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MODULATION SYSTEM

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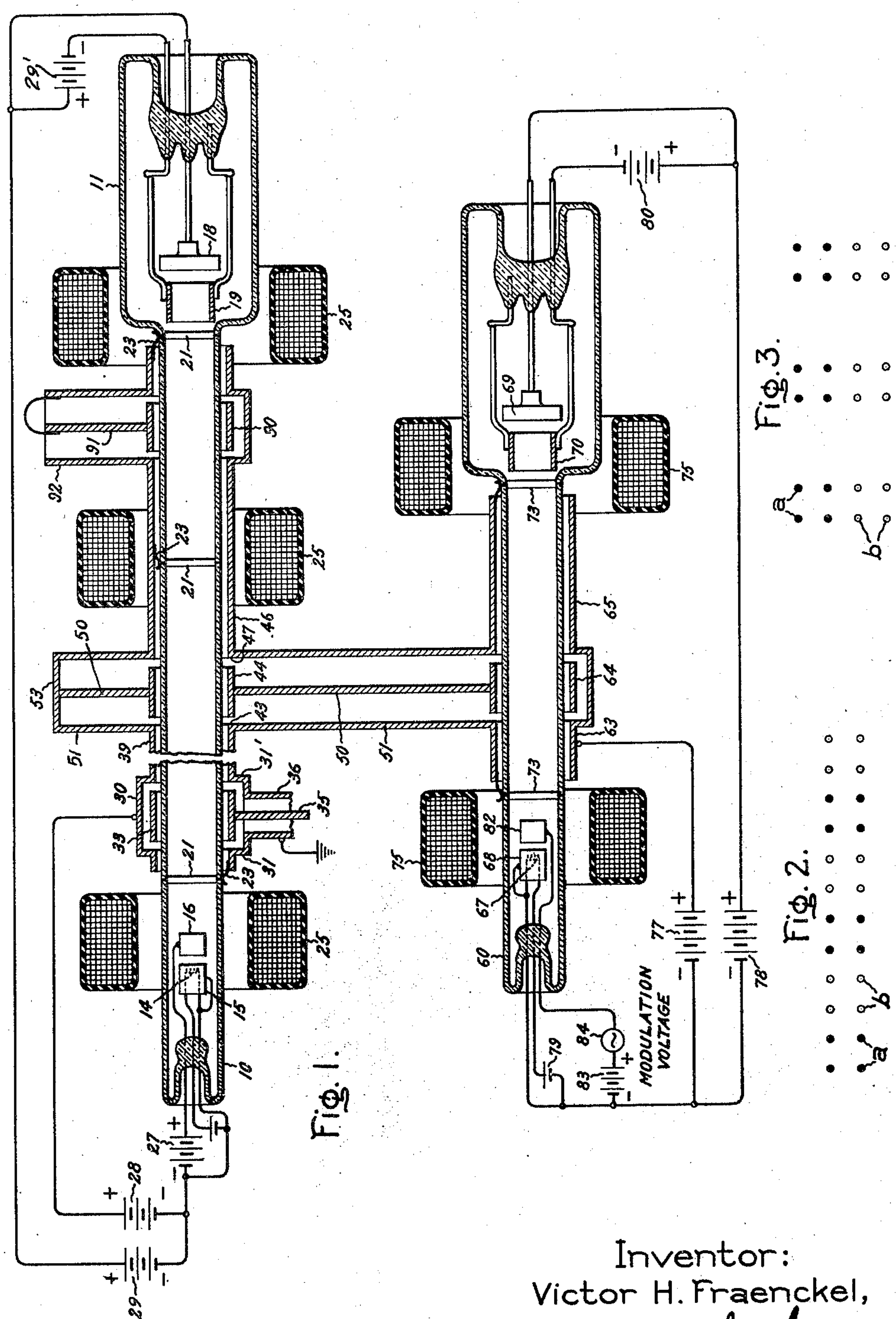

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MODULATION SYSTEM

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5 Claims. (Cl. 179—171.5)

The present invention relates to improvements in high frequency modulators and the like.

It is an object of the invention to provide improved means, usable at ultra high frequencies, for modulating a primary wave, such as a carrier wave, with a secondary or signal wave. The invention is also applicable in connection with heterodyne detectors or converters and, indeed, may be used in any connection where the mixing of two or more frequencies is desired.

In its preferred embodiment the invention utilizes a discharge device of the cathode ray type in combination with means for successively modulating the electron beam produced by the device with the various frequencies desired to be mixed. An important feature of the invention consists in the particular means provided for superimposing the secondary or signal modulation on the primary or carrier modulation.

The features which I desire to protect herein are pointed out in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the drawing, in which Fig. 1 represents a modulating system suitably embodying the invention and Figs. 2 and 3 are diagrammatic representations useful in explaining the invention.

Inasmuch as the invention is considered to be primarily applicable to discharge devices of the character described and claimed in W. C. Hahn application S. N. 153,602, filed July 14, 1937, it will be helpful to refer briefly to some of the principles utilized in such devices.

An electron stream such as flows between the electrodes of a vacuum tube may be modulated either as to "electron velocity" or as to "charge density." The first type of modulation involves the production of systematic irregularities in electron velocity from point to point along the beam. The second involves the production of charge density variations, such variations being manifested as systematic irregularities in the electron grouping.

In the conventional design of electronic discharge devices no distinction is made between these two types of modulation. In connection with ultra-short-wave devices, however, it is advantageous to utilize modulating electrodes which are capable of producing velocity modulation without simultaneously causing appreciable charge density variations. For reasons which need not be elaborated here this expedient avoids the large input losses which are observed with conventional prior art devices when they are operated at extremely high frequencies. By additional means, also described in the aforesaid Hahn application, velocity modulation produced as above specified may be subsequently converted into charge density modulation of a higher order of magnitude so as to produce amplification effects.

It is found that the velocity modulation principle may be most readily utilized in a discharge device of the cathode ray type, wherein the elongated stream of electrons is susceptible of being variously influenced at different points along its length. I have, therefore, chosen a device of this kind to illustrate my present invention.

Referring particularly to Fig. 1 there is shown an electron beam tube which comprises an evacuated envelope having an elongated shaft portion 10, and an enlarged anode-containing portion 11. This envelope may be suitably constituted of glass, quartz, or any equivalent low-loss insulating material.

The shaft portion 10 encloses means for producing an electron beam, such as a known type of electron gun. The combination shown comprises a cathode 14 which is indicated in dotted outline and a focusing cylinder 15 for confining the electrons from the cathode to a concentrated beam. This cylinder may be either connected directly to the cathode or maintained at a few volts positive or negative with respect to it. In order to accelerate the electrons to a desired extent, there is provided an accelerating electrode 16 which is spaced from the cathode and which may be biased to a suitable positive potential, say several hundred volts.

In order that the intermediate portion of the beam path may be maintained at a desired potential level there are provided a number of intermediate electrodes 21 which suitably comprise rings of conducting material applied to the inner wall surface of the envelope. These are provided with external contact-making terminals 23. A number of magnetic focusing coils 25 distributed along the envelope serve to prevent dispersion of the electrons and to maintain the beam in focus during its passage through the discharge space. In some cases these coils may be advantageously replaced by electrostatic beam focusing means.

After traversing the envelope, the electron beam is collected by an anode 18 which consists of graphite or other suitable material. A tubular electrode 19 in the nature of a suppressor grid serves to prevent secondary electrons emitted by the anode from returning to the discharge space.

In the operation of the device the intermediate electrodes 21 may be maintained at ground potential, the cathode 14 at one thousand to several thousand volts below ground, and the anode 18 at one thousand to several thousand volts above the cathode. The suppressor grid 19 should be biased fifty to several hundred volts negative with respect to the anode 18. These potential relationships may be established by means of suitable sources of potential, conventionally represented in the drawing as batteries 27, 28, 29 and 29', connected as shown.

The combination of elements so far described comprises means for producing a unidirectional electron beam of substantially constant average intensity and velocity. As pointed out in the aforesaid Hahn application, Serial No. 153,602, an electron beam of this type may be velocity modulated by applying to the beam longitudinal potential gradients which vary cyclically at a desired frequency. In order that such modulation may be accomplished without the stimultaneous production of substantial charge density variations, it is desirable that it occur in a modulating space which is adequately shielded from the cathode. In this way, the variations of the modulating potential are prevented from reacting directly on the cathode emission. One suitable velocity modulating structure is shown in the drawing.

The structure referred to comprises a chamber 30 formed by a combination of conducting members arranged outside the discharge envelope. It is provided with transversely extending wall portions 31 and 31' which extend relatively close to the outer surface of the envelope and which serve to fix the potential level of the boundaries of the modulating space. Within this space there is provided a modulating electrode comprising a conducting tube 33 which surrounds the beam path so as to be coupled thereto. By alternately raising and lowering the potential of this electrode with respect to the boundaries of the modulating space, variable potential gradients are produced which act longitudinally on the electron beam as it traverses the approach spaces or gaps between the wall members 31 and 31' and the extremities of the electrode 33. The modulating effect thus produced will be most pronounced if the length of the tubular electrode 33 is so correlated to the velocity of the beam that the electron transit time therethrough corresponds at least approximately to a half-cycle of the control potential (or to an odd number of such half-cycles). If this condition is fulfilled, an electron which enters the modulating space when the potential of the control electrode 33 is a maximum is accelerated first by the gradient existing between the wall 31 and the electrode, and again as it leaves the electrode one-half cycle later, when the electrode potential is at a minimum with respect to that of the boundary wall 31'. Similarly an electron which enters the modulating space in such time phase as to be retarded by the effect of the control electrode, is also retarded as it leaves the electrode. As a result of these effects the electron beam leaving the chamber 30 is made up of alternate elements, some of which have a velocity above the average of the beam and others a velocity below such average.

Modulating potential may be supplied to the control electrode 33 from any desired source such, for example, as a high frequency oscillation generator (not shown). As a means for connecting this potential to the control electrode structure, there is provided a concentric conductor transmission line comprising an inner conductor 35 and outer conductor 36, these being shown partly broken away.

If only weak control potentials are available, the velocity modulation produced may be relatively slight. However, it may be converted into charge density modulation of a high order of magnitude by means now to be described. The mechanism by which such conversion may be accomplished will best be understood by a consideration of the following explanation.

In Fig. 2 the beam is shown at it is assumed to issue from the modulating space. It will be seen that at this point it comprises alternate groups of fast and slow electrons, the former being indicated by the black dots *a*, and the latter by the light dots *b*. So far, the beam is still substantially uniform as far as charge density or electron grouping is concerned.

In Fig. 3, the condition of the same beam is indicated at a somewhat later time when the more rapidly moving electrons have caught up with the slower electrons. The electrons have now become grouped so that the beam is charge density modulated in the sense that systematic irregularities in charge density occur from point to point along the beam. The change that has taken place is in its very nature one that requires only the elapse of time and the absence of extraneous influences which might tend adversely to affect conditions within the beam. These requirements may be fulfilled by the provision of an electrostatically shielded drift space in which sorting of the electrons can take place. This may comprise, for example, simply a section of the discharge envelope which is shielded from any but static potentials.

Referring again to the particular structure of Fig. 1 it is to be considered that the drift space of the illustrated device is coextensive with the tubular conducting section which extends from the boundary wall 31' to the point indicated by th enumeral 43. The length of this tubular conducting section should be at least several times its diameter. It is shown partly broken away in the drawing in order to save space.

If the device illustrated were to be used simply for amplification purposes, it would be expedient to provide means for abstracting energy from the charge density modulated beam at the right hand extremity of the drift tube 39. For the purposes of the present application, however, it is desired to provide additional means for superimposing secondary modulation on the primary modulation caused by the control electrode 33. This is done by the use of additional modulating means comprising an additional electrode structure coupled to the electron beam at a point along the beam path. Such electrode structure may be taken to include the extremity 43 of the drift tube 39, an electrode 44 which is generally similar to the electrode 33 previously described, and the extremity 47 of another conducting tube 46.

In order to assure effective mutual reaction between the beam and the electrode structure it is necessary that the dimensions of the latter and particularly of the electrode 44, be properly correlated to the transit time of the electrons in the beam. Most perfect correlation is obtained if the length of the electrode 44 corresponds approximately to the spacing between adjacent charge density maxima and minima in the beam when the beam is modulated at the particular frequency which is to be impressed on the control electrode 33. Under these conditions, it will be seen that the approach of a charge density maximum will correspond with the recession of a charge density minimum and vice-versa. Consequently, the action of the charge density modulated beam in traversing the approach spaces which exist between the extremities of the electrode 44 and the boundary walls 43 and 47 will be to induce a cyclically varying current in the electrode 44. In order that the induced current may be caused to produce the effect desired in the present connection, the control electrode 44 should be connected to a high impedance circuit. This has the function of causing the induced current variations to produce relatively great potential variations between the electrode 44 and the elements 43 and 47. A high impedance of the desired characteristics is best provided by means of the resonant circuit, and at the frequencies here involved, it is expedient to utilize in this connection a resonant transmission line of the parallel conductor type.

In the arrangement illustrated a resonant transmission line is provided by conductors 50 and 51, the conductor 51 being in the form of a hollow tube which concentrically surrounds the conductor 50. As shown, one section of the transmission line extends above the beam tube and is short circuited by means of a transversely extending conducting wall 53. This section is preferably approximately a quarter-wave-length long. The other portion of the transmission line, that is, the section which extends below the discharge tube, comprises a half-wave line which is open circuited at both ends.

With an arrangement such as that indicated, the current induced in the electrode 44 will tend to produce sustained oscillations of the transmission line and will cause a voltage maximum or anti-node to exist between the electrode 44 and the adjacent surfaces 43 and 47. A further voltage maximum will exist at the end of the lower or half-wave length section of the line which is more remote from the tube 10. The voltages appearing at the anti-nodal points will be cyclically varying character and will have a frequency of variation determined by the rate of approach and recession of charge density maxima in the beam; that is to say, by the frequency of the modulating potential applied to the electrode 33.

By analogy with the operation of the control electrode 33 it will be seen that the potential gradients produced in this way will necessarily act to cause secondary velocity modulation of the electron beam. Furthermore, since the voltage swing of the electrode 44 may be very much greater than that of the electrode 33, the magnitude of the new velocity modulation may be correspondingly larger than that of the initial modulation. In other words, the eventual condition of the beam may be controlled almost entirely by the modulation produced by the electrode 44 and only to an insignificant degree by the modulation produced by the electrode 33.

The discussion so far has been predicated upon the assumption of a particular condition of resonance of the transmission line 50—51. It will be observed that changing this condition of resonance, this is, either changing the resonant frequency of the transmission line or varying the amount of its damping, will produce a corresponding effect on the secondary modulation. Assuming that maximum modulation is obtained when the transmission line is in perfect resonance, it is clear that any detuning or damping of the line should tend to lessen the amplitude of modulation. Therefore, if means are provided for cyclically varying the condition of resonance of the transmission line in accordance with a signal desired to be superimposed on the initial modulation of the beam, such superposition will in fact occur. I propose to utilize this possibility in order to obtain conventional modulator action, that is to say, the mixing of a carrier and signal frequency.

Numerous arrangements may be employed for cyclically varying the condition of resonance of the transmission line. For example, one might employ mechanical means for cyclically changing the dimensions of the line so as to change its resonant frequency. For practical reasons, however, it is very much preferable to accomplish the desired result by the use of an additional electronic discharge device connected to vary the effective coupling of the conductors 50 and 51.

In the lower portion of Fig. 1 I have shown another beam tube 60 adapted to provide an electron beam in proximity to the extremities of the conductors 50 and 51. Effective coupling of the conductors and the beam is accomplished by passing the beam axially through a series of tubular elements 63, 64 and 65 which are respectively connected to the inner and outer conductors of the transmission line.

The tube 60 is in many respects similar to the device 10 previously described and includes a cathode 67, a focusing cylinder 68, an anode 69 and a suppressor grid 70. There are also provided intermediate electrodes 73 and focusing coils 75 which correspond in function to the elements 21 and 25 discussed above. Batteries 77, 78, 79 and 80 serve to maintain a desired D. C. potential relationship between the various electrodes referred to.

It is apparent that the voltage variations of the electrode 64 resulting from the oscillations of the transmission line will produce cyclical velocity variations in the electron beam as it enters the electrode. The effect of these variations in producing electron sorting (drift tube effects) within the electrode and in causing induced currents in the electrode at its exit and will be determined mainly by the relationship between the average beam velocity and the length of the electrode. With a proper correlation of these factors, this effect can be made such as to cause the condition of resonance of the transmission line to be a function of the amount of the beam current and to vary in accordance with changes in such current. Specifically the reaction of the beam current on the electrode 64 and the associated transmission line may be made such as cyclically to vary the resonant frequency of the line or its damping, or both, in accordance with the variations in beam current magnitude.

In view of the foregoing and the previously explained action of the transmission line in superimposing secondary modulation on the electron stream flowing through the tube 10, it should now be apparent that the amount of such modulation may be controlled by varying the beam current in the tube 60. My invention takes advantage of this fact by the provision of means for controlling the current in the tube 60 in accordance with a signal or modulation voltage desired to be impressed on the carrier wave. While this may be done in various ways, it is accomplished in the present case by means of an accelerating electrode 82 arranged to function as a control grid. This electrode 82 is biased positively by means of a battery 83 and is varied in potential by means of a signal generator 84 which is connected in series with the battery. The beam current is thus varied above and below its average or no-signal value in accordance with the voltage variations impressed on the electrode 82. As a final result the state of resonance of the transmission line 50—51 and consequently the amplitude of the secondary modulation applied to the tube 10 are correspondingly varied.

It will be seen that the nature of the secondary modulation effects obtained depends in part upon the normal or no signal condition of resonance of the transmission line. If the line is perfectly resonant when no signal is applied to the electrode 82 it is obvious that the application of either a positive or negative potential to this electrode will result in some damping or detuning of the line and a consequent change in the magnitude of the secondary modulation produced in the beam of tube 10. On the other hand if the transmission line is initially somewhat detuned or damped, then at least one-half of the signal wave will tend to improve its tuning. Obviously either of these conditions may be used to produce a modulating reaction on the tube 10.

It will be understood that the tube 60 may under some circumstances be advantageously replaced by some other variety of electronic discharge device properly coupled to the extremity of the transmission line. For example, if the signal voltage is itself in the ultra high frequency range it may be desirable to employ a tube having an input system similar to that shown in connection with the tube 10.

Referring again to the functioning of the tube 10, it will be seen that the beam issuing from the electrode 44 is variably velocity modulated in accordance with the signal voltage. In the drift space provided by the conductive tube 46 to the right of the electrode 44 this variable velocity modulation may be converted into variable charge density modulation as explained in connection with Figs. 2 and 3. By thereafter passing the beam through a further electrode 90, energy may be abstracted from the beam and fed to a desired output circuit. The output circuit is not illustrated in Fig. 1, but there is shown a concentric conductor transmission line 91—92 comprising a suitable connection means for such a circuit.

The frequencies observed in the output circuit include the carrier and signal frequencies as well as sideband frequencies corresponding to the sum and difference of the carrier and the signal. These may be fed into suitable utilization circuits.

After traversing the electrode 90, the beam is finally collected by the anode 18.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, means including a discharge device of the cathode ray type for producing a concentrated electron beam, an electrode structure coupled to the beam at a point along the beam path, said structure having dimensions which are so correlated to the transit time of electrons in the beam as to assure effective mutual reaction between the structure and the beam when the beam is preliminarily modulated at a particular frequency, means for preliminarily modulating the beam at the said particular frequency, resonant circuit means connected to the said electrode structure and adapted to be excited to oscillation by the reaction of the modulated beam thereon, the electrode structure in turn reacting on the beam to produce a secondary modulation thereof in accordance with the condition of resonance of the said circuit means, means for varying the condition of resonance of the circuit means at a desired frequency to produce secondary modulation of the beam at such frequency, and means for abstracting energy from the doubly modulated beam.

2. In combination, means including a discharge device of the cathode ray type for producing a concentrated electron beam, means for initially modulating the beam at a particular frequency, an electrode structure positioned along the path of the modulated beam and having dimensions which are correlated to the transit time of electrons in the beam so as to assure effective mutual reaction between the electrode structure and the beam when the beam is initially modulated at the said particular frequency, a resonant type transmission line terminally connected to said electrode structure, and adapted to be excited to oscillation by the reaction of the modulated beam thereon, the electrode structure in turn reacting on the beam to produce secondary modulation thereof in accordance with the condition of resonance of the transmission line, means for varying the condition of resonance of the transmission line at a desired frequency, thereby to modulate the beam at such frequency, and means for abstracting energy from the doubly modulated beam.

3. In apparatus for modulating a higher frequency carrier the combination which includes a discharge device of the cathode ray type for producing an electron beam, means for producing initial modulation of the beam at the carrier frequency, resonant circuit means coupled to the beam so as to be excited to oscillation by the beam by virtue of its said initial modulation, the said circuit means being effective by reaction on the beam to produce a secondary modulation thereof in accordance with the condition of resonance of the circuit means, means for varying the condition of resonance of the circuit means at a signal frequency, and means for abstracting energy from the doubly modulated beam.

4. In combination, means including a discharge device of the cathode ray type for producing an electron beam, a resonant type transmission line coupled to the beam at an intermediate region thereof and adapted to be excited to oscillation by the beam when the beam is preliminarily modulated at a particular frequency, the said transmission line in turn reacting on the beam to produce a secondary modulation thereof in accordance with the condition of resonance of the line, means for preliminarily modulating the beam at the said particular frequency, and means including a second discharge device coupled to the transmission line for varying the condition of resonance thereof at a desired frequency, thereby additionally to modulate the beam at such frequency.

5. In combination, means including a discharge device of the cathode ray type for producing an electron beam, a resonant parallel conductor transmission line coupled to the beam at an intermediate region thereof and adapted to be excited to oscillation thereby when the beam is preliminarily modulated at a particular frequency, the said transmission line in turn

reacting on the beam to produce secondary modulation thereof in accordance with the condition of resonance of the line, means for preliminarily modulating the beam at the said particular frequency, means providing a second electron beam passing in proximity to the conductors of the transmission line so as to control their coupling and thereby the condition of resonance of the line, and means for varying the current flow in the second beam at a desired frequency, thereby additionally to modulate the first beam at such frequency.

VICTOR H. FRAENCKEL.