

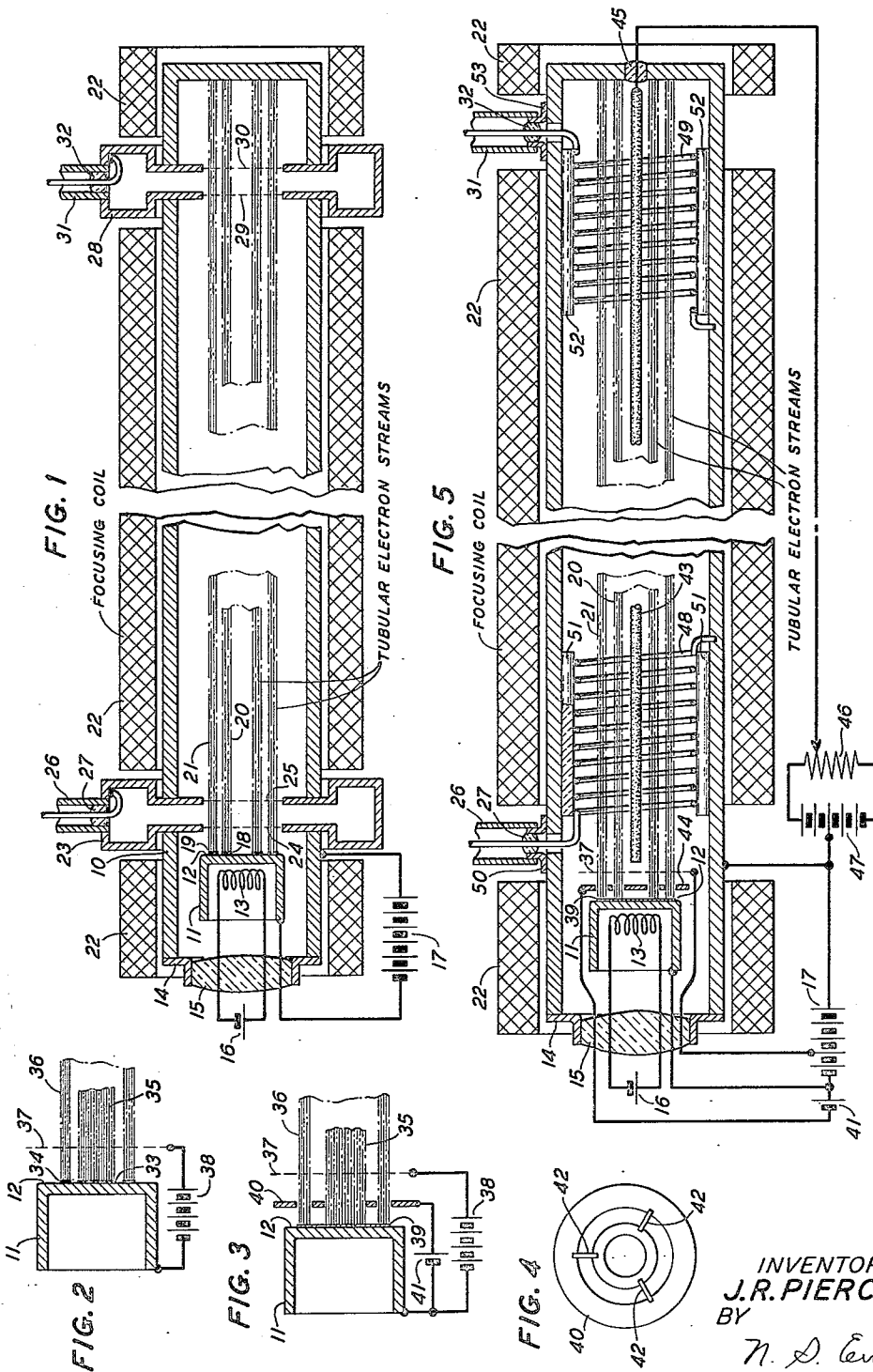
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MICROWAVE AMPLIFIER

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2,694,159

MICROWAVE AMPLIFIER

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This invention relates to amplifying devices which utilize the interaction of a pair of closely coupled electron streams having different average velocities to secure gain.

One object of the invention is to simplify the structure of such devices, thereby enabling them to be produced in greater quantities and at less cost than would otherwise be possible.

Another object of the invention is to enable double-stream amplifiers to be made smaller and more compact than would otherwise be practical.

Still another object is to simplify the structure of double-stream amplifiers so that they can be made small enough to operate effectively at very high frequencies.

Previous double-stream amplifiers are disclosed in the application of W. B. Hebenstreit and J. R. Pierce, Serial No. 38,928, filed July 15, 1948, and in that of A. V. Hoi- lenberg, Serial No. 64,889, filed December 11, 1948 (is- sued September 15, 1953, as United States Patent 2,652,513). In those amplifiers, a pair of closely coupled electron streams are emitted from respective different cathodes which are at different potentials. Accelerating means positive with respect to both cathodes, causes the electrons emitted from the two cathodes to travel at re- spective different velocities, since one stream is subjected to a greater accelerating voltage than the other.

In accordance with the present invention, two physi- cally separated but closely coupled electron streams are emitted from a single equipotential cathode and projected through a radial electric field. The radial field, combined with the usual accelerating field, causes the two streams to travel at different velocities, thus furnishing one of the primary requisites for double-stream gain. The neces- sary radial or diverging electric field may be secured in several ways, two of which will be described in detail.

The nature of the invention will appear more fully upon a study of the following detailed description of several specific embodiments. In the drawings:

Fig 1 shows an amplifier which utilizes the radial elec- tric field set up by the space charge of the electron streams themselves;

Figs. 2, 3 and 4 show two alternative beam-projecting cathode structures; and

Fig. 5 shows an amplifier which employs a central elec- trode and the conducting envelope of the amplifier to produce a diverging field.

In Fig. 1 the elongated, cylindrical tube envelope 10 is made of a highly conductive metal such as, for ex- ample, copper. The left-hand end section of envelope 10 encloses a hollow cylindrical metallic cathode 11. Cath- ode 11 is axially aligned with envelope 10 and its right- hand end is closed by a metallic face 12. A heating coil 13 is located within cathode 11.

The left-hand end of envelope 10 is open and the right- hand end is closed. An annular flange 14 is attached to the left-hand end of envelope 10. A glass seal 15 is located in the opening left by flange 14 and permits envelope 10 to be evacuated. A battery 16 is connected to supply power to heating coil 13 by leads passing through glass seal 15. Cathode 11 is connected, by means of a lead passing through glass seal 15, to the negative terminal of a battery 17. Cathode 11 may, if desired, be sup- ported by that connecting lead. The positive terminal of battery 17 is connected to envelope 10.

Cathode face 12 is coated with two concentric rings of emitting material 18 and 19. The inner ring 18 pro- duces a hollow cylindrical inner electron stream 20 and

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the outer ring 19 produces a hollow cylindrical outer stream 21. Magnetic focusing coils 22 surround en- velope 10, are axially aligned with it, and are supplied with direct current from an appropriate direct-current source (not shown).

An input resonator 23 is provided to enable the sig- nal which is to be amplified to be impressed upon either stream 20 or 21 or both. Resonator 23 is annular and surrounds envelope 10 at a point just to the right of cathode face 12. A pair of parallel grids 24 and 25 are connected to opposite walls of resonator 23 within en- velope 10 and are at right angles with the axis of en- velope 10. A coaxial line 26 is coupled to resonator 23 and is used to supply the input signal to resonator 23. Coaxial line 26 is sealed off from resonator 23 by a glass seal 27.

An output resonator 28 is similar to input resonator 23 and enables energy to be withdrawn from either stream 20 or 21 or both. Resonator 28 surrounds en- velope 10 near its far right-hand end. Parallel grids 29 and 30 are connected to opposite walls of resonator 28 within envelope 10 and are, as were grids 24 and 25, at right angles with the axis of envelope 10. Energy is ex- tracted through a coaxial output line 31 which is coupled to resonator 28 and sealed off by a glass seal 32.

The potential difference between cathode 11 and en- velope 10 sets up an electric field within envelope 10 which tends to accelerate electrons leaving emitting surfaces 18 and 19 to the right. The longitudinal mag- netic field established by focusing coils 22 confines the electrons to the two tubular streams 20 and 21, causing them to travel to the right until they reach the extreme right-hand end of envelope 10.

In the absence of other effects, the accelerating field would set up equipotential surfaces of such shape that the portions intersected by streams 20 and 21 would be practically parallel to cathode face 12. Electrons flowing in outer stream 21 would be, at any given distance from cathode face 12, subjected to substantially the same po- tential gradient as those flowing in inner stream 20. The electrons of streams 20 and 21 would, therefore, be ac- celerated equally as they progress and, at any instant, would be traveling at substantially the same velocity.

While the electrons introduce a negative space charge and modify the accelerating field, the presence of the conducting grids 24 and 25 assures that the electrons of both streams have, in passing grids 24 and 25, substan- tially the same velocity.

The electrons comprising streams 20 and 21 introduce a negative space charge that tends to reduce the po- tential in the region through which they pass, especially in the extended region between grids 25 and 29. Near the center of this region the equipotentials will be substan- tially cylindrical and coaxial with the electron stream, the potential falling as one goes in from the conducting en- velope 10 toward the axis of the tube, but being constant in the region inside of stream 20 where there is no current. Very near grids 25 and 29 the equipotentials must be sub- stantially parallel to the grids, and a little way from grids 25 and 29 the equipotentials are cap-shaped, con- vex toward the grids.

The electrons of streams 20 and 21 then encounter equipotential surfaces having pronounced curvature. Electrons of inner stream 20 encounter surfaces of lower potential than the lowest potential encountered by elec- trons of outer stream 21. In any given portion of the path to the left of the extreme right-hand end of en- velope 10, the electrons of inner stream 20 are caused to travel at a velocity lower than that of the electrons of outer stream 21. The velocity difference necessary for double-stream gain is thus provided, and the tube will act as a double-stream amplifier.

In obtaining useful gain it is important to have streams of two rather distinct velocities, rather than merely a smooth spread of velocities. For that reason, two separated concentric electron streams, rather than a single solid cylinder of flow, are used. A radial elec- tric field would cause the inner electrons of a solid cyl- inder of flow to travel at a different velocity from the

outer electrons, but the smooth spread of velocities thereby obtained is not suitable for producing gain.

Fig. 2 shows an alternative cathode structure which may be employed in the amplifier of Fig. 1. The right-hand face 12 of cathode 11 is coated with a center circular area of emissive material 33 and with a ring of emissive material 34 concentric with and surrounding area 33. A solid central inner electron beam 35 is emitted from area 33 and a hollow cylindrical outer electron beam 36 is emitted from ring 34. When this cathode arrangement is employed in the amplifier of Fig. 1, the electrons comprising outer beam 36 travel at a greater velocity than those comprising inner beam 35. Since the two electron streams 35 and 36 are closely coupled, the conditions necessary to support double-stream gain are attained.

If desired, an accelerating grid 37 may be placed just to the right of cathode face 12 and held at a positive potential with respect to cathode 11 by a battery 38. The plane of grid 37 is perpendicular to the direction of flow of streams 35 and 36.

Fig. 3 shows still another form of cathode structure. In Fig. 3, cathode face 12 is entirely coated with emissive material 39. A beam-forming electrode 40 is placed just to the right of and parallel to cathode face 12. Electrode 40 is held either slightly positive or slightly negative with respect to cathode 11 by a biasing battery 41.

Details of electrode 40 are shown in Fig. 4. Electrode 40 consists of two concentric metallic rings held together by several spaced wires 42. A central aperture permits electrons from cathode face 12 to pass and form a solid central inner beam 35. An annular aperture, concentric with the central aperture, allows passage of electrons from face 12 and the formation by such electrons of a hollow cylindrical outer beam 36.

As in Fig. 2, the cathode structure of Fig. 3 may include an accelerating grid 37, parallel to and to the right of cathode face 12. Electrode 40 is between grid 37 and face 12. Grid 37 is held positive with respect to cathode 11 by battery 38.

The amplifier shown in Fig. 5 is much like that of Fig. 1, with the exception that a radial electric field is produced by an additional electrode 43 and the tube envelope 10. An alternative signal input and output arrangement is also illustrated in Fig. 5. Parts of the Fig. 5 amplifier which are substantially identical with parts previously described in connection with Fig. 1 have been given similar reference numerals and will not be described in detail at this point.

In Fig. 5, cathode face 12 is entirely coated with electron-emissive material 39 and a beam-forming electrode 44 is situated parallel to and slightly to the right of cathode face 12. Electrode 44 has two concentric annular apertures which allow electrons from cathode face 12 to pass and form two concentric hollow cylindrical electron streams 20 and 21. Electrode 44 is biased slightly positive or slightly negative with respect to cathode 11 by battery 41. An accelerating grid 37 is located to the right of electrode 44 and is connected through glass seal 15 to an intermediate point on battery 17.

An additional rod-like electrode 43 is provided within the inner electron beam 20 concentric with envelope 10. Center electrode 43 may extend from a point just to the right of grid 37 to a point just to the left of the extreme right-hand end of envelope 10 and may be held in place in any appropriate manner. The right-hand end of center electrode 43 is attached to a lead which is brought out of envelope 10 through a glass seal 45 to the movable tap of a potentiometer 46. The resistance arm of potentiometer 46 is connected across a battery 47. The positive terminal of battery 17 and envelope 10 are connected to an intermediate point of battery 47.

Center electrode 43 can be made positive or negative with respect to envelope 10 by varying the position of the movable tap of potentiometer 46. A radial electric field is set up between center electrode 43 and envelope 10 whenever they are at different potentials, and the equipotential surfaces produced within envelope 10 tend to become parallel to the tube axis, causing the electrons of outer stream 21, until they arrive at the extreme right-hand end of envelope 10, to travel at a potential different than that at which the electrons of inner stream 20 travel.

When center electrode 43 is made positive with re-

spect to envelope 10, the electrons of inner stream 20 encounter equipotential surfaces which are higher in potential than any encountered by electrons of outer stream 21. In most of the left-hand portion of their path of travel, electrons of inner stream 20 are subjected to a greater potential gradient than are those of outer stream 21 and are, therefore, subjected to a greater accelerating force. In any particular portion of the path to the left of the far right-hand end of envelope 10, the electrons of inner stream 20 are caused to travel faster than those of outer stream 21.

On the other hand, when center electrode 43 is made negative with respect to envelope 10, the electrons of outer stream 21 encounter higher-potential equipotentials than those encountered by the electrons of inner stream 20. In the left-hand portion of their path of travel, electrons of outer stream 21 are subjected to a greater potential gradient than are those of inner stream 20 and are, therefore, subjected to a greater accelerating force. In any given portion of the path to the left of the right-hand end of envelope 10, the electrons of outer stream 21 are caused to travel faster than those of inner stream 20.

By adjusting the potential of center electrode 43 the velocity difference between the two streams 20 and 21 can be made optimum for double-stream gain, with either inner stream 20 or outer stream 21 the faster.

It may be desirable to make electrode 43 of "lossy" material, as by making it a graphite-coated ceramic rod, to avoid high frequency transmission along electrode 43.

The signal input and output circuits shown in Fig. 5 include a pair of short metallic helices 48 and 49. A hole is bored in envelope 10 at a point just to the right of grid 37. A circular flange 50 is connected to the outside of envelope 10 at that point and surrounds the hole. An input coaxial line 26 is connected to flange 50 and is sealed off by a glass seal 27. The inner conductor of coaxial line 26 is connected to the left-hand end of the input helix 48. Helix 48 is concentric with and surrounds electron beams 20 and 21 and has its right-hand end connected directly to envelope 10. Helix 48 is located to the right of grid 37 and is separated from envelope 10 by several ceramic rods 51 which are spaced around its periphery. A matched termination is provided for helix 48 by coating the right-hand ends of ceramic rods 51 with "lossy" material such as, for example, graphite.

The output helix 49 is located to the left of the right-hand extremity of envelope 10 and is separated from envelope 10 by several ceramic rods 52. The left-hand ends of ceramic rods 52 are terminated with "lossy" material in the same manner as ceramic rods 51 were terminated. The left-hand end of helix 49 is connected to envelope 10. To the right of helix 49, a hole is bored in envelope 10 and is surrounded by a circular flange 53. An output coaxial line 31 is connected to flange 53 and is sealed off by a glass seal 32. The inner conductor of coaxial cable 31 is connected to the right-hand end of helix 49.

The signal input and output circuits shown in Figs. 1 and 5 are by way of example only. They may be used interchangeably. Many other input and output combinations, examples of which are shown in the previously noted Hebenstreit-Pierce and Hollenberg applications, may be used to advantage.

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

What is claimed is:

1. A space discharge device comprising an electrically conductive envelope defining a path of travel for electrons, an equipotential electron-emissive cathode, a conducting rod extending along said path, said rod and said envelope being adapted to be maintained at substantially different direct potentials relative to each other, means for projecting a pair of physically separated concentric tubular electron streams from said cathode along said path concentric with said rod, whereby the radial electric field established between said rod and said envelope causes electrons of the respective streams to travel along said path at different velocities, means for impressing a signal on at least one of said streams, and means for

withdrawing amplified signal energy from at least one of said streams.

2. A space discharge device comprising a metallic envelope enclosing a path of travel for electrons, an equipotential source of a pair of physically separated concentric cylindrical electron streams, means for establishing an accelerating electric field within said envelope, and means comprising said envelope and an electrode extending along the axis thereof which when energized is adapted to superimpose a radial electric field, axially aligned with said streams, on said accelerating field, whereby in a portion of said path electrons of one of said streams are subjected to a greater potential gradient than electrons of the other of said streams.

3. A microwave amplifier comprising a cylindrical electrically conductive envelope defining a path of travel for electrons, an equipotential electron source, means for projecting a pair of physically separated concentric cylindrical electron streams along said path from said source, and means comprising said envelope and an electrode extending along the axis thereof and maintained at a substantially different direct potential therefrom for establishing an electric field within said envelope and along said path in which the equipotential surfaces tend to be parallel with said streams over a substantial portion of said path, whereby the electrons of the respective streams are caused to travel at respective different velocities over said portion of said path.

4. An amplifying space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electron-emissive electrode at one end of said tubular electrode, means coupled between said electrodes to maintain said tubular electrode at a direct potential positive with respect to the direct potential of said electron-emissive electrode, means including said potential-maintaining means to project a pair of physically separated, substantially concentric, tubular electron streams from said electron-emissive electron along said path through said tubular electrode in an electromechanically intercoupled relationship, means adjacent said tubular electrode to confine moving electrons to said path, a rod-like electrode located within the inner of said pair of streams and extending along the axis of said tubular electrode, said tubular electrode and said rod-like electrode being adapted to be maintained at substantially different direct potentials relative to each other, means at the end of said path nearer said electron-emissive electrode to impress a signal on at least one of the electron streams, and means at the other end of said path to withdraw amplified signal energy from at least one of the electron streams, whereby both streams become modulated under the control of the signal and the signal is amplified by interaction between the two electron streams as they progress along said path.

5. An amplifying space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electron-emissive cathode at one end of said path, means to project a pair of physically separated electromechanically coupled cylindrical electron streams, one within the other, from said cathode along said path lengthwise through said tubular electrode, and means comprising said tubular electrode for establishing a radial direct-current electric field in said path substantially concentric with said streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

6. A microwave amplifier which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electron source at one end of said path, means to project a pair of physically separated electromechanically coupled cylindrical electron streams, one within the other, from said source along said path lengthwise through said tubular electrode, and means comprising said tubular electrode and a rod-like electrode extending along the axis thereof and maintained at a substantially different direct potential therefrom for establishing a radial direct-current electric field in said path substantially concentric with said streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

7. An amplifying space discharge device in accordance with claim 5 which includes means at one end of said path to modulate at least one of said streams in accordance with a signal which is to be amplified and means

at the other end of said path to abstract amplified signal energy from at least one of said streams.

8. A space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electrode at one end of said path having a pair of substantially concentric electron-emissive surfaces, means to project a pair of physically separated substantially concentric electromechanically coupled electron streams from said equipotential electrode along said path lengthwise through said tubular electrode, and means comprising said tubular electrode for establishing a radial direct-current electric field in said path substantially concentric with said streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

9. A space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electrode at one end of said path having a pair of substantially concentric electron emissive surfaces, means to project a pair of physically separated substantially concentric electromechanically coupled electron streams from said equipotential electrode along said path lengthwise through said tubular electrode, and means comprising said tubular electrode and a rod-like electrode extending along the axis thereof of which when energized is adapted to establish a radial direct-current electric field in said path substantially concentric with said streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

10. A space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electron-emissive electrode at one end of said path, means to project a stream of electrons along said path from said electron-emissive electrode, electron intercepting means having a pair of substantially concentric apertures located athwart said path close to said electron-emissive electrode, whereby a pair of physically separated substantially concentric electromechanically coupled electron streams are directed along said path lengthwise through said tubular electrode, and means comprising said tubular electrode for establishing a radial direct-current electric field in said path substantially concentric with the electron streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

11. A space discharge device which comprises an elongated tubular electrode defining a path of travel for electrons, an equipotential electron emissive electrode at one end of said path, means to project a stream of electrons along said path from said electron emissive electrode, electron intercepting means having a pair of substantially concentric apertures located athwart said path close to said electron emissive electrode, whereby a pair of physically separated substantially concentric electromechanically coupled electron streams are directed along said path lengthwise through said tubular electrode, and means comprising said tubular electrode and a rod-like electrode extending along the axis thereof which when energized is adapted to establish a radial direct-current electric field in said path substantially concentric with the electron streams, whereby the electrons of the respective streams are caused to travel along said path at respective different velocities.

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