encasing means and said focusing means, said cooling fluid and the pressure within said hermetically sealed housing being selected such that said fluid exists in the liquid state under quiescent conditions but is capable of being vaporized by heat generated by said traveling-wave tube subassembly during operation thereof.

2. An assembly according to claim **1** wherein said chamber is of a cylindrical shape, said conduits are tubes having their respective longitudinal axes disposed parallel to the longitudinal axis of said cylindrical chamber, and said cooling fins are bristle-like elements extending radially outwardly from the outer circumferential surfaces of said tubes.

3. An assembly according to claim **1** wherein said hermetically sealed housing further defines an upper chamber disposed above and communicating with the respective other ends of each of said conduits, and wherein an automatic pressure safety valve and a controllable pressure valve are provided in a wall of said upper chamber.

4. An assembly according to claim **1** wherein means are provided for directing a coolant through the space between the outer surfaces of said conduits.

5. An assembly according to claim **1** wherein said encasing means includes: a plurality of dielectric support rods equally circumferentially disposed about said slow-wave structure, an essentially tubular member

clamped about said rods, a pair of like elongated blocks of a material having a high thermal conductivity disposed about said tubular member, each of said blocks defining a longitudinally extending semi-cylindrical groove having a radius slightly greater than the outer radius of said tubular member, said blocks being mechanically fastened together in a rigid arrangement such that the semi-cylindrical grooves face one another in an aligned relationship to provide a cylindrical space for receiving said tubular member, and a layer of solder material disposed between and soldered to the outer circumferential surface of said tubular member and the surface of said blocks defining said cylindrical space.

6. An assembly according to claim **5** wherein said solder material is indium.

7. An assembly according to claim **5** wherein each of said blocks further defines a plurality of longitudinally extending ridges on a surface opposite to the surface defining said groove.

8. An assembly according to claim **1** wherein said focusing means includes: elongated annular means coaxially disposed about said slow-wave structure for generating a magnetic field along said axial path, a pair of ferromagnetic annular disks coaxially disposed about said axial path and spaced from the respective ends of said elongated annular means, each said ferromagnetic annular disk extending radially outwardly beyond said elongated annular means and defining a plurality of radially extending slots therethrough, and a ferromagnetic tubular member mounted on said ferromagnetic annular disks and spaced from and encircling said elongated annular means.

9. An assembly according to claim **1** wherein said focusing means includes: a non-magnetic electrically conductive tubular member coaxially disposed about said slow-wave structure, a foil solenoid having a length slightly less than the length of said non-magnetic tubular member wound about said non-magnetic tubular member, a pair of ferromagnetic annular disks mounted on respective ends of said tubular member and spaced from the respective ends of said foil solenoid, each said ferromagnetic annular disk extending radially outwardly beyond said foil solenoid and defining a plurality of radially extending slots therethrough, each end of said non-magnetic tubular member defining a plurality of notches registering with respective ones of said slots, and a ferromagnetic tubular member mounted on said ferromagnetic annular disks and spaced from and encircling said foil solenoid.

10. An assembly according to claim **1** wherein said cooling fluid is a fluorinated hydrocarbon.

References Cited

UNITED STATES PATENTS

3,246,190	4/1966	Boyd et al.	315—3.5 X
3,306,350	2/1967	Beurtheret	165—105
3,388,740	6/1968	O'Loughlin	165—105

HERMAN KARL SAALBACH, *Primary Examiner.*

SAXFIELD CHATMON, JR., *Assistant Examiner.*

U.S. Cl. X.R.

165—105; 174—15; 313—18, 22, 34, 35

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,444,419 Dated May 13, 1969

Inventor(s) J. W. Hansen et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 2, line 47, "slow-type" should be --slow-wave--.
Col. 3, line 3, "berryllia" should be --beryllia--;
line 29, "definies" should be --defines--.
Col. 4, line 23, "39" should be --49--.
Col. 6, line 14, "it" should be --is--.

SIGNED AND
SEALED
MAR 3 - 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents