

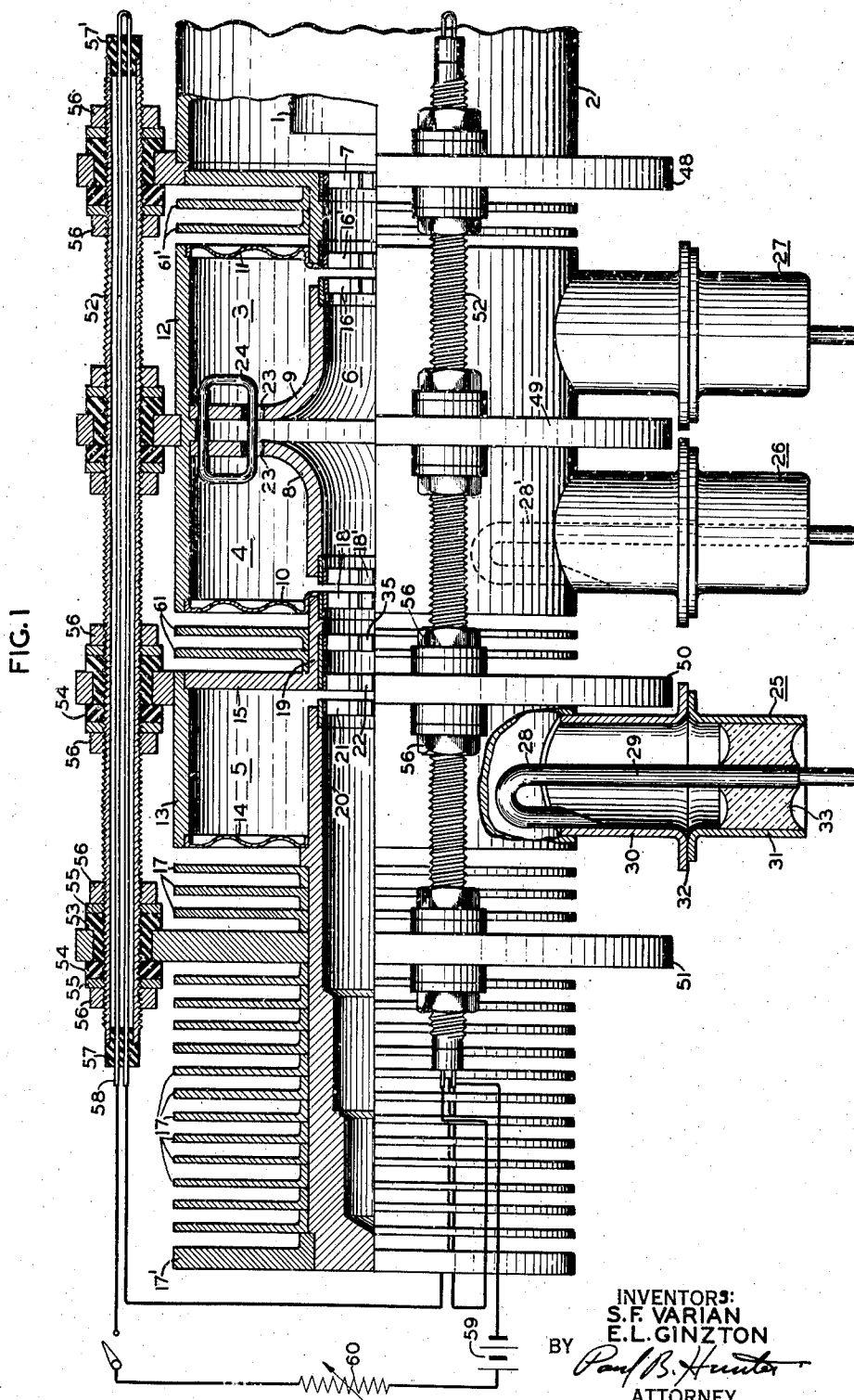
July 12, 1949.

S. F. VARIAN ET AL
HIGH-FREQUENCY TUBE STRUCTURE

2,475,652

Filed Aug. 3, 1942

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

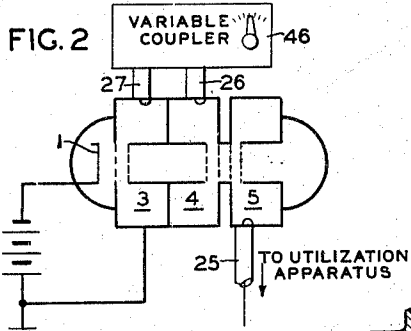


FIG. 3

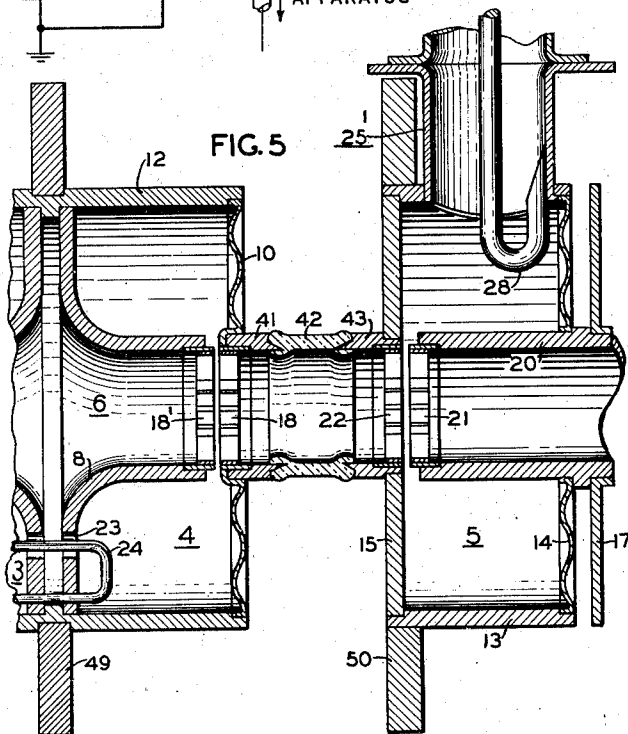
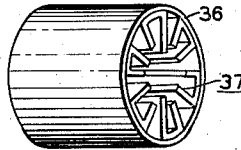
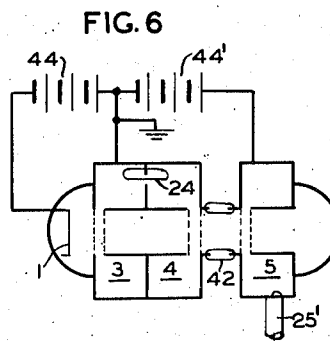
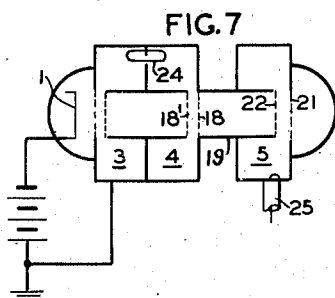
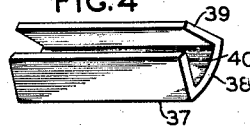


FIG. 4



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2,475,652

HIGH-FREQUENCY TUBE STRUCTURE

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Application August 3, 1942, Serial No. 453,482

19 Claims. (Cl. 315-6)

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This invention relates, generally, to ultra high frequency electron beam velocity grouping tubes, and, more specifically, to improvements in oscillator or amplifier types of high frequency tubes of the general type disclosed in copending application Serial No. 420,771, entitled "High-frequency tube structures," filed November 28, 1941, and now U. S. Patent No. 2,450,893, issued October 12, 1948, in the names of William W. Hansen and John R. Woodyard, in which velocity grouping tubes utilizing "buncher" and "catcher" resonators as well as a third resonator serving as a buffer stage are described.

The purpose of the addition of this buffer resonator was to provide a more or less electromagnetically independent resonator from which large and variable amounts of high frequency energy might be extracted without adversely reflecting back into the prior resonators and thereby altering the output frequency of the tube. In this type of tube this result has been to a large extent accomplished since the only electromagnetic coupling between the buffer resonator and the earlier resonators is along the interconnecting electron stream itself.

One object of the present invention is to provide means in a tube structure of the above type for reducing still further the undesirable electromagnetic coupling between the buffer stage and the earlier stages, thereby increasing the frequency stability of the output under varying loads.

An object of the invention is to provide a novel coaxial terminal for extracting high frequency energy from the resonator, so designed as to eliminate the danger of cracking the glass to metal seal during attachment of the coaxial terminal to the resonator.

Another object of the invention lies in the provision of external variable coupling means between "buncher" and "catcher" resonators in order to obtain optimum "bunching" of the electron beam at the buffer amplifier resonator for various operating conditions by a simple adjustment.

A further object is to provide a novel high frequency electron beam velocity grouping vacuum tube in which natural cooling is readily and uniformly effected over a large portion of the length of the tube.

A still further object lies in the provision of a three-resonator tube in which energy may be simultaneously extracted from any combination of the three resonators.

Other objects and advantages will become ap-

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parent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 is a fragmentary partial cross-section elevation view of a preferred form of the present invention.

Fig. 2 is a schematic block diagram of an alternate form of the device shown in Fig. 1.

Fig. 3 is a perspective view of an alternate form of a detail of Fig. 1.

Fig. 4 is a perspective view of a detail of Fig. 3.

Fig. 5 is a fragmentary cross-section view of an alternate form of the invention.

Fig. 6 is a schematic block diagram of the device shown in Fig. 5.

Fig. 7 is a schematic block diagram of an alternate form of the invention.

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

Referring now to Fig. 1, there is shown an electron beam velocity grouping vacuum tube consisting of an indirectly heated oxide coated cathode 1 placed axially in an end bell jar 2 in front of a smoothing or accelerating grid 7, grid 7 forming an entrance into axially spaced resonators 3, 4 and 5. Resonators 3 and 4 are formed by a conducting tubular outer wall 12, flexible end diaphragms 10 and 11, and flared inner conducting tubes 8 and 9, which cooperate to form electron beam drift space 6, and whose outwardly flared portions form a separating wall between resonators 3 and 4. Holes 23 are placed in the flared drift tubes 8 and 9 in order to accommodate coupling loop 24, opposite ends of which extend into resonators 3 and 4. Grids 16, 16' and 18, 18' are shown in resonators 3 and 4, respectively, through which the electron beam from emitter 1 is projected by a unidirectional acceleration voltage placed between cathode 1 and grid 7. A tube 19 projects from resonator 4, on which tube is mounted a rigid end plate 15 which, together with tubular outer wall 13, flexible end wall diaphragm 14, reentrant tube 20, and grids 21 and 22 form the buffer resonator 5.

Tube 20 extends past resonator 5 and the inner diameter of the tube decreases to zero in successive steps, and it has mounted on its exterior spaced circular cooling flanges 17. An end cooling flange 17' is made of greater thickness than flanges 17 in order to prevent damage thereto due to handling. Similar cooling flanges 61 and 61' are provided between resonators 4 and 5, and

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between resonator 3 and end bell jar 2, respectively.

Resonators 3, 4 and 5 are provided with similar concentric line structures 25, 26 and 27 for the removal or introduction of energy from or into any one or any combination of these respective resonators. These concentric line devices consist of an inner conducting rod 29 terminated inside of the resonator by a coupling loop 28, which joins directly to the inner wall of a tubular outer conductor 30, whose inner surface is preferably plated with a highly conducting material such as copper or silver. In construction, inner conductor 29, whose outer surface is also preferably plated with a highly conducting material, is sealed by glass to metal end seal 33 concentrically in a short flanged tubular outer conductor 31. The tube 30 is silver-soldered in position in the resonator wall 12 or 13, and the structure 29, 31, 33 is inserted into tube 30 and spot-welded at 32. The end of loop 28 and the inner wall of tube 30 adjacent thereto have been previously tinned with a soft solder, so that the application of a slight amount of heat to the exterior of tube 30 near its point of contact with loop 28 completes the electrical junction. Thus, a method of assembly of the concentric line structure is provided without exposing the glass to metal end seal 33 to the elevated temperatures necessary for silver-soldering tube 30 in place, thereby eliminating the danger of cracking seal 33 during attachment to a resonator. This method also eliminates oxidation of the inner surface of tubular conductors 30 and 31 and the outer surface of conductor 29, thereby preventing the increased impedance which would naturally result from such oxidation.

Flanges 48, 49, 50 and 51 are provided on end bell jar 2, outer conducting wall 12 of resonators 3 and 4, outer conducting wall 13 of resonator 5, and finned end tube 20, respectively, in order to transmit relative motion from the tuning device of this invention to the respective grids. Spaced directly oppositely on each of these four flanges at an angular separation of substantially 120° are three holes through which are inserted three rigidly clamped exteriorly threaded thin tubes or thermal struts 52, each of which extends parallel to the vacuum tube axis and projects slightly past flanges 48 and 51 at opposite ends. Each of the three thin tubes 52 is rigidly held at each flange in a thermally insulating clamp, each clamp consisting of an insulating bushing 53, insulating washer 54, and on opposite sides of the flanges, two metal washers 55 and two metal nuts 56. The ends of the thin tubes 52 are closed by apertured insulating plugs 57, 57', through which heater wires 58 extend. Heater wires 58 run the length of the tube 52 and may be supported therein by a powdered insulating material such as magnesium oxide, or may be supported only by the end plugs 57, 57'. The ends of heater wires 58 in each of the three thin tubes 52 are connected in series by the leads shown and supplied with current controlled by a rheostat 59 from battery 59. If desired, the inner and outer surfaces of tubes 52 may be treated in any well known manner, as by coating the same with a reflecting material, to increase or decrease thermal radiation from their surfaces.

In operation, the electron beam from cathode 1 is accelerated successively through grid 7, grids 16, 16' of resonator 3, grids 18, 18' of resonator 4, grids 21, 22 of resonator 5, and finally impinges upon the inner wall of end tube 20. Cou-

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pling loop 24 may be adjusted so that the electrons arrive between grids 18 and 18' of resonator 4 in a somewhat "under-bunched" condition, and do not obtain optimum "bunching" until they arrive between grids 21 and 22 of resonator 5. The location of these grids 21 and 22 at which the optimum bunching is obtained may be termed the "primary bunching point." Such an adjustment produces the result that resonator 4 is excited only so much as is necessary to properly excite resonator 3, while buffer resonator 5, from which it is usually intended to extract high frequency energy, is excited to the highest amplitude of oscillation possible.

As the dimensions chosen for loop 24 are suitable for only one set of operating conditions of the device, it may be preferable to dispense with this coupling loop 24 and utilize coaxial lines 26 and 27 for feed-back purposes, as shown in Fig. 2. Coaxial line 26 feeds energy back through a variable coupling or attenuation device 46, which may be of any suitable type, and through coaxial line 27 to "buncher" resonator 3. In this case, coupling loop 28' of coaxial line 26 may be made somewhat larger than loop 28 of line 25, so that the shunt impedance of resonator 4 is thereby reduced. This is desirable, as a lower shunt impedance of resonator 4 will result in the extraction of less energy from the "bunched" beam when it passes through resonator 4.

If coupling loop 24 is used in place of external coupling between resonators 3 and 4, the shunt impedance of resonator 4 may be reduced by connecting coaxial line 26 to a suitable load, i. e., a matched terminal loss device such as a radiating antenna or other energy sink device. Similarly, a load may be connected to coaxial line 27 of resonator 3. Thus, high frequency energy may be simultaneously extracted from any or all of resonators 3, 4 and 5.

As is well known, electron beam velocity modulating tubes are generally provided with flexible diaphragms, such as diaphragms 11, 10, 14 of resonators 3, 4, 5, respectively, of Fig. 1, in order to enable the changing of the distance between the respective resonator grids and thus enable individual or gang tuning of the resonance frequency of the resonators. Such tubes are also usually provided with flanges, such as flange 48 on end bell jar 2, flange 49 on resonators 3 and 4, flange 50 on resonator 5, and flange 51 on finned end tube 20, which normally cooperate with mechanical devices for obtaining the desired relative grid motions. In the case of two-resonator tubes, gang tuning devices of mechanical types such as those disclosed in prior application Serial No. 342,912, entitled "High-frequency tube structures" and filed June 28, 1940, in the names of William T. Cooke, Joe J. Caldwell, Jr., and David G. Clifford, have proved useful, but in the case of multi-resonator tubes, mechanical tuning becomes a complex problem for the following reasons. Referring to Fig. 1, if flange 50 is relatively fixed and used to support the tube, as from an apparatus panel, it is seen that for gang tuning, if flange 51 is moved one unit to the left, flange 49 must then be moved one unit to the right, and flange 48 must be moved two units to the right. A mechanical motion device to perform this function must necessarily be complex. Also, in gang tuning of multi-resonator tubes, which necessarily utilize long electron beams, there is the further requirement that the flanges must all be moved absolutely parallel to each other in order to preserve the alignment of the tube.

Referring to Fig. 1, it is seen that heat generated by current passing through heater wires 53 will cause uniform thermal expansion of the thin tubes 52, which in turn will produce equal parallel relative motion of the flanges 48, 49, 50 and 51. This motion of the flanges is transmitted to the grids, changing the relative spacing thereof, resulting in simultaneous tuning of all resonators. A further advantage of this novel system of gang tuning is that it may readily be adapted to a system of remote automatic frequency control by replacing battery 59 and rheostat 60 by any suitable voltage source which provides a current related to the desired output frequency. Initial individual tuning of the resonators 3, 4 and 5 is accomplished by mechanical adjustment of the nuts 56. This thermal type of tuning device may be equally well applied to single-resonator, or to two-resonator tubes, or to tubes having a plurality of resonators, wherever tuning by parallel motion of the resonator grids is necessary, or wherever electrically controllable remote tuning is desired. This gang tuning apparatus is claimed in divisional application Serial No. 544,730, filed July 13, 1944.

In many applications in which the present invention is useful, energy from the buffer resonator 5 is used in a load having great variability in time. Therefore it is desirable to prevent coupling between the buffer resonator 5 and the "catcher" resonator 4, since otherwise the amplitude variation resulting in the buffer resonator 5 due to the changing load will produce simultaneous frequency variations in resonator 4, and consequently in the output of resonator 5. Unless otherwise prevented, some degree of coupling between resonators 4 and 5 will exist due to looping of the fields extending externally from the grids 18 and 22.

In the present invention this undesirable coupling is materially reduced by the introduction of another grid 35 within the tube 19, similar to and preferably equidistant between grids 18 and 22, as shown in Fig. 1. If desired, the three grids 18, 35 and 22 may be replaced by a single axially elongated grid structure such as illustrated in Fig. 3, the structure consisting of a thin-walled tube 36 to which is spot-welded folded grid members 37, as shown in Fig. 4, consisting of a short grid partition 40, an arcuate portion 38 of outer diameter equal to the inner diameter of tube 36, and a long grid partition 39. Either method results in substantially eliminating electromagnetic coupling between resonators 4 and 5 due to the shielding action of the additional grid.

In general, coupling between resonators 4 and 5 can also be greatly diminished by increasing the length of tube 19, i. e., by increasing the distance between grids 18 and 22. This means of reducing the coupling has not heretofore been adopted because of the apparent necessity that grids 18 and 22 be kept close together in order that the electron stream, while being "bunched" to an optimum degree between buffer resonator grids 21 and 22, will also be fairly well "bunched" although somewhat unbunched when traversing the space between grids 18 and 18' of resonator 4.

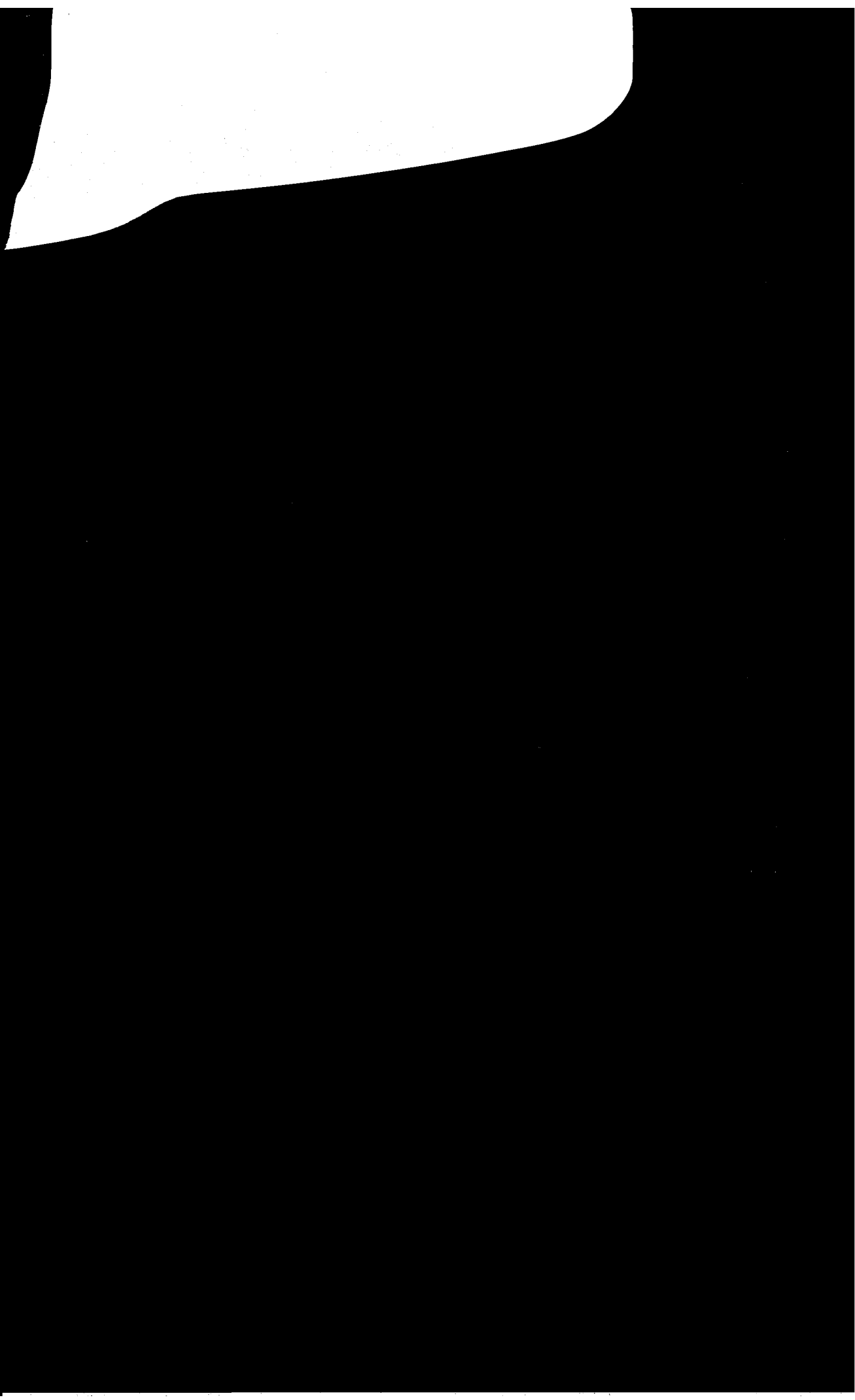
In detail in Fig. 5, and diagrammatically in Fig. 6, there is shown a method whereby coupling between resonators 4 and 5 is reduced by increasing the distance between grids 18 and 22, and the proper "bunching" of the electron beam at resonators 4 and 5 is nevertheless retained. Resonators 3 and 4 are shown similar to those of Fig. 1, the operation of this oscillator portion of

the tube being the same as that of the oscillator resonators 3 and 4 of Fig. 1. As may be seen in Fig. 6, the cathode 1 is supplied by a unidirectional voltage negative with respect to the grounded resonators 3 and 4, from a battery or other power source 44, while buffer resonator 5 is supplied from battery 44' with a voltage positive with respect to ground, which may be substantially equal to the voltage from the battery 44 or differing from the same. The potential difference maintained between resonator 4 and buffer resonator 5 necessitates the insertion of an insulating glass or ceramic tube 42 between resonators 4 and 5 and joined to them by glass to metal seals at 41 and 43, respectively.

Thus, the electron stream, upon emerging from grid 18 in a slightly "under-bunched" condition, is subjected to an additional accelerating voltage from battery 44'. Since the relative velocity between individual electrons in the stream has already been fixed by the degree of velocity modulation at the "buncher" resonator 3, the time interval required for optimum "bunching" to occur after leaving grid 18 will not be affected by the accelerating voltage 44'. However, the space interval required for obtaining optimum "bunching" after leaving grid 18 will be increased in proportion to the uniform increase in the velocity of the electron stream as a whole caused by the additional accelerating voltage 44'. The distance between grids 18 and 22 may, therefore, be increased, the additional accelerating voltage 44' acting to compensate for the increased distance between said grids, so that the correct "bunching" conditions of the electron stream are still maintained at each of said grids.

Another advantage obtained by splitting a definite electron beam accelerating voltage into two portions and introducing said portions at successive axial positions along the electron beam, as is done in Figs. 5 and 6, is that, since the velocity of the electron stream is lower, a smaller proportion of the input power is lost when electrons impinge upon the various grids, resulting in higher tube efficiency and a lessening of the cooling problem. Further, power supply design is simplified as the power supply for the device only needs insulation from ground for substantially half of the total driving voltage. Coaxial lead 25' must be supplied with a suitable capacity joint in order to insulate the voltage applied to resonator 5 from grounded utilization apparatus. Also, if the gang tuning device shown in Fig. 1 be used, it is necessary that the bushings 53 and washers 54 be made of material which is electrically as well as thermally insulating.

In Fig. 7 there is shown another method whereby the coupling between resonators 4 and 5 is reduced by separation of grids 18 and 22. As is well known, a velocity grouped electron beam, having travelled far enough to reach its optimum condition of "bunching," if allowed to continue its travel, will begin to "debunch" and, at a still farther point in its travel, will again become "bunched." This effect can continue indefinitely except for loss of beam current due to grids and due to radial and transverse scattering effects caused by mutual repulsion of the electrons themselves. In Fig. 7 there is shown a three-resonator tube in which grids 21 and 22 of buffer resonator 5 are placed at the second point of optimum "bunching." The tube 19 acts as a drift space for the electron beam, which may emerge from grid 18 in a slightly "under-bunched" condition and reaches optimum "bunching" shortly



point and coupled to said first resonator means for providing feedback of high frequency energy to sustain said velocity modulation, third cavity resonator means in the path of said stream beyond said bunching point and separated from said second cavity resonator means sufficiently to prevent undesired inherent coupling between said second and third cavity resonator means, and a source of accelerating voltage connected between said second and third cavity resonators for accelerating the electrons of said stream to shift said bunching point to the location of said third cavity resonator means.

8. A high frequency tube structure comprising a plurality of resonators, electronic means for projecting an electron beam through said resonators in succession, coupling means coupled to said resonators for coupling the fields of the first and second of said resonators whereby the first of said resonators acts to recurrently change the velocity of electrons passing therethrough, which electrons become partially bunched before passing through the second of said resonators, thereby serving to drive such resonator, the third of said resonators being coupled to the second resonator solely by said electron beam and being adjacent to said second resonator whereby undesirable inherent coupling between said second and third resonators exists, and shielding means interposed between said second and third resonators for preventing coupling of their fields.

9. High frequency electron discharge tube structure, comprising means for producing an electron stream, first, second and third cavity resonator means mounted consecutively along the path of said stream, coupling means connected between said first and second resonator means for providing feedback of energy therebetween, means coupled to said third resonator means for extracting high frequency energy therefrom, means defining a first field-free drift space between said first and second cavity resonator means, means defining a second field-free drift space between said second and third cavity resonator means, said second drift space being too short to prevent undesired inherent coupling between said second and third cavity resonator means, and means within said second drift-space-defining means for preventing said undesired coupling between said second and third cavity resonator means, whereby variations in the load supplied by said third cavity resonator means are substantially ineffective to affect the oscillation frequency of the oscillating system including said first and second cavity resonator means.

10. Apparatus as in claim 9, wherein said coupling-preventing means comprises a grid mounted within said second drift space defining means between said second and third cavity resonators.

11. Apparatus as in claim 9, wherein said coupling-preventing means comprises an elongated grid structure within said second drift-space-defining means and extending substantially completely between said second and third cavity resonator means.

12. A high frequency tube structure comprising a plurality of resonators, electronic means for projecting an electron beam through said resonators in succession, coupling means for coupling the fields of the first and second of said resonators whereby the first of said resonators acts to recurrently change the velocity of electrons passing therethrough, which electrons become partially bunched before passing through the second of said resonators, thereby serving to drive

such resonator, the third of said resonators being coupled to the second resonator solely by said electron beam, said third resonator being positioned at a secondary bunching point of said velocity-varied electron stream whereby undesirable coupling between said second and third resonators is substantially prevented by their separation without impairing efficient extraction of energy from said third resonator.

13. High frequency apparatus comprising means defining a resonator chamber adapted to contain an oscillatory electromagnetic field, means defining a second resonator chamber also adapted to contain an oscillatory electromagnetic field, means for projecting an electron beam through said first resonator and into said second resonator in energy exchanging relation with said fields, said resonators being closely adjacent so that undesirable inherent coupling exists therebetween, and means for substantially isolating the electromagnetic fields of said resonators from each other so that load disturbances in said second resonator will not be effective on the field in said first resonator, said isolating means comprising electrode means between said resonators in the path of said beam.

14. The apparatus defined in claim 13, wherein said isolating means comprises grid means located between said resonators and in the path of the electron beam.

15. High frequency tube structure comprising means for producing an electron stream and a hollow cup-shaped collector electrode for receiving said stream, the interior of said electrode comprising a plurality of substantially cylindrical stepped wall sections decreasing in diameter in the direction of flow of said stream.

16. High frequency tube structure comprising means defining a cavity resonator adapted to contain an oscillatory electromagnetic field, means for projecting an electron beam through said field, an electron permeable electrode in a wall of said resonator, and a plurality of heat dissipating discs connected to said electrode and extending substantially radially of the path of said electron beam, the planes of said discs being parallel to each other and the axis of said discs being coincident with the axis of said electron beam.

17. High frequency electron discharge apparatus comprising means for producing an electron stream, first, second and third cavity resonator means in the path of said stream and tuned to substantially the same frequency, means coupling said first and second resonator means to provide feedback of energy therebetween, and means coupled to said third resonator means, for extracting output energy from said third resonator means, said second resonator means having lower shunt impedance than said first and third resonator means, whereby more efficient energy output may be derived from said third resonator means.

18. Apparatus as in claim 17, wherein said coupling means comprises a coupling loop within said first resonator means, a second coupling loop within said second resonator means, and high frequency energy-conducting means coupling said two coupling loops, said second coupling loop having larger area than said first coupling loop, whereby the shunt impedance of said second resonator means is lower than that of said first resonator means.

19. High frequency tube structure comprising means for producing an electron stream and a

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hollow cup-shaped collector electrode for receiving said stream, the interior of said electrode comprising a plurality of substantially cylindrical stepped wall sections decreasing in diameter in the direction of flow of said stream, said stepped wall sections being connected by tapered transition sections and the smallest of said cylindrical section having a tapered conical end section.

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