Dec. 5, 1950 R. WARNECKE ET AL 2,532,796

VELOCITY MODULATION ELECTRONIC VALVE

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Fig.1

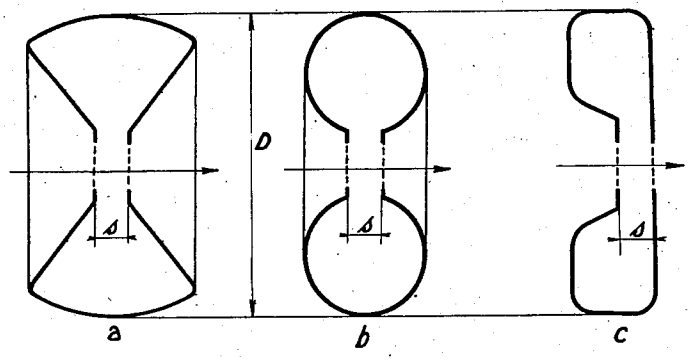

Fig.2

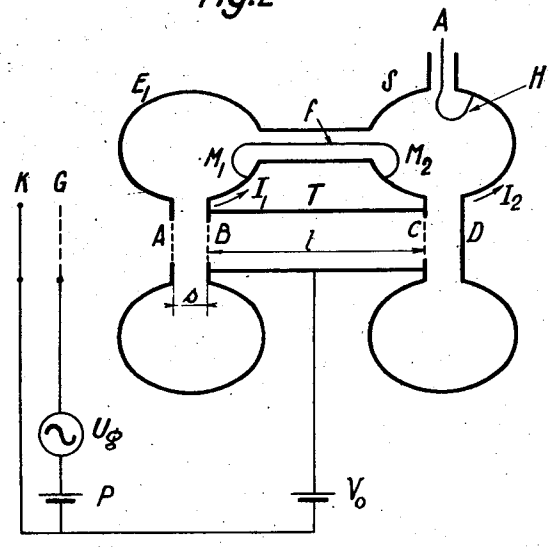

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Fig.3

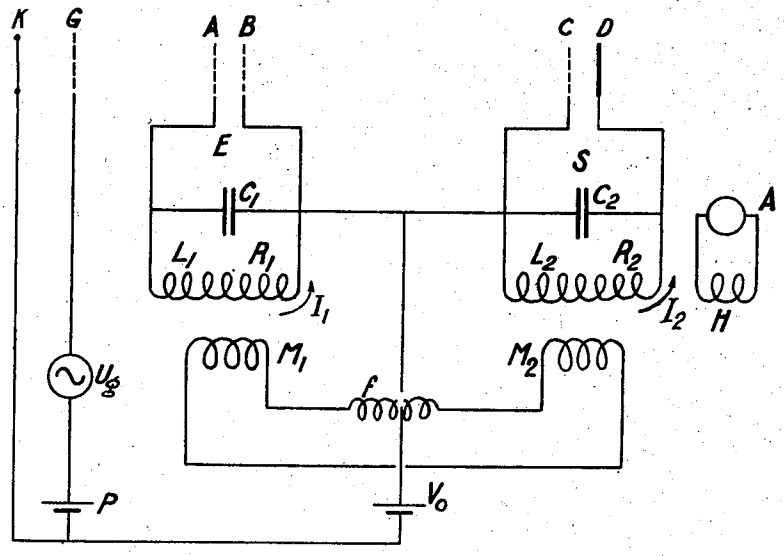


Fig.4

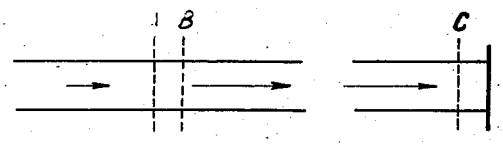


Fig.5

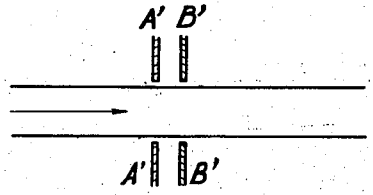
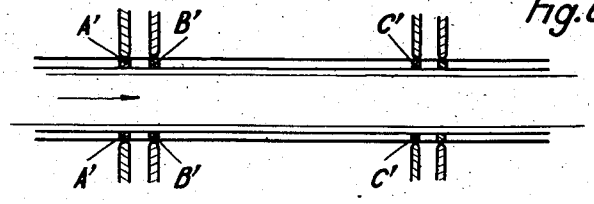


Fig.6



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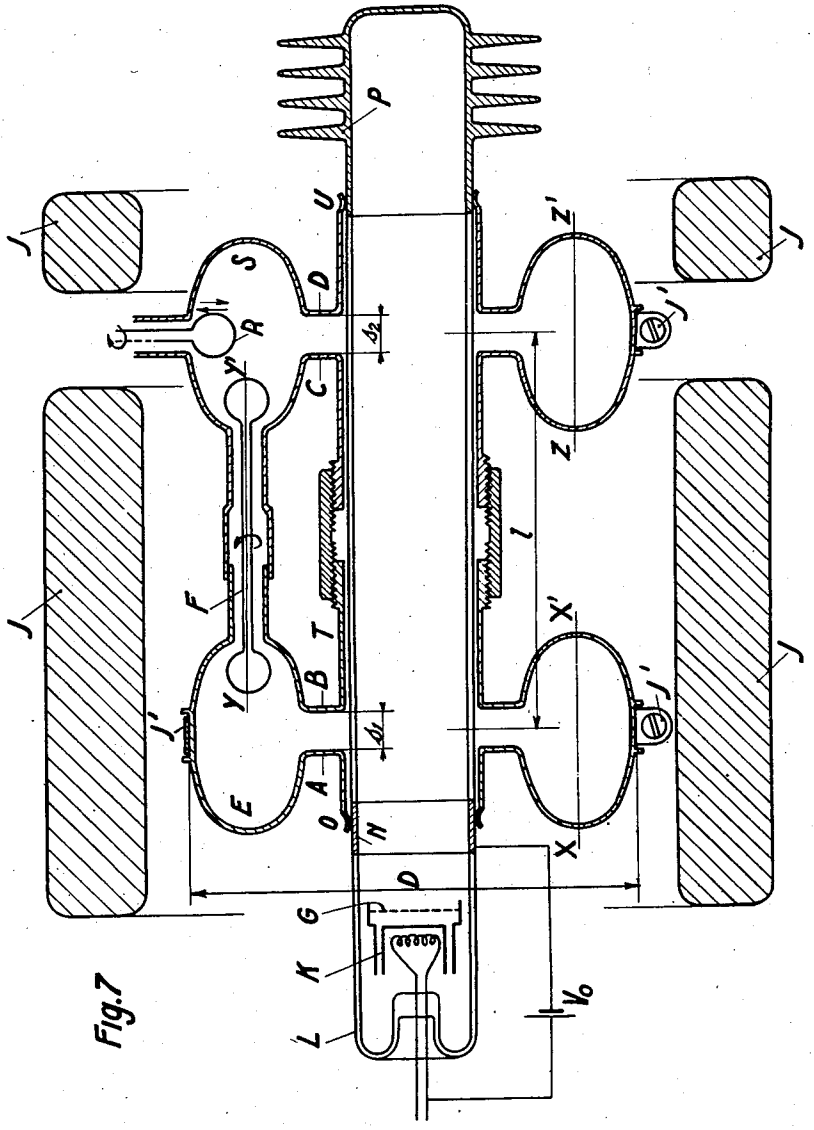

Fig.7

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VELOCITY MODULATION ELECTRONIC VALVE

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Section 1, Public Law 690, August 8, 1946
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4 Claims. (Cl. 250—27.5)

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The present invention relates to "velocity modulation" valves which comprise cavity resonators with space resonance and which are generally known by the name of klystrons.

The present invention has for its object to simplify and improve the construction of cavity resonators and provides for more flexible employment of such devices, particularly when the valves of this type are those which are required to operate on very short waves, for example centimetric waves.

In order to illustrate the subject matter of the present invention the theory of the operation of valves of the klystron type may be briefly summarized as follows:

In such apparatus as in valves defined as "having velocity modulation," a beam of electrons of uniform velocity issuing from any cathode traverses a region where an oscillating electric field is produced parallel or inclined to the beam, the result of which is that according to their period of arrival in the said field, certain electrons are accelerated and others are retarded. The valve then comprises a space free from a field such that in moving in the direction of the movement of the electrons it is possible to find a position in the space where the more rapid electrons have caught up with the slower electrons of the preceding cycle, with the result that the electrons pass this point not in a uniform flow but in a series of groups in which the density of charge is particularly high.

Since, for a definite initial frequency and velocity the concentration into groups is proportional at the same time with the extent of the variation of the velocity and with the size of the path traversed, the variation of velocity, that is to say, the high frequency control potential may be very small; the result is—and this being common to all valves defined as velocity modulation valves—that the power necessary to place the electrons into groups of high density may be very slight.

In the klystron, these groups are always employed directly to excite a resonator from which energy is taken, which arises from the conversion of the kinetic energy of the electrons by slowing down, but the essential characteristic of the klystron as compared with other velocity modulation valves, is that this resonator as also that which causes the grouping of the electrons are of a special type consisting of a hollow chamber with space resonance to which the name of "rhumbatron" has been given. The best form for resonators adapted for klystron valves has

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probably not yet been found, but certain forms derived from a deformation of a sphere, have given experimentally some excellent results.

Our invention will be more fully understood by reference to the following specification and the accompanying drawing, wherein:

Figure 1 represents forms of known cavities of revolution used in klystrons over which the structure of our invention is a very substantial improvement;

Fig. 2 diagrammatically illustrates the structure of our invention, illustrating the improvements thereof over heretofore known klystrons;

Fig. 3 diagrammatically illustrates the circuit arrangement of the cavity resonator system of our invention;

Fig. 4 schematically illustrates the arrangement of the electron discharge path through the cavity resonator of our invention;

Fig. 5 schematically illustrates one method of controlling the electron discharge path through the cavity resonator of our invention;

Fig. 6 schematically illustrates a modified method of controlling the electron discharge path through the cavity resonator; and

Fig. 7 illustrates one form of assembly of the control system of our invention with a cavity resonator system.

In practice, there have hitherto been used for klystrons, cavities of revolution about the axis of the beam, the section of which resembles one of those (*a*, *b*, *c*) of Fig. 1.

The principle of operation of the klystron valve may be described as follows:

The beam of cathode rays of constant velocity emitted by the cathode is sent through a pair of grids between which there exists an oscillating electric field the intensity of which is such that it causes the velocities of the electrons to vary by a slight (but appreciable) fraction from their initial value. After the passage in this first "velocity modulation" grid the electrons emerge into a space free from any field where they continue their path without fresh alteration of velocity and collect together into separate groups in spaces where the electronic density is comparatively slight. At the place where the electrons arrive in concentration of very high density, there is arranged a second "velocity modulation" grid in which there is developed a field alternating in phase such that it collects the energy of the electrons.

Due to a suitable determination of the elements of the system, the intensity of this field can be regulated to a value such that it takes from the

electrons much more energy than is necessary for collecting them. The apparatus in its entirety then transforms the energy borrowed from the continuous source of acceleration of the electrons, into oscillating power and a considerable fraction of the energy of the beam can be transformed into utilizable energy by reason of the advantageous characteristics of the resonator and of the extremely efficient manner in which it is coupled with the beam. The alternating fields grouping the electrons and collecting energy, are obtained due to the differences of high frequency potential developed between the side plates of the resonator.

In the valves described up to the present, the solid electrodes playing the part of grid elements and between which these differences of potential appear, form materially a part of the resonators of which they are the concrete extension on the path of the beam. Thus, an auto-oscillator klystron is composed essentially of two conductive spaces traversed by an electronic beam; these cavity resonators are electrically closed and are coupled electrically in such manner that their oscillations are in a phase so that energy can be taken from the kinetic energy of the beam in the outlet space. Together with this coupling corresponding to the reaction of the anode circuit on the grid circuit in an auto-oscillator of the usual type (and which may be effected by induction or by capacity) there exist those of the electronic beam with the electrodes of the resonator.

Fig. 2 of the drawings is a diagrammatic illustration employing the usual symbols of a klystron oscillator; K is the cathode forming the source of electrons, G is a control grid of the usual type serving to control the size of the current penetrating into the high frequency part of the apparatus due to the polarization P. E_1 is the space resonator of electric elements C_1 L_1 R_1, producing the variations of velocity in the electronic flux due to the difference of high frequency potential which appears between the side walls A and B. T is the tube defining the space free from the field, in which, due to a varying length *l*, the electrons arrive, at a point C, in groups of high density. S is the resonator of electric elements C_2 L_2 R_2, between the side walls C and D of which the electrons are slowed down. In the klystron valves, known previously to this invention, A, B, and C are electrodes in the form of grids placed in the path of the electrons, D is an electron collecting plate or a grid similar to the preceding one, V_0 is the source of continuous current potential serving to accelerate the electronic flux from the cathode, U_g is a difference of low frequency potential which can serve to modulate in density the inlet current, *f* is a coupling line allowing a small amount of high energy being taken from the outlet resonator in order to control the arranging into groups; the transfer of energy takes place in the system represented by reason of an inductive coupling of the loops M_1 and M_2 with the magnetic field created by the induced current I_1 and I_2 in the walls of the resonators. A is the aerial transferring the useful energy obtained due to the difference of potential induced in the loop H by the induced current I_2 in the energy collector resonator.

This system can be represented at least approximately by Fig. 3 where corresponding usual elements of circuit are employed. The correspondence is clearly shown by the diagram and,

according to such an image, it is possible to study the operation of the entire system as is done in the case of ordinary electron valves and in particular to draw up the equations of the coupled circuits with the appropriate modification for the systems with space resonance. Such an investigation shows the advantage there would be in being able, in operation, to modify certain of the constants of the circuits in order to use the resonators to the best advantage.

This being borne in mind, experience in the construction and utilization leads to a certain number of observations:

1. Since the advantage of the valves of the klystron type as compared with other systems constructed in particular for ultra-high frequency becomes great, especially when the length of wave is less than 50 cm. or, better still, when it reaches say 10 cm., even in principle, the dimensions of the resonators become so small (the actual wave length of a resonator of the type of those in Fig. 1 is of the order of 2.5 times the the diameter D) that their correct assemblage ceases to be an immediate and simple problem.

2. Furthermore, it is not possible to construct space cavity resonators suitable for the klystrons with sufficient precision for them to have automatically exactly the same natural frequency. Owing to the high quality factor of these cavity resonators (of the order of 1,000 at 10 cm.) the latter must therefore be deformable in such manner that the inlet resonator (electron gatherer) and the outlet resonator (collector of energy) may be tuned in frequency one on the other and this must be accomplished when the valve is complete and ready to be used.

3. With the constructions described up to the present, difficulties of embodiment arise from the fact that either the space cavity resonators form the vacuum recipient, or they are contained with the remainder of the apparatus in a closed space in which consequently it is difficult to obtain access in order to produce modifications of dimensions for any object whatever.

4. When the cavity resonators form the vacuum space, the assemblage of the different parts is difficult because brazings or solderings must be made very close to each other and with metallic elements sometimes somewhat different; for example between the massive parts which are to give solidity to the valve and the flexible parts which are to allow of the slight deformations necessary to take up initial differences of dimensions arising in the construction.

5. In the case of valves in which the cavity resonators form part of the vacuum space, the degassing necessarily far-reaching in order to obtain a stable operation, is difficult and delicate from the fact of the preceding principles of construction.

6. Finally, with cavity resonators forming an integral part of the vacuum recipient only small alterations in shape are possible and this except when relatively complicated constructions not very adapted to industrial uses are employed.

7. Apart from the foregoing it is very difficult to construct apparatus in which an action on the different couplings between the elements is possible.

8. In general, the klystron valves constructed up to the present have as variable element only the distance "s" between the side walls of the resonators and this within a restricted range sufficient to tune them in frequency, but this modification alters at the same time (and necessarily)

the size of the space serving to control the gathering and the slowing down of the electrons. It is obviously possible to effect a construction with resonators (forming a part of the evacuated space or being located at this space) permitting these two effects to be rendered independent, and in which the coupling of the gatherer rhumbatron and of the collector rhumbatron can be made variable, as also that of the aerial loop with the magnetic flux created in the collecting cavity resonators, but the construction is then very complicated and often very fragile since it must make use of elastic joints or equivalent systems all of which must be air-tight at the high vacuum.

To sum up, with klystron valves such as those which have been described up to the present in which the resonators form a part of the evacuated space into which the electronic flux passes, or which are contained in this space, the greater part of the variations, of the adjustments and the elements which would require to be variable to render the operation more flexible and sometimes more efficient, are not at all compatible with a simple and strong construction. In other words, an oscillator klystron constructed according to the principles of construction recognized up to the present is shown as an ordinary triode oscillator in which the construction would be such that it would not be possible to modify in any way the grid and anode circuits (except as regards a very slight variation of the natural-frequency) nor the coupling of these and in which the only variable would be the heating potential of the filament and the anodic potential, whereas it is obviously desirable to be able to vary among other factors the grid anode coupling, the anode-aerial coupling and possibly the relative phase of the grid and anode circuits.

It must be noted that the foregoing difficulties are due to the fact that up to the present it had been presumed that the cavity resonators had to be extended by grids having solid elements arranged over the path of the electronic flux.

It has been discovered as a result of the present invention that it is possible to replace the effect of the solid parts in the form of a grid—grid in the usual sense of the word, that is to say, an electrode permeable to the electrons, having apertures and solid elements located in the path of the beam such as A, B, C (Fig. 4)—by the actuation of metallic pieces arranged externally of the beam, for example hollow rings A' B' surrounding the latter (Fig. 5). These parts must be attached to the side walls of the cavity resonators and, according to experiments carried out, a pair of these parts can play the role of a velocity modulation grid; in other words, the latter can be constituted by the slot existing between two rings (for example) surrounding the beam. Between the edges of this slot, there will be applied difference of gathering and of braking potential. In other words, the possibility has been found of acting on the movement of the electrons of the beam by electrodes located externally of the path of the beam but in the immediate vicinity thereof. If the rings previously mentioned are not separated from the beam by any insulating material and can consequently be impinged upon by some electrons after a slight modification of the trajectories of the latter, it may be indispensable due to a suitable electronic optical system—using or not using a magnetic focalization—to act in such manner that few electrons are collected by the rings. Experiments have shown that with

a suitable dimensioning of the rings and of the diameter of the beam, a coupling between the rings and the electronic flux can be obtained in a sufficiently efficient manner for the operation of the valve to be suitable in certain cases. The effects of the differences of gathering and braking potentials can be kept at a sufficiently high value either by the rings A' B' being arranged on the outside of an insulating tube surrounding the electronic beam (Fig. 5) or by their being embedded in the lateral wall of this insulating tube (Fig. 6). This observation permits of easily constructing klystron valves which then have cavity resonators arranged externally of the evacuated space in which the electrons are in movement. This constitutes the principal characteristic of the invention. According to what has been stated, the rings forming a control electrode may be embedded in the glass of the evacuated space containing the beam, arranged in the interior or on the exterior of this space by any process, but in any manner so that they are provided in immediate contact with the cavity resonator. By way of example, in the valves comprising the principal feature of the invention, the insulating tube containing the electronic beam will be made in glass with very slight losses, in quartz, in ceramic material or any other materials suitable for the insulation at ultra-high frequency.

By reason of the equivalent value of the effect of electrodes external of the beam and of actual grids arranged in its path, it is thus seen that the construction of an amplifier, oscillator or detector, frequency mixer or other klystron valve can be carried out under much better conditions than those which have been hitherto known:

1. The construction will be simple and the advanced degassing necessary of the electrodes will be considerably facilitated since the electronic discharge valve and the cavity resonators or circuits will be separately constructed.

2. It will be possible to make the cavity resonators so that the mechanical modifications thereof can be carried out during the operation of the valve. The coupling between the rhumbatrons may be easily modified either in size, or in phase and the couplings with the aerial circuit can also be changed—all this by means arising simply from usual mechanical practice.

3. Furthermore, being freed from the fear of anxieties in connection with the possibilities of degassing and of the other conditions necessary for the internal elements of a vacuum tube, the constructor can make cavity resonators with a precision which is considerably greater than that which can be reasonably expected when the parts serve for example as constructional elements of the vacuum recipient.

4. The cavity resonators not having to be heated in order to be degassed, may be constructed in a very exact manner permitting the realization of different apparatus as nearly alike as possible. This allows of constructing different valves of the same type with very small variations in length of wave proper to the systems and thus renders the utilization more convenient for example when it is a question of making identical valves, for example transmitter and receiver, for a particular wave length.

The use of the external cavity resonator offers two further advantages:

(*a*) It lends itself still better than other constructions, to the addition of an external cooling

system, which permits the thermal drift of frequency being diminished.

(*b*) Owing to the fact that the number of electrons caught by the grid may be considerably diminished with respect to what is obtained in an actual grid valve, the stability of frequency with low frequency modulation can be improved since in certain methods of use the consumption of current by the grids as a function of the potential, plays a part.

There will now be given by way of nonrestrictive example, one method of carrying the invention into effect which comprises an oscillator klystron valve (Fig. 7). The cavity resonators, external of the evacuated space L, are capable of allowing all the regulations necessary for the best possible utilization of the valve; adjustment of the natural frequency variation of the distance of gathering, of the auto-excitation coupling, of the aerial coupling and modification of its own electric constants.

Referring to Fig. 7, it will be seen that according to the invention the apparatus comprises:

1. An evacuated space L containing: an electron emitting cathode K; a grid G of usual type, fixed on a concentration electrode and capable of serving for a low frequency modulation of the electronic beam emitted by the cathode; a metallic ring N embedded in the glass space L which constitutes the evacuated space and serving to define the continuous potential at the inlet of the valve and to impart to the electrons the suitable continuous velocity; a metallic anode P which forms the extension of the insulating tube.

2. A part external of the space and comprising: the two gatherer and collector cavity resonators E and S. They are connected to N and P by means of continuous and flexible metallic contact O and U which are the extension of external side plates of the cavity resonators. In a modification of the system, the metallic part U can equally well be omitted in such manner that the anode P is no longer electrically connected to the cavity resonators and can be raised to a potential different from theirs, for example that of the cathode. In this case, the anode P can then be contained if so desired in the interior of the evacuated space;

The discs A, B, C, D, which are the extensions of the side plates of the cavity resonators between which appears the high frequency potential difference which has for its effect to modulate the velocity for the beam in the gatherer and of permitting energy to be taken from the bunches of electrons in the collector;

The metallic tube T connected to the side plates B and C and which defines the drift space free form field.

F which represents the coupling line between the two cavity resonators and R the aerial by which the energy of the valve is radiated outwardly;

Finally, J is the section of a continuous or subdivided magnetic coil intended to prevent the electrons from deviating from their normal trajectory. The magnetic coil J may be formed as one continuous winding where the construction of the cavity resonator permits synchronizing of the associated circuits. However, where there are a pair of cavity resonators, as shown in the drawing, it is more effective to divide the magnetic coil J into two parts as illustrated for synchronizing the operation of the separated parts of the system.

It can be seen that it is easy with this mounting arrangement to vary all the magnitudes as desired.

The magnitude of the path between the cavity resonators or gathering space may be modified, the tube T being a telescopic tube. The distances s_1 and s_2 between the grids of the gatherer and collector cavity resonators may be changed by pressing together on the chords XX′ and ZZ′. The natural frequency of the cavity resonators E and S may be modified by closing together the cavity resonators along the diameters D by means of, for example, clamping collars J′. The length of the coupling line F as also its electric constants can be easily varied in order to modify the phase of the oscillations of the inlet and outlet cavity resonators.

The amount of the mutual inductions M_1 and M_2 can be regulated at will for example by rotating the coupling line about its symmetrical axis YY′.

Similarly it is easy to modify the constants of the loop R taking energy in the collector, its coupling with this cavity resonator and the constants of the concentric line by which the aerial emerges, which renders the correct adaptation of the utilization charge easy.

These modifications cited, by way of example to show the possibilities presented by external cavity resonators may be made independently of each other by using suitable known mechanical systems. It is evident that numerous possibilities of utilization are facilitated by the embodiment of external cavity resonators to the klystron valve from the fact that these do not appreciably alter the actual efficiency of the principle. At the same time it is possible to obtain a better embodiment of the discharge valve by reason of the facility of construction and of evacuation which leads to stronger and more accurate valves.

What we claim is:

1. A velocity modulation tube comprising an elongated cylindrical envelope having electrodes therein, a pair of cavity resonators concentrically surrounding said envelope, coupling means interconnecting said cavity resonators and concentrically surrounding said envelope, means adjusting the effective length of said coupling and selecting the spatial relation of said cavity resonators, and means spaced from said elongated cylindrical envelope and disposed in substantially parallel relation thereto and interconnecting said cavity resonators.

2. A velocity modulation tube comprising an elongated cylindrical envelope having electrodes therein, a pair of cavity resonators concentrically surrounding said envelope, coupling means interconnecting said cavity resonators and concentrically surrounding said envelope, means adjusting the effective length of said coupling and selecting the spatial relation of said cavity resonators, means spaced from said elongated cylindrical envelope and disposed in substantially parallel relation thereto and interconnecting said cavity resonators, and means carried by said resonators for establishing adjustable connection with certain of the electrodes in said elongated cylindrical envelope.

3. A velocity modulation tube comprising in combination an elongated cylindrical envelope enclosing electrodes, a pair of substantially cylindrical members concentrically disposed about said envelope and establishing slidable electrical connection with certain of the electrodes in said envelope, a cavity resonator connected with each

of said cylindrical members and including a toroidal portion and a restricted radially disposed connecting portion, means adjustably interconnecting said cylindrical members, and means spaced from said cylindrical members and interconnecting the toroidal portions of said cavity resonators.

4. A velocity modulation tube comprising in combination an elongated cylindrical envelope enclosing electrodes, a pair of substantially cylindrical members concentrically disposed about said envelope and establishing slidable electrical connection with certain of the electrodes in said envelope, a cavity resonator connected with each of said cylindrical members and including a toroidal portion and a restricted radially disposed connecting portion, means adjustably interconnecting said cylindrical members, means spaced from said cylindrical members and interconnecting the toroidal portions of said cavity resonators, and means encircling said cavity resonators for effecting deformation thereof for regulating the frequency of operation of said cavity resonators.

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MARTHE LORTIE.

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