

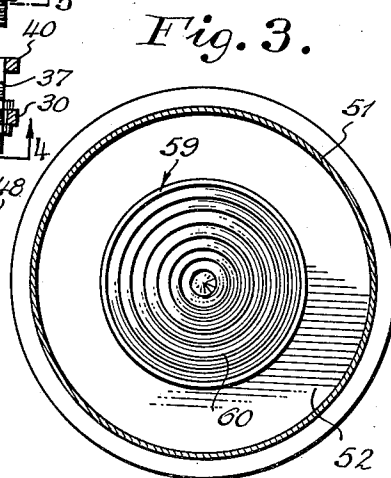
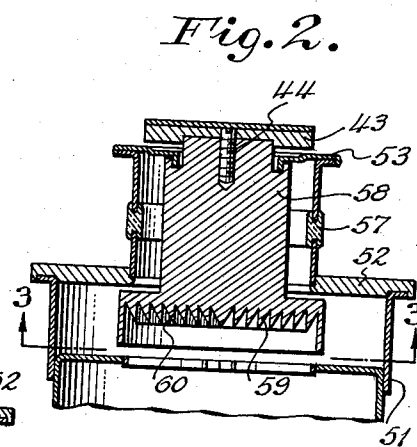
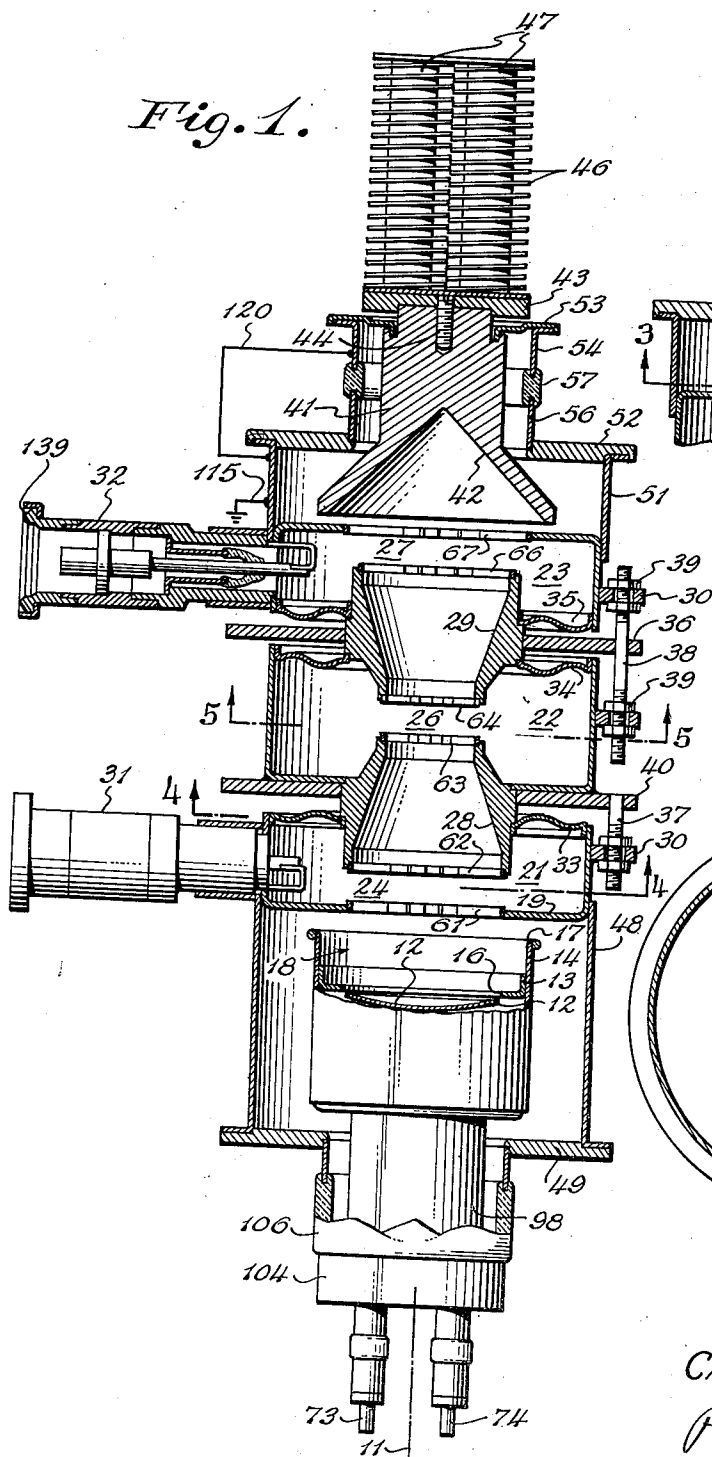
June 1, 1954

C. M. VERONDA
HIGH-FREQUENCY APPARATUS

2,680,209

Filed May 12, 1950

2 Sheets-Sheet 1



INVENTOR
CAROL M. VERONDA
BY
Paul B. Hunter
ATTORNEY

June 1, 1954

C. M. VERONDA
HIGH-FREQUENCY APPARATUS

2,680,209

Filed May 12, 1950

2 Sheets-Sheet 2

Fig. 7.

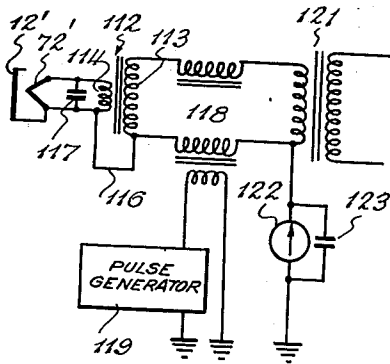


Fig. 8.

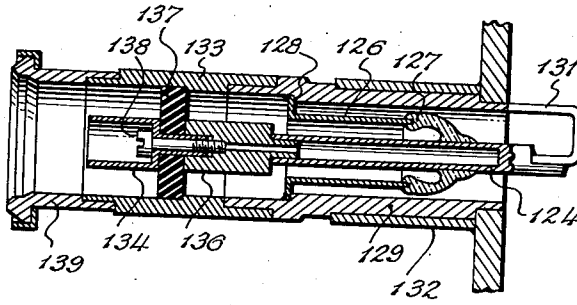


Fig. 4.

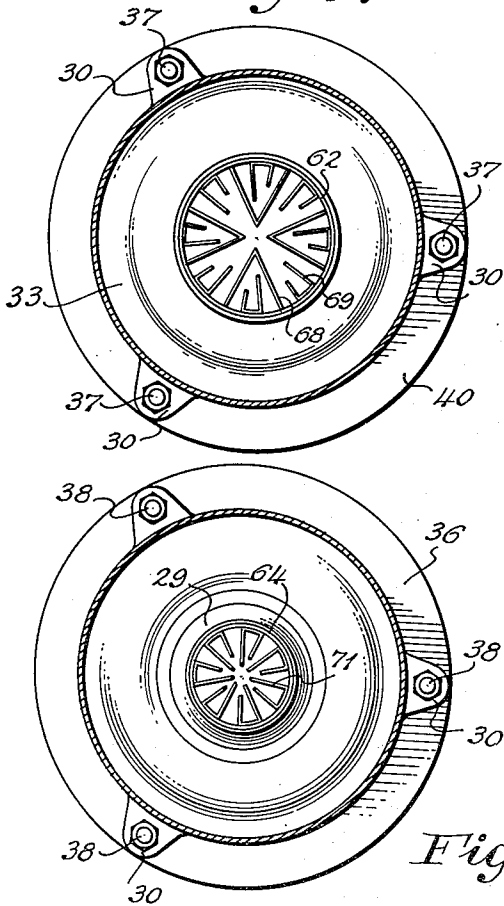


Fig. 6.

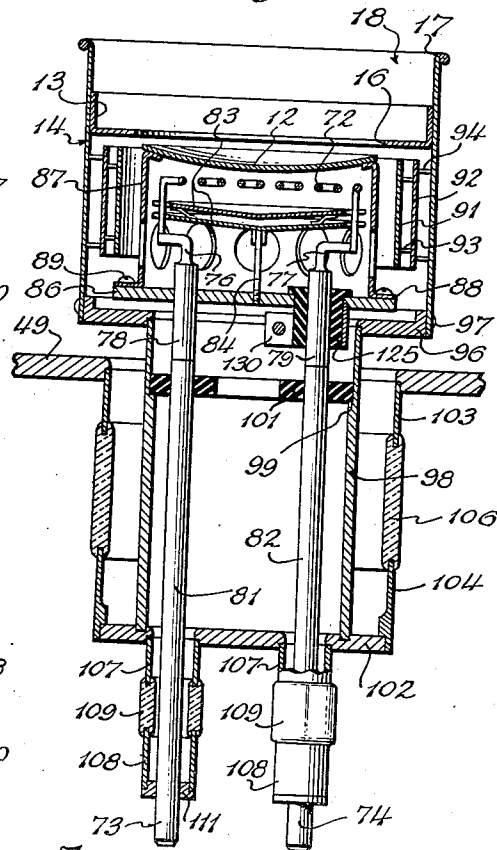


Fig. 5.

INVENTOR
CAROL M. VERONDA
BY
Paul B. Hunter,
ATTORNEY

UNITED STATES PATENT OFFICE

2,680,209

HIGH-FREQUENCY APPARATUS

Carol M. Veronda, Island Trees, N. Y., assignor to
The Sperry Corporation, a corporation of Delaware

Application May 12, 1950, Serial No. 161,684

12 Claims. (Cl. 315-6)

1

This invention relates to electron discharge devices and, more particularly, to such devices having a novel electron beam focusing arrangement.

For certain types of electron tubes it is desirable to provide an electron beam with a small diameter. However, where the electron beam density involved is not large, it is not very difficult to accomplish this result, such as in the case of a cathode ray tube or electron microscope, in which the mutual repulsion forces of electrons are negligible. The electron optics employed in such electron discharge devices are based on a consideration of the trajectories of individual electrons without taking into account the presence of other electrons.

To provide a high power electron discharge device, such as a klystron suitable for transmitter type applications, it is advisable to employ a high density electron beam. By providing a klystron transmitter for pulsed applications it is possible to operate with properly controlled frequency stability.

Where employing a high density electron beam in klystron tubes the problem of maintaining such a high density beam in focus during its transit through the velocity modulation system is present. Three different types of beam focusing may be noted, including ion focusing, magnetic focusing, and space charge focusing.

With regard to ion focusing, where residual gas molecules are present within the vacuum envelope of the tube structure, such ions are effective for neutralizing the space charge of the electrons of the beam, thereby permitting the beam to traverse the length of the tube without undergoing excessive defocusing owing to the mutual repulsion of electrons. Generally speaking, ion focusing is limited to electron discharge devices operated as continuous wave generators in view of the fact that there are no ions present at the beginning of a pulse to form a suitable electron beam configuration. Consequently, a pulse generator tube employing ion focusing may provide a high power output pulse having sides or edges which are not sufficiently steep for certain applications.

Magnetic focusing may be provided by an axially-directed magnetic field, which is effective for maintaining a high density electron beam uniform in cross-sectional area for any desired distance. Such magnetic focusing is useful for velocity modulation devices operated both as continuous wave and radio frequency pulse generators. The use of magnetic focusing

2

for maintaining an electron beam in a suitable configuration is described in copending application Serial No. 117,187 entitled High Frequency Apparatus, in the name of Charles E. Rich, filed September 22, 1949.

An electron discharge device including, among other things, space charge focusing is provided by the present application. With regard to space charge focusing, an electron beam, generally speaking, may be permitted to follow a trajectory determined by the initial angle of the electron gun and by the mutual space charge repulsion forces of the electrons. Under such circumstances the beam converges to a minimum and then diverges so that the beam does not have a uniform cross-sectional area over its length. The electron beam provided by this arrangement has a substantially apically conjugate conoidal configuration and, while useful for the generation of continuous waves, is particularly suitable for use in conjunction with a velocity modulation device intended for pulsed operation and having gridded interaction resonator gaps.

In certain applications where space considerations are important it is desirable to employ a velocity modulation device operating with a high density electron beam without resorting to the use of magnetic focusing means. An electron discharge device employing space charge focusing is particularly suitable for such applications. By employing a high density space charged focused electron beam it is possible to obtain high power output pulses of desirable configuration with a compact electron discharge structure. In addition, with cascade bunching of electrons an electron discharge device may be operated with a relatively low drive power.

Accordingly, it is an object of the present invention to provide a space charge focusing means for obtaining an electron beam having a substantially apically conjugate conoidal configuration.

A further object lies in the provision of an improved velocity modulation device suitable for supplying steep sided radio frequency output pulses.

A still further object is to provide a velocity modulation electron discharge device of a compact configuration.

An additional object is to provide an improved electron discharge device for generating pulses having a relatively large magnitude of power.

Another object lies in the provision of a klystron having electrostatic and space charge focusing means.

Another object is to provide an improved electron collector.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings, wherein the invention is embodied in concrete form.

Fig. 1 is a longitudinal view, mainly in cross section, of an electron discharge device according to the present invention.

Fig. 2 is a fragmentary cross-sectional view of an alternate embodiment of an electron collector, which may be employed with the electron discharge device of Fig. 1.

Fig. 3 is a view, mainly in cross section, taken along lines 3—3 of Fig. 2.

Fig. 4 is a view showing, among other things, a grid structure taken along lines 4—4 of Fig. 1.

Fig. 5 is a view showing, among other things, a grid structure taken along lines 5—5 of Fig. 1.

Fig. 6 is an enlarged view, mainly in cross section, showing the structure of the cathode of Fig. 1.

Fig. 7 is a circuit diagram showing part of the external circuit elements for electrical energization of the electron discharge device of Fig. 1.

Fig. 8 is an enlarged cross-sectional view of one of the coaxial line terminal posts of Fig. 1.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

Referring to Fig. 1 aligned along the longitudinal axis 11 of an electron discharge device is an electron beam producing means, which includes a means for supplying electrons, such as cathode button or electron emitter 12, the upper surface of which is suitably oxide coated and substantially spherically concave in cross section about the longitudinal axis 11. The edge of the aperture of the apertured cup 13, which is supported by sleeve 14, provides a first line conductor or edge 16 positioned outwardly of and along the longitudinal axis 11 in a direction away from the cathode button 12. Accordingly, it will be noted that the diameter of the aperture of cup 13 is larger than the diameter of the cathode button 12.

The end of the sleeve 14 in a direction toward the main body of the electron discharge device provides a second line conductor or edge 17, with the second edge 17 being located outwardly of the cathode button 12 to a greater extent than the first edge 16. The second edge 17 is, in addition, disposed along the longitudinal axis 11 in a direction away from the cathode button 12 to a greater extent than the first edge 16. The first and second line conductors or edges 16, 17 constitute an electrostatic field forming means or focusing electrode 18, which is designed according to the principles disclosed in copending application Serial No. 81,480 entitled High Frequency Apparatus in the name of Chao Wang, filed March 15, 1949, now Patent 2,564,743.

For accelerating and directing electrons emanating from the cathode button 12 toward the main body of the electron discharge device, an accelerating electrode or anode 19 is provided, which anode 19 is suitably energized by an external potential source, as discussed hereinbelow. Under the influence of the focusing electrode 18 and the anode 19, a high density electron beam is formed, in which the individual electrons thereof traverse substantially rectilinear trajectories and travel toward a point.

Three separate and distinct electromagnetic field defining means are positioned to receive or

to be traversed by this high density beam successively in energy-exchanging relation. The electromagnetic field defining means may include cavity resonators 21, 22 and 23, each being provided with an electron-permeable region or gap 24, 26 and 27, respectively, through which the high density beam passes. The wall of resonator 21 which faces the cathode button 12 provides the previously identified accelerating electrode or anode 19.

Between the first two resonators 21, 22 there is provided a means defining a drift space, such as drift tube 28. Similarly, between the second and third resonators 22, 23, there is provided a means defining a further drift space, such as drift tube 29. It will be noted that the end ones of the resonators 21, 23 are provided with singly-reentrant configurations.

The walls of the drift tubes 28, 29 are tapered inwardly toward the gap 26 of the intermediate resonator 22, so that the drift tubes 28, 29 have a minimum cross-sectional area in the vicinity of the gap 26. It will be noted that the walls of the drift tubes 28, 29 are provided with an appreciable thickness, which permits heat developed internally of the electron discharge device to be more readily conducted to the exterior thereof. To the same end, the walls of the drift tubes 28, 29 are preferably formed of a material having a relatively high thermal conductivity, such as copper. The configuration of the internal walls of the drift tubes 28, 29 is such as to substantially follow, while being somewhat spaced from, the envelope of the electron beam passing therethrough. The internal walls of the resonators 21—23 are preferably constituted of highly conductive material to achieve efficient electrical operation. This may be accomplished by forming these parts 21—23 of copper, silver, or of a material plated with such metallic substances.

In view of the fact that resonator 21 is effective for impressing velocity variations upon the electron beam traversing the gap 24 thereof, this resonator 21 may more generally be termed a first means for velocity modulating the electron beam. To suitably excite resonator 21, which resonator 21 may also be termed an input or buncher resonator 21, a means for coupling electromagnetic energy thereto, such as an input coaxial transmission line terminal post 31, is provided. The intermediate resonator 22 is effective for further impressing velocity variations upon the electron beam traversing its gap 26 and hence may more generally be termed a second means for velocity modulating the beam. It will be noted that no provision is made for coupling electromagnetic energy to or exciting the intermediate resonator 22, the necessary excitation being provided by the electron beam traversing the gap 26 thereof.

Resonator 23 is effective for extracting electromagnetic energy from the electron beam traversing its gap 27 and, consequently, may more generally be termed a means for extracting electromagnetic energy. At times such a resonator 23 is referred to as an output or catcher resonator 23. To deliver electromagnetic energy from the output resonator 23 to a load (not shown) a means for coupling electromagnetic energy, such as output coaxial line terminal post 32, is provided.

In order to provide for the adjustment of the resonant frequency or tuning of the resonators 21—23, they are formed with flexible diaphragms

or end walls 33, 34 and 35, respectively. Lugs 30 are rigidly mounted on the exterior walls of the resonators 21-23 and flange-like members 36, 40 are rigidly secured to the drift tubes 28, 29, respectively. The lugs 30 and flange-like members 36, 40 are suitably apertured to accommodate longitudinally-extending tuning screws 37, 38, with nuts 39 cooperating with the tuning screws 37, 38 to regulate the axial separation of the lugs 30 and flange-like members 36, 40. The upper end of tuning screw 37 and the intermediate portion of tuning screw 38 are rigidly secured to the flange-like members 40, 36, respectively, as by soldering.

By such adjustment the resonant frequency of the resonators 21-23 may be varied. With an increase in the axial separation or longitudinal spacing of a resonator gap, such as, for instance, gap 24, the frequency is increased. The tuning is accomplished by opening one of the nuts 39 and tightening one of the opposing nuts 39 in the desired direction. Similarly, the resonant frequency is decreased as the axial separation of a gap, such as gap 24, is reduced.

If desired, thermal compensation for variations in ambient temperature may be employed. Such ambient temperature variations alter the volumes of the resonators 21-23; thereby introducing changes in the resonant frequencies thereof. By suitably selecting the tuning screws 37, 38 both as to length and linear coefficient of thermal expansion, such volume changes in the resonators 21-23 owing to ambient temperature variations may be compensated for; thereby minimizing spurious frequency changes in the electron discharge device. To achieve this end, the tuning screws 37, 38 may preferably be formed of suitable lengths of a material having a relatively high linear coefficient of thermal expansion, such as aluminum.

An electron collecting means, such as metallic member or block 41 is disposed to receive the spent electron beam after it traverses the gap 27 of the output resonator 23. The end portion of the block 41 is provided with a conically-shaped surface 42 facing the cathode button 12. Block 41 is joined to a plate 43 by means of a screw 44. In view of the fact that considerable heat is developed in the block 41, means are provided for dissipating such heat, such as cooling fins 46, supported by rods 47. More specifically, four symmetrically disposed rods 47 are supported by plate 43 and have helically-shaped cooling fins 46 extending around their outer surfaces.

Resonator 21 is joined by a tubular member 48 to the plate 49. A further tubular member 51 is connected to plate 52 and also to the outer wall of resonator 23. Disc 53, which is connected to the metallic block 41, is also joined to sleeve 54, which, in turn, is secured to sleeve 56 through the vitreous tubular member 57, with sleeve 53 being additionally connected to plate 52. All of the aforementioned connections are effected in a vacuum-tight manner in order to insure the preservation of the internal vacuum of the electron discharge device. To the same end, the connections of the diaphragms 33-35 to the drift tubes 28, 29 as well as to the wall portions of the resonators 21-23 are of a vacuum-tight construction.

The resonators 21-23 may each be provided with a pair of grids 61, 62; 63, 64; and 66, 67, respectively. The electrical diameter of the gaps or apertures 24, 26, 27 of the resonators 21-23, respectively, by virtue of the presence of grids

61-64, 66, 67 may be larger than would otherwise be the case without loss of efficiency resulting from unevenness of bunching across the diameter of the electron beam.

Although not essential, it is preferable to form the exit grid 67 of the output resonator 23 of a larger diameter, as compared, for instance, with the entrance grid 66 thereof. Thus, the possibility of interception of the bunched electron beam by the walls of the output resonator 23 is minimized. It will be noted that the gap or aperture 27 is formed with a tapered configuration. However, it is believed that no misunderstanding will occur by describing, for instance, the end ones of the resonators 21, 23 as having larger apertures 24, 27 than the aperture 26 of the intermediate resonator 22.

In operation, electrons emanating from the cathode button 12 are accelerated toward the anode 19, when a difference of electrical potential is impressed therebetween, as discussed more fully hereinbelow in connection with Fig. 7. During the transit of electrons toward the anode 19 the field forming means or focusing electrode 18, which is constituted of first and second line conductors 16, 17, respectively, is effective for maintaining the individual electrons of the beam in rectilinear trajectories, with such trajectories converging toward a point. Thus, the action of the electron beam prior to its entrance into the gap 24 of the input resonator 21 is similar to that disclosed in the aforementioned Patent 2,564,743.

By reason of the focusing electrode 18 the potential distribution along the boundary of the electron beam is designed to simulate a spherical flow of electrons. Accordingly, along the beam boundary in the region between the cathode button 12 and the anode 19 there is no tendency for the electrons to deviate from rectilinear paths owing to the fact that the potential distribution existing outside the electron beam is similar to the potential distribution existing inside the electron beam. Stated somewhat differently, the focusing electrode 18 is effective for providing, in the presence of complete space charge, a zero voltage gradient normal to the edge or boundary of the electron beam.

The high density electron beam after passing the anode 19 traverses in succession the gaps 24, 26 and 27 of the resonators 21-23, respectively. Owing to the presence of an electromagnetic field in the input resonator 21, which resonator 21 is excited by means of high frequency energy supplied thereto through coaxial line terminal post 31, the electron beam is subjected to velocity modulation. After passing beyond the gap 24 the velocity varied beam in traversing the drift tube 28 undergoes density modulation by reason of the faster moving electrons overtaking the slower moving electrons. Such a density modulated beam serves to excite the intermediate resonator 22 by traversing the gap 26 thereof. During the transit of the electron beam through the gap 26 the beam is further velocity varied.

In traversing the drift tube 29 the further velocity varied beam is substantially bunched or grouped by the action of the faster moving electrons overtaking the slower moving electrons to provide an effectively density modulated beam. In traversing the gap 27 of the output resonator 23 such density modulated beam is effective for exciting the output resonator 23. Electromagnetic energy may be coupled from the output resonator 23 to a load (not shown), by means of

7
the output coaxial transmission line terminal post 32.

After passing the gap 27 the spent electrons are collected on the conical surface 42 of the metallic block 41.

With such cascade bunching, it will be noted that the first two resonators 21, 22 are both effective for providing velocity modulation of the electron beam. The intermediate resonator 22 is excited into oscillation solely through the interaction of the electron beam therewith, with no electromagnetic energy being introduced therein from an external source. Resonators 21, 22 may be said to operate as a voltage amplifier and resonators 22, 23 may be said to operate as a power amplifier.

In the case of three resonator klystrons operated as an oscillator-buffer tube a small drift space between the second and third resonators is employed to prevent overbunching, inasmuch as the electrons are satisfactorily bunched at the second gap of an oscillator and additional bunching is undesirable. In the case of a three resonator tube, such as the electron discharge device of Fig. 1, additional bunching is desirable to achieve suitable amplification, thereby permitting the operation of the device with a relatively small magnitude of drive power. The bunching at the gap 26 will not be complete, but the additional bunching occurring in the drift tube 29 will result in optimum bunching at the gap 27 of the output resonator 23. In the event that maximum gain is desired, the axial lengths of the drift tubes 28, 29 are made substantially equal.

With such cascade bunching it is preferable that the intermediate resonator 22 be provided with a relatively large magnitude of shunt resistance. Under such circumstances the resultant small current variation in the electron beam during its interaction with resonator 22 will be effective for developing a relatively large radio frequency voltage across the gap 26. Where it is possible to develop a sufficiently large magnitude of voltage across the gap 26 of the intermediate resonator 22 by means of a relatively low current variation in the electron beam, a corresponding relatively low magnitude or drive voltage is required.

In order to achieve substantial bandwidth, which is an important consideration in the production of steep-sided or steep-edged pulses, it has been found advisable to design the intermediate resonator 22 with a relatively low Q , which may be defined as follows:

$$Q = \frac{R_{sh}}{\omega L} = R_{sh} \omega C \quad (1)$$

Where R_{sh} is the shunt resistance, ω is the angular operating frequency, L is the inductance and C is the capacitance. It is the Q of the intermediate resonator 22 which is important for determining the overall Q of the electron discharge device. It is apparent that the Q of the intermediate resonator should have a relatively small magnitude in view of the following relationship:

$$BW = \frac{f}{Q} \quad (2)$$

where BW is the bandwidth, and f is the operating frequency.

From Equation 2 it is apparent that the bandwidth may be increased for a given operating frequency by employing a smaller magnitude of

Q . From a consideration of Equation 1 it appears that the Q may be reduced by employing a smaller magnitude of capacitance. To this end, the diameter of the gap 26 of the intermediate resonator 22 is made smaller than the diameter of the gaps 24, 27 of resonators 21, 23, respectively. Stated somewhat differently, the diameter of the gaps 24, 27 of the end ones of the resonators 21, 23 is larger than the diameter of the gap 26 of the intermediate resonator 22. By reducing the Q of a resonator, such as intermediate resonator 22, it is apparent from a consideration of Equation 1 that the shunt resistance will correspondingly be reduced in view of the fact that these quantities are directly proportional.

As pointed out previously, in order to achieve the effective cascade bunching it is advisable that the intermediate resonator 22 be provided with a relatively large magnitude of shunt resistance. However, it has been found possible to reduce the magnitude of the capacitance of the intermediate resonator 22 and at the same time obtain a sufficiently high magnitude of shunt resistance for this resonator 22 to obtain efficient cascade bunching. In addition, the electron discharge device is provided with an appreciable bandwidth, which permits the generation of steep-sided radio frequency pulses. Such pulses owing to the high density of the electron beam have a considerable magnitude of power.

The shunt resistance of a resonator, such as intermediate resonator 22, is constituted of transit time electron loading, slow secondary electron loading and radio frequency circuit losses. With regard to transit time electron loading, electrons require a finite time to traverse a resonator gap, such as gap 26 and, consequently, load the resonator 22. It is possible to reduce transit time electron loading by decreasing the gap transit angle.

With regard to slow secondary electron loading, primary electrons impinging upon the grid structures, such as grids 63, 64, cause the emission of secondary electrons. With the emission of such secondary electrons having substantially zero velocity, there is present in the radio frequency field of the resonator gap, such as gap 26, spurious or secondary electrons during several cycles of the radio frequency energy. Such spurious electrons leave the gap 26 in random phase, thereby extracting energy from the electromagnetic field. Such loading is proportional to the current intercepted at the resonator grids, such as grids 63, 64, and to the secondary emission coefficient of the grid material. This loading is also inversely proportional to the square of the gap transit angle for the beam electrons. Accordingly, it appears that by increasing the gap transit angle, secondary electron loading may be reduced.

With regard to the radio frequency circuit losses of the resonator 22, such losses are inversely proportional to the spacing of the gap 26, while the coefficient of coupling between the radio frequency field at the gap 26 and the electron beam passing therethrough decreases as the gap spacing is increased. Consequently, in order to provide a suitable resonator, such as resonator 22, it is essential to select its dimensions in view of all of the foregoing considerations.

While, generally speaking, all of the resonators 21-23 are tuned to the same resonant frequency, it is possible to increase the power output of the electron discharge device by detuning the

second or intermediate resonator 22 slightly to the high frequency side of the resonant frequency of the input and output resonators 21, 23 and by increasing at the same time the magnitude of the drive power supplied to the input resonator 21 through its associated terminal post 31.

In the absence of such detuning an improvement in the electron bunching phenomenon results owing to the fact that at the gap 27 of the output resonator 23 the electrons are more highly grouped or, stated differently, fewer electrons are present intermediate the bunches. However, under such circumstances the radio frequency field developed in the intermediate resonator 22 may be said to lag by 90° an electron which is at the center of a bunch. Such an electron which has traversed the gap 24 at a time when the radio frequency field in the input resonator 21 was zero and increasing may be subjected to more effective further velocity modulation by traversing the gap 26 of the intermediate resonator 22 at a time when the radio frequency field in the intermediate resonator 22 similarly is zero and increasing. Such a condition may obtain when the intermediate resonator 22 is tuned to the high-frequency side of resonance, with the result that there is a higher component of radio frequency current in the electron beam. By detuning the second resonator 22 an improvement in the phase relationship of the radio frequency voltages developed across the gap 27 of the output resonator 23 results. In this manner the most effective cascade bunching occurs with maximum power developed in the output resonator 23.

In order to achieve an output power in excess of that which would occur, for instance, by use of cascade bunching, the electron discharge device of Fig. 1 is made to cooperate with and maintain a high density electron beam having a substantially apically conjugate conoidal configuration. While the electron beam might be described as having a hyperboloid configuration, it is deemed advisable to avoid the somewhat rigorous mathematical connotation that might attach to the latter term. To achieve efficient operation with such an electron beam shape, the walls of the drift tubes 28, 29 are formed to converge toward the second velocity modulation means or intermediate resonator 22. In this manner, the walls of the drift tubes 28, 29, while being spaced from, follow the envelope of the electron beam. Thus, the drift tubes 28, 29 which couple the resonators 21, 22 and resonators 22, 23, respectively, are provided with oppositely tapered configurations.

By virtue of the high density electron beam of the aforementioned conoidal shape, a large magnitude of output power is developed in the catcher resonator 23 with an electron discharge structure which is axially or longitudinally compact. In addition, there is no necessity for the provision of any external magnetic energizing structure. In order to form a suitable high density beam prior to its action with the gap 24 of the input resonator 21, electrostatic field forming means, such as focusing electrode 18, are provided. To maintain the electron beam throughout its transit of the modulation system, including resonators 21-23, means are provided for maintaining the electron beam in a substantially apically conjugate conoidal configuration, which last-named means may include the previously-discussed spaced charge focusing means.

Where it is advisable to discuss jointly the action of the focusing electrode 18 and the space charge focusing means, which may include, for instance, the converging configuration of the drift tubes 28, 29, it is convenient to regard the focusing electrode 18 as being effective for forming a high density electron beam and the space charge focusing means as being effective for maintaining the electron beam in a substantially conoidal configuration.

It is frequently convenient to speak of the size of the electron-permeable regions or apertures 24, 26 and 27 of the resonators 21-23, respectively. Such apertures 24, 26 and 27 extend longitudinally through the resonators 21-23 along the longitudinal axis 11 of the device of Fig. 1. It will be noted that the size of such apertures 24, 26 and 27 may be defined in terms of the cross-sectional area of their sections taken at right angles to the longitudinal axis 11. With a circular aperture 24, 26 and 27 as shown (Fig. 1) the dimensions thereof may be defined in terms of the diameters.

By reason of the structural arrangement of the gaps 24, 26 and 27, the magnitude of the capacitance of the intermediate resonator 22 is less than the magnitudes of the capacitances of the end ones of the resonators 21, 23.

While the focusing electrode 18, which is similar to that disclosed in the aforementioned application Serial No. 81,480, is particularly suitable for forming a high density electron beam and cooperating with the remainder of the structure of the device of Fig. 1, it will be understood that other electron beam forming arrangements might be employed. For instance, if desired, a focusing electrode constituted of a surface of complex configuration, and suitable for providing a zero voltage gradient perpendicular to the edge of the electron beam might be employed.

While the electron discharge device of Fig. 1 has been shown as constituted substantially of a figure-of-revolution about the longitudinal axis 11, it will be understood that a device could be formed with a longitudinal axis extending parallel to the axis 11 and positioned exterior of the cross-sectional structure of Fig. 1. Moreover, the longitudinal cross-sectional view of Fig. 1 might be regarded substantially as a figure-of-translation, in which case an elongated strip-type cathode could be employed together with a focusing electrode, such as described in the aforementioned application Serial No. 81,480.

Referring to Figs. 2 and 3, an alternate embodiment for the electron collecting means, including the block 41, of the device of Fig. 1 is shown. A metallic member or block 58 is provided with means, including the end portion 59 of the block 58, for collecting electrons of an electron beam having a substantially apically conjugate conoidal configuration. More specifically, the end portion 59 of the block 58, which portion 59 faces the cathode button 12, is provided with a toothed configuration in cross section. Each tooth member 60, with the exception of the central one, is formed with a right-triangular shape, such that the leg closest to the longitudinal axis 11 extends parallel thereto.

The arrangement of the portion 59 is particularly suitable for collecting spent electrons of a beam of the aforementioned conoidal configuration without permitting spurious electrons, such as those arising from secondary emission, from traversing the gap 27 of the output resonator 23. Such spurious electrons will act to impair the

11

operating characteristics of the electron discharge device.

Referring to Fig. 4, an enlarged cross-sectional view of exit grid 62 of the input resonator 21 is shown. Grid 62 is formed with a plurality of V-shaped members or vanes 68 and a plurality of J-shaped members or vanes 69, with each of the V-shaped members 68 substantially surrounding a J-shaped member 69. A J-shaped member 69 is additionally positioned between the V-shaped members 68.

Both the V-shaped members 68 and the J-shaped members 69 are preferably formed of a ribbon-type material to provide a vane-type structure with the wider dimension extending parallel to the longitudinal axis 11. In addition, the V-shaped members 68 are preferably formed of a metallic ribbon which is thinner than the ribbon employed for the J-shaped members 69 so that fewer electrons are intercepted thereby.

At the same time it is advisable to provide a more rigid type construction for these members 68 in view of the fact that they extend for a greater distance than the J-shaped members 69. This is accomplished by the V-shaped construction in that the two leg portions of the members 68 are continuous in the region of the center of the grid 62. In connection with the J-shaped members 69, it has been found preferable to employ the J-shaped configuration as contrasted, for instance, with a V-shaped configuration so that a minimum electron beam interception area is presented to the electron beam. This is particularly important in view of the fact that the electrons in the outer region of the grid 62 are traveling in paths which are less parallel with respect to the longitudinal axis 11 than electrons in the central region of the grid 62. Consequently, such outer region electrons would be presented with a larger intercepting area in the event that a grid element, such as members 69, was formed with a V-shaped configuration.

Dimensions for the members 68, 69 may be as follows: member 68, 69 may be formed of ribbons having thicknesses of 0.003 and 0.005 inch, respectively, while both members 68, 69 may be formed of ribbons having widths of .062 inch. Such dimensions, it will be understood, are merely illustrative and are not to be construed in a limiting sense.

The entrance grids 61, 66 of resonators 21, 23, respectively, may have the same construction as grid 62 of resonator 21. The exit grid 67 of the catcher resonator 23 may be formed with the same general configuration as that of grid 62, but it will be noted that grid 67 is of larger diameter.

Referring to Fig. 5, an enlarged view of the exit grid 64 of resonator 22 is shown. Grid 64 is constituted of a plurality of J-shaped members or vanes 71. The J-shaped construction for the members 71 provides a minimum of electron beam intercepting area in the central region of the grid 64. The entrance grid 63 of the intermediate resonator 22 is similarly formed.

Referring to Fig. 6, an enlarged view of the cathode structure of the electron discharge device of Fig. 1 is shown. For the thermal energization of the electron emitter 12, there is positioned therebeneath a heater 72, which may preferably be formed of tungsten wire. Electrical energy may be coupled to the heater 72 by means of input leads 73, 74, which galvanically contact the ends of the heater 72 through leads 76, 77,

which may be formed preferably of molybdenum. The upper portions 78, 79 of the input leads 73, 74, respectively, may be formed preferably of copper while the lower portions 81, 82, respectively, may be constituted preferably of nickel.

While for purposes of electrical conduction, copper is a particularly suitable material, it is also an excellent thermal conductor. Accordingly, to prevent the excessive dissipation of heat endwise of the electron discharge device, it has been found preferable to employ a less highly thermal conducting material for the lower portions 81, 82 of the input leads 73, 74, respectively. It will be understood that the input leads 73, 74 may be formed of a single material, such as copper, nickel or other suitable electrically conducting material.

In order to direct toward the cathode button 12 and prevent the escape in the direction of the input leads 73, 74, the heat developed by the heater 72, heat shields 83 are positioned therebeneath and supported by a heat shield supporting rod 84, which in turn is rigidly secured to the platform 86. The upper portions 78, 79 of the input leads 73, 74, respectively, are also positioned and supported by the platform 86, with an insulative member 125 together with its associated clamp 130 interposed between upper portion 79 of the input lead 74 and the platform 86. The cathode button 12 is supported by the platform 86 by means of a cylindrically-shaped cathode supporting member 87, which is provided with a flange portion 88. Screws 89 positioned in suitably cooperating apertures in the platform 86 and the flange portion 88 are effective for accomplishing the desired result. The upper end of the cathode supporting member 87 is rigidly secured to the lower surface of the cathode button 12, as by welding.

Additional heat shields 91, 92, positioned substantially coaxially with respect to the longitudinal axis 11, are spaced from one another and sleeve 14 and, in addition, supported by struts 93, 94.

Sleeve 14 is fastened to an apertured disc 96 by means of screws 97. A tube 98 is provided with a shoulder 99 to suitably position and support insulating member 101, which in turn serves to position and additionally support the input leads 73, 74. Plate 49 is connected to the end plate 102 by means of sleeves 103, 104, which sleeves 103, 104 are interconnected by a tubularly shaped insulating member 106. In view of the fact that the parts 49, 102—104 and 106 define a portion of the vacuum envelope of the electron discharge device, the interconnections thereof are formed in a vacuum tight manner.

The tube 98 is also supported by end plate 102. Sections of the lower portions 81, 82 of the input leads 73, 74 are surrounded by tubular members 107, 108 which are interconnected by means of vitreous insulating members 109, in a vacuum-tight manner. Rings 111 are provided at the lower end of the tubular portions 108. The connections between the end plate 102, the tubular members 107, the insulating members 109, the tubular members 108, rings 111 and the respective input leads 73, 74, similarly provide vacuum-tight joints. The operation of the device of Fig. 6 will be discussed hereinbelow in connection with the operation of the circuit of Fig. 7.

Referring to Fig. 7, there is shown the cathode button 12' and the heater 72' in schematic form, with these parts joined together electrically as shown in Fig. 6 where the cathode button 12 is

13

connected to the input lead 73 through the cathode supporting member 87 and the platform 86. A filament transformer 112 is arranged with its primary winding 113 and secondary winding 114 interconnected by means of lead 116, with a condenser 117 disposed across the secondary winding 114. In the primary winding 113 of the filament transformer 112 there is arranged a pulsing transformer 118 by means of which electrical impulses emanating from a pulse generator 119 may be impressed upon the cathode button 12, 12'. To couple electrical or heater power to the filament transformer 112, an additional transformer 121 is provided with an indicating meter 122 extending between the secondary winding of the further transformer 121 and a point maintained at ground potential. A bypassing condenser 123 is shunted across the indicating meter 122.

During operation, the electrical energy for supplying the heater 72 may be continuously delivered thereto through the transformers 112 and 121. Suitable pulses may be impressed upon the cathode 12 by means of the pulse generator 119 and the pulsing transformer 118. In view of the fact that the main body of the device, including the resonators 21-23, and, more particularly, the anode or accelerating electrode 19 are preferably maintained at ground potential, the potential of the cathode 12, 12' is reduced during such times as an energy interchange between an electron beam and the resonators 21-23 is desired. Thus, pulses are introduced by means of pulse generator 119 having a repetition rate and pulse length depending upon the type of ultra high frequency output pulses, which it is desired to obtain from the output coaxial line terminal post 32.

To complete the electrical circuit of the electron discharge device, a lead 115 extends from the main body of the device (Fig. 1), as for instance the tubular member 51, to a point of ground potential thereby maintaining the envelope of the device at ground potential. In addition, lead 120 (Fig. 1) interconnects the electron collector, including metallic block 41, with the main body of the device of Fig. 1. It will be noted that there is no provision for the internal connection of these parts.

Owing to the construction of the cathode assembly (Fig. 6) it is possible to apply a potential to the focusing electrode 18, which is different from that applied to the cathode button 12, 12'. A suitable focusing electrode potential may be applied to the end plate 102. Such an arrangement is useful for exploring the operating characteristics of the device of Fig. 1. In view of the fact that it is possible to operate the focusing electrode 12 at the same potential as the cathode button 12, the insulating member 106, the insulative member 125 together with its associated clamp 130, the platform 86, screws 89, and the cathode supporting member 87 may be eliminated. Under such circumstances the cathode button 12 may be supported by members extending between its periphery and the lower surface of the apertured cup 13. In addition, the heat shields 83 may be supported by members securing such shields 83 to the additional heat shield 91.

It is possible to construct the discharge device of Fig. 1 in such a manner as to eliminate the necessity for an external lead, such as lead 120, interconnecting the tubular member 51 and the sleeve 54. Under such circumstances the vitreous tubular member 57 may be dispensed with, with members such as sleeves 54, 56 being integral. As

14

arranged (Fig. 1) the magnitude of the current of the spent electron beam, which is collected by the metallic block 41, may be conveniently measured.

Referring to Fig. 8, an enlarged view of the coaxial transmission line terminal post 31, 32 is shown. These posts 31, 32 are formed with a hollow rod 124 preferably made of an electrically conductive material, which may effect a suitable vacuum-tight glass seal, such as Kovar. Extending between the rod 124 and a flanged tube 126 is a vitreous member 127, with the flanged portion 128 of the tube 126 connected to the tube 129. A coupling loop 131 is secured, as by soldering or brazing, to the ends of the rod 124 and the tube 129. Surrounding the tube 129 is a sleeve 132. The interconnections of the rod 124, vitreous member 127, flanged tube 126, tube 129, and sleeve 132 are effected in a vacuum-tight manner to insure the preservation of the internal vacuum of the electron discharge device. To the same end, sleeve 132 is connected to the side walls of the resonators 21, 23 in a vacuum-tight manner.

A tubular member 133 is secured to the tube 129 and in turn serves to support and position the stepped-diameter member 134 as well as the conductive member 136 through the action of the insulative support 137, with screw 138 being effective for joining members 134, 136. An additional tubular member 139 is rigidly secured to the tubular member 133.

Typical operating conditions for the electron discharge device of Fig. 1 at a frequency of 1200 megacycles per second and with a beam accelerating voltage applied between the cathode button 12 and the anode 19 include the following: an output power of 10 kilowatts with a duty cycle of .01 and a pulse length of 2.5 microseconds. For such operation a drive power of 40 watts and a beam current of 4.3 amperes is employed. It will be understood that such operating conditions are to be construed as illustrative and not in a limiting sense.

While the device of Fig. 1 is particularly useful for the generation of high power pulses with suitably steep-edged configurations, it is also possible to utilize the device for the generation of continuous waves.

It is apparent that many changes could be made in the construction of the device of Fig. 1 and that many apparently widely different embodiments of this invention could be made without departing from the scope thereof. For instance, as discussed hereinabove, the electron collector of Fig. 2 might be employed in the device of Fig. 1, the cathode assembly might be modified, and the device operated either as a pulse or continuous wave generator. Accordingly, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. High frequency apparatus comprising first, second and third cavity resonators, each of said resonators having an electron-permeable gap; a first drift tube positioned intermediate said first and second resonators, and a second drift tube positioned intermediate said second and third resonators, the inner walls of said drift tubes being tapered and converging toward the gap of said second resonator.

2. The high frequency apparatus as defined in

15
claim 1 wherein the lengths of said first and second drift tubes are substantially equal.

3. The high frequency apparatus as defined in claim 1 wherein the distance between the midpoint of the electron-permeable gap of said first cavity resonator and the midpoint of the electron-permeable gap of said second cavity resonator is substantially equal to the distance between the midpoint of the electron-permeable gap of said second cavity resonator and the midpoint of the electron-permeable gap of said third resonator.

4. The high frequency apparatus as defined in claim 1 wherein the cross-sectional area of the electron-permeable gap of said second cavity resonator is less than the cross-sectional area of the electron-permeable gaps of said first and third cavity resonators.

5. An electron discharge device comprising means for producing an electron beam, first, second and third cavity resonators, each of said resonators having an electron-permeable gap, said gaps being aligned along an axis and positioned for receiving and passing said electron beam in succession, the distance between the electron-permeable gap of said first resonator and the electron-permeable gap of said second resonator being substantially equal to the distance between the electron-permeable gap of said second resonator and the electron-permeable gap of said third resonator, the cross-sectional area at right angles with respect to said axis of said gap of said second resonator being smaller than the cross-sectional area at right angles with respect to said axis of said gaps of said first and third resonators.

6. An electron discharge device comprising three cavity resonators, each of said resonators having an electron-permeable gap, said gaps being substantially aligned along an axis, means including a cathode located along said axis for producing and projecting an electron beam along said axis successively through said gaps in energy-exchanging relation with said resonators, said electron beam having a diminished cross-sectional area within said electron-permeable gap of the intermediate one of said resonators and having a larger cross-sectional area within the electron-permeable gaps of the end ones of said resonators, each of said gaps of the end ones of said resonators having a larger cross-sectional area at right angles relative to said axis than that of said gap of the intermediate one of said resonators.

7. High frequency apparatus comprising means for producing an electron beam, a first cavity resonator, a first drift tube, a second cavity resonator, a second drift tube, and a third cavity resonator, all of said foregoing elements being aligned along an axis and located in axial consecution, all of said resonators being provided with substantially circular apertures for receiving and passing said electron beam, the diameter of said aperture of said second resonator being smaller than the diameters of said apertures of said first and third resonators, the walls of said drift tubes being tapered in the direction of said aperture of said second resonator, whereby a space charge focused electron beam is formed having a substantially apically conjugate conoidal configuration.

8. The invention set forth in claim 7, further including a collector electrode in the path of said beam beyond said third cavity resonator, said

electrode including a surface facing said resonator and provided with a plurality of substantially concentric and approximately co-planar grooves, said grooves having in cross section a substantially right triangular shape, with the hypotenuse diverging outward from the central axis of the structure in the direction of said beam.

9. In an ultra high frequency velocity modulation device, an electron source, electrostatic field forming means for initially converging the electrons emanating from said source to form a high density beam, the cross-sectional area of said high density beam of electrons converging to a minimum value at a predetermined point along the path of said beam and diverging beyond said predetermined point, and three cavity resonators having electron-permeable portions aligned along the path of said beam to be successively traversed by said high density beam, the electron-permeable portion of the intermediate one of said resonators being situated along the path of said beam at said predetermined point and being of smaller cross-sectional area than the electron-permeable portions of the others of said resonators.

10. An electron discharge device comprising cathode means for producing an electron stream directed along an axis; and first, second, and third resonators located successively along said axis and each having an electron-permeable portion aligned with said cathode along said axis; said cathode means including a focusing electrode extending toward said resonators comprising means for causing the electrons of the electron stream to converge to a minimum cross-sectional area within the electron-permeable portion of said second resonator, said electron stream diverging along said axis beyond the electron-permeable portion of said second resonator.

11. The apparatus of claim 10, wherein the cross-sectional area of the electron-permeable portion of said second resonator at right angles with respect to said axis is smaller than the cross-sectional areas of the electron-permeable portions of said first and third resonators.

12. The apparatus of claim 11 further including a first drift tube located intermediate said first and second resonators, and a second drift tube located intermediate said second and third resonators, said drift tubes being tapered and converging toward said second resonator.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,136,610	Colby	Nov. 15, 1938
2,316,276	Motz	Apr. 13, 1943
2,394,396	Mourmtseff	Feb. 5, 1946
2,399,752	McCullough	May 7, 1946
2,407,707	Kilgore	Sept. 17, 1946
2,413,725	McNally	Jan. 7, 1947
2,422,695	McRae	June 24, 1947
2,464,349	Samuel	Mar. 15, 1949
2,466,704	Harrison	Apr. 12, 1949
2,469,843	Pierce	May 10, 1949
2,475,652	Varian et al.	July 12, 1949
2,480,133	Hansen	Aug. 30, 1949
2,498,673	Goudet et al.	Feb. 28, 1950
2,544,675	Hamilton	Mar. 13, 1951

FOREIGN PATENTS

Number	Country	Date
606,801	Great Britain	Aug. 20, 1948