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MODULATION OF CARRIER FREQUENCIES

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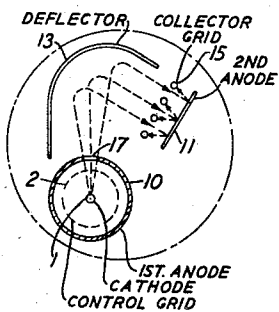


FIG. 1

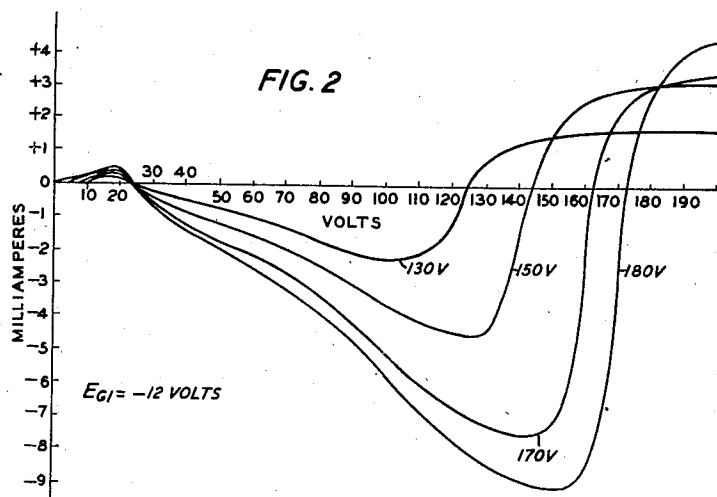


FIG. 2

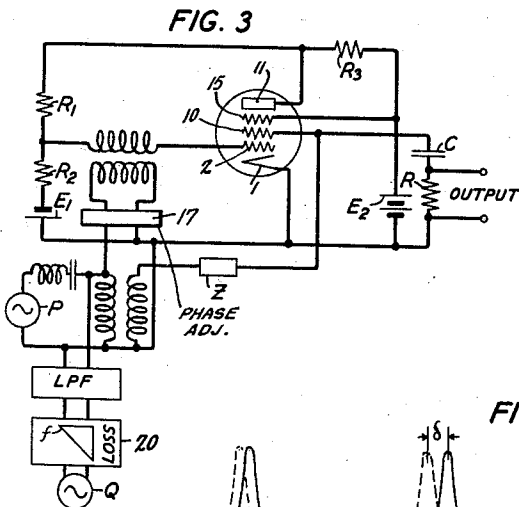


FIG. 3

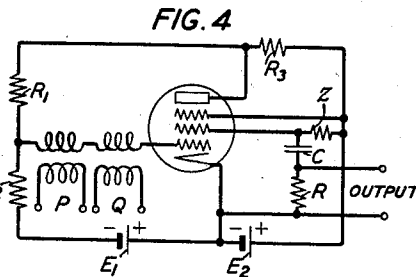


FIG. 4

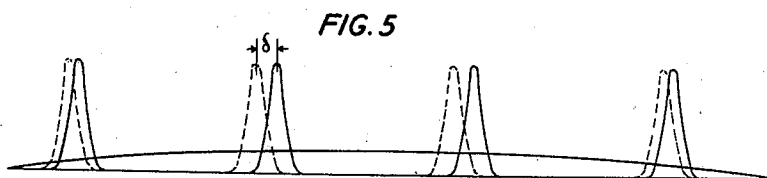


FIG. 5

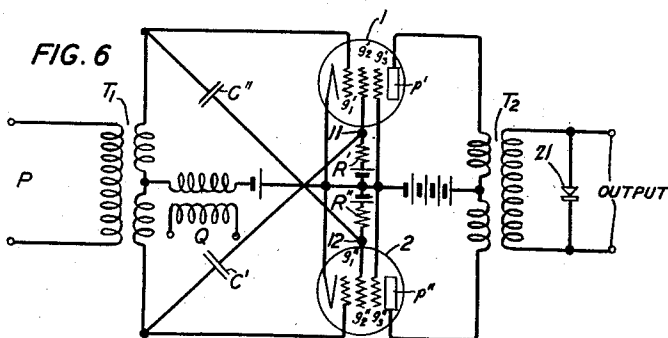


FIG. 6

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MODULATION OF CARRIER FREQUENCIES

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Application September 20, 1940, Serial No. 357,521

4 Claims. (Cl. 179—171.5)

This invention relates to production and modulation of carrier frequencies and more particularly to phase modulation or frequency modulation. Still more particularly it relates to such means in which sharp pulses at a certain base frequency are generated and in which the pulses are phase modulated in accordance with a signal to be transmitted.

Various devices have been proposed from time to time for generation of sharp and well-timed pulses which are rich in harmonics so that they may be used as frequency multipliers. Gas discharge tubes have been used in a number of different circuit arrangements as illustrated for example in patent to Peterson, 2,174,165, September 26, 1939. Such gas discharge tubes are limited to some extent in the frequency of the base source with which they are to be excited. Furthermore, in such tubes it frequently occurs that the bombardment of the cathode by positive ions gradually decreases its effectiveness and shortens the life of the tube.

It is the purpose of this invention to make use of a tube and to devise a circuit therefor in which there is no ionization and the deionization period does not enter as a limiting factor. To this end I make use of a high vacuum tube associated with a circuit which gives it triggering actions, making possible the generation of pulses of short duration.

Associated with the circuit of the trigger tube there are means for altering the instant of the triggering in accordance with a signal to be transmitted and from this set of pulses there is selected a desired carrier frequency and its modulating side-bands yielding what may be called a phase modulated wave. This wave may then be converted into a frequency modulated wave in a manner to be described.

The invention will be better understood by the following specification and the accompanying drawing in which:

Fig. 1 represents the cross-section of one particular type of tube with triggering properties;

Fig. 2 is a set of characteristics for such a tube;

Figs. 3 and 4 show circuits for carrying out the purposes of my invention with that tube;

Fig. 5 shows curves relating to Figs. 3 and 4; and

Fig. 6 shows a circuit with a different type of tube but giving the same end results.

A type of high vacuum tube with triggering characteristics which I find particularly useful in this invention is shown and described in detail in application of A. M. Skellett Serial No. 321,852, 55

filed March 2, 1940. It is not necessary here to describe the structure or behavior of the tube further than by reference to Figs. 1 and 2 of this specification. As shown in cross-section in Fig. 1 the tube comprises a cathode 1, a control grid 2, a first anode 10, a second anode 11, a deflector 13 and a collector grid 15. In the anode 10 there is a small opening 17 through which electrons from the cathode may be projected towards the deflector 13 which member deflects the electrons to the second anode 11. This anode has a surface of such a nature as to readily give rise to secondary electrons which are then collected by the collector grid 15 so long as this grid is kept at a positive potential with respect to the second anode. This tube may be considered as a triode in which the control potential is applied to the grid 2 and the load current is obtained across the anode 10 and cathode 1 as in the usual triode. In order to secure a trigger action whereby a grid potential change in the positive direction of sufficient magnitude to initiate current flow in the triode section will cause a rapid rise of the current to some maximum value, a small amount of cathode emission is allowed to pass through the aperture in the first anode to the second anode. The external circuit is so arranged that the current to the second anode reacts upon the control grid potential to produce the triggering action referred to.

This action can best be understood after considering the volt-ampere characteristic of the second anode as given in Fig. 2. In this figure the current to the second anode is plotted as ordinates against the voltage of the second anode as abscissae, each curve corresponding to a different fixed potential on the collector grid. For any one of these curves it is seen that there are two potentials of the second anode for which the current to that anode is zero. One of these may be called the low voltage point and the other the high voltage point, each of these points corresponding to conditions in which the number of secondary electrons leaving the second anode is equal to the number of primary electrons arriving.

As pointed out in the Skellett application, if the second anode is connected to ground through a high resistance, electrons will flow to it from ground through this resistance because of its positive potential. In order that there shall be no accumulation of charge on the second anode, the net charge arriving at the second anode is still required to be zero. Since electrons are being supplied to the second anode partly through

the high resistance, a smaller primary electron current is required. This means that the secondary current is greater than the primary current, and this can only happen provided the potential of the second anode decreases. Actually, therefore, under these conditions the equilibrium potential occurs slightly below the high potential point in Fig. 2, corresponding to a resultant electron flow away from the second anode. It is found that if the conditions of the circuit are such that the second anode is at the equilibrium point just below the high potential point it is stable and the tube may be operated as the normal three-electrode tube in which the plate current of interest is, as noted, the current to the first anode, which current, of course, is much larger than that to the second anode. Furthermore, this current is subject to control of the control grid 2 so that the tube behaves in the normal way for a three-electrode tube as an amplifier for amplification or any other of the usual functions of a three-electrode tube. Furthermore, it is found that if the potential of the second anode is at the low point then a slight increase in the potential of the second anode will, with proper external circuit connections, react to increase the potential of the control grid, the two cooperating to cause the potential of the second anode to rise quickly to some equilibrium point near the high potential point, whereupon it again functions as a normal three-electrode tube. If, on the other hand, there is a slight decrease in potential of the second anode from this low point, then it is found that the potential of the control grid will, under control of the external circuit, decrease and the current to the second anode and to the first anode will both fall to zero and the tube is triggered off.

This action will be better understood by reference to Fig. 3 which also shows one application of the tube for the purpose given above. In the circuit of Fig. 3 let us assume for the moment that no signal at P and at Q is applied. The source E_2 has some suitable voltage value such that considering the potential drop across the resistance R_3 the potential of the second anode will be in excess of the low point indicated in Fig. 2. The resistances R_1 , R_2 , and R_3 and the potentials E_1 and E_2 are so adjusted that in the absence of any applied voltage from P or Q the grid has negative bias voltage in excess of the cut-off value but such that if the first anode potential were at a value E_m or above, then the tube would trigger on when the control grid is raised above cut-off. The value of the cut-off will depend on the value of E_m . It will be noted that either source P or Q is connected to apply a voltage to the control grid and also through impedance Z to the condenser C and first anode 10. Let it be assumed that the voltage from source P in the positive half cycle is applied to condenser C charging it to a potential sufficiently high to raise the potential of the first anode above the value E_m , and that this same half cycle of voltage unblocks the grid to permit current flow in the tube. The phase adjuster 17 is set to secure the most effective phase relation for this operation. The current to the second anode, in the manner heretofore described, reacts to increase the grid potential to cause the current to the first anode to build up rapidly to a high value determined by the maximum value to which the control grid potential rises. In this way the tube triggers on. This high current condition in the triode section corresponds to a

low internal impedance and the condenser C discharges rapidly through the tube and resistance R so that a pulse appears across R. The impedance Z is of such character and magnitude that it will limit the current after the discharge of the condenser C and should also be one which presents a high impedance to harmonics of the generator impulse. As the condenser C discharges the potential on the first anode will fall and eventually a state will be reached where the tube will cease conducting and the tube is triggered off and will remain triggered off until the charging of the condenser C again brings the potential of the first anode to a sufficiently high point. In order to avoid multiple firing due to recharging of the condenser after the tube ceases conduction, the time constant of the charging circuit should be sufficiently large compared to the desired frequency of operation, as determined by the source P. If the source P supplies a sinusoidal voltage then with suitable adjustment of the constants of the circuit there will be one pulse for each complete cycle of the wave from source P. The resulting train of pulses will be rich in harmonics any one of which may be selected by suitable selective circuits associated with the resistance R or some other suitable portion of the pulse generator. In view of the exceedingly rapid action of the triggering tube the base frequency of the generator P may itself be a fairly high frequency, such as 100,000 cycles per second or more. The impedance Z may take on a variety of forms such as a pure resistance or a reactive network of some form.

A modified form of impulse generator is shown in Fig. 4 in which the condenser C is charged from a constant voltage source through Z and R. The action in other respects is similar to that of circuit 1. An advantage to be derived from this arrangement, however, is that the condenser is not charged from the source P and thus little high frequency power is required for control. For both of these circuits more positive operation may be obtained by applying a peaked wave to the control grid instead of the sinusoidal wave. Such a peaked wave may, for example, be obtained from the voltage across a saturable reactor.

The circuits of Figs. 3 and 4 as thus far described will generate a train of uniformly spaced pulses, as shown by the full lines of Fig. 5, the frequency of occurrence of which is the same as the frequency of the source P. Such pulse generation by gas tube circuits has been used heretofore but with the limitations referred to. Now it is possible in any of these to displace the timing of the pulses by the addition of a biasing voltage and this biasing voltage may take the form of a signal wave the frequency of which in general is relatively low compared with the frequency of the source P. Such a signal source is indicated at Q. In Fig. 3 the source Q is shown as parallel to the source P, there being present in its path a low-pass filter to prevent substantial shunting of the source P. Also it will be convenient to introduce in the circuit of the source P an impedance which will be relatively low for the source P but high for the source Q such, for example, as a series resonance circuit and the impedance Z should be made high for the source Q. In Fig. 4 the sources P and Q are shown as being in series with each other. With such a signal wave present the timing of the pulses will be altered giving rise to a phase displacement. If the amplitude of the biasing volt-

age is not too high this phase displacement will be substantially proportional to the instantaneous value of a signal voltage from Q in the manner indicated by the dotted pulses in Fig. 5 where δ is the phase displacement.

As disclosed in an application of Wrathall Serial No. 354,357, filed August 27, 1940, a series of phase displaced pulses of the kind shown in Fig. 5 is generated and it is pointed out that they may be resolved into a series of harmonics of the base frequency each accompanied by a series of modulation side-bands constituting what may be called a phase modulated wave. The equation for any one of these harmonics, a carrier with its side-bands, is given by

$$i = A \cos (npt \pm mQ \cos qt) \quad (1)$$

where p and q are 2π times the frequency of the base source and of the variable signal source, respectively, n is the order of the harmonic selected as a carrier, Q is a signal amplitude and m takes on integral values from one to infinity. By suitable selective circuits then it is possible to select any desired harmonic representing a carrier, the frequency of which may be high compared to that of the base frequency source P , this carrier being accompanied by its side-bands to constitute a phase modulated wave. In generating such a phase modulated wave it is naturally desirable that the amplitude of the harmonic to be selected should be quite high in amplitude. If the pulses indicated in Fig. 5 are sharp and of short duration, then the amplitude of the successive harmonics falls off quite slowly. The high vacuum trigger type tube shown in my circuits gives the circuit the characteristic of producing pulses of this type and are, therefore, especially adapted for deriving a carrier of high frequency with its associated side-bands. By introducing suitable reactances for tuning or near tuning it is possible to emphasize certain harmonics.

In many instances it will be desirable to obtain a frequency modulated rather than a phase modulated wave and a transformation from the latter to the former may be readily made as will now be pointed out. It will be recognized that the component of current flowing in the output which is here of interest and which is represented by the equation above may be placed in the form

$$i = A \cos (npt + \theta) = A \cos \Phi \quad (2)$$

where Φ is the total instantaneous phase and θ is also a phase angle given by

$$\theta = \pm mQ \cos qt$$

Here mQ is the maximum angular displacement for the side-band components. The instantaneous value of the angular velocity in this wave is equal to the time derivative of Φ and is given by

$$p_i = \frac{d}{dt} \Phi = np \pm qmQ \sin qt$$

showing that the frequency swings back and forth at a frequency proportional to the signal frequency and with an amplitude which is proportional to the signal frequency and the signal amplitude. The equation in the form of (2) then does not represent a true frequency modulated wave. If, however, the coefficient qmQ can be made independent of frequency, then there results a true frequency modulated wave and this is accomplished by the introduction of a loss device 20, shown in Fig. 3. Thus, if mQ_1 is the actual amplitude from the signal source and the

device 20 introduces a loss which is proportional to q then the amplitude on the output side of the loss device is given by

$$mQ = \frac{mQ_1}{q}$$

whereupon the current for the component in question is given by

$$i = A \cos (npt \pm mQ_1 \sin qt)$$

This will be recognized as the normal expression for a frequency modulated wave in which the swing from the carrier frequency is itself of signal frequency q and the amplitude of the frequency swing is proportional to the signal amplitude Q_1 . A similar loss device may be associated with the circuit of Fig. 4.

Fig. 6 is a further figure showing the use of high vacuum tubes for generating sharp impulses of a frequency controlled by a base frequency source and in which the timing of the pulses is biased in accordance with a low frequency signal. This circuit is also one in which certain limitations of gas discharge tubes are avoided. In the figure, 1 and 2 represent two similar pentode tubes, each containing a control grid g_1 , a screen grid g_2 , and a suppressor grid g_3 . With the circuit connections as shown the control grids are biased to a point at or near cut-off for the tubes. If a sinusoidal wave is coming through the transformer T_1 , and is in such a direction at a given instant as to raise the potential of g_1' then the tube 1 will commence to conduct whereas the tube 2 will not. As the sign of the incoming wave changes, the potential of the grid g_1' falls, reducing the current to the screen grid g_2' and thus raising the potential at the point 11 which increase of potential is transferred through condenser C' to control grid g_1'' . In time this will cause current to flow through tube 2, a part of it going to grid g_2'' . This lowers the potential of point 12 which transfers through condenser C'' and further lowers the potential of grid g_1' , thereby bringing it to well below cut-off. Thus, first one tube conducts and then the other; the transfer from the one to the other giving pulses in the primary windings of transformer T_2 , which yield pulses of short duration in the secondary. The circuit in this form will operate as an effective harmonic generator rich in harmonics.

If in addition one adds a signal biasing voltage as shown at Q , in the common portion of the grid circuit, then the pulses will be displaced in time phase approximately in proportion to the instantaneous amplitude of the biasing signal voltage.

The symmetry of the circuit of Fig. 6 is such that it is apparent that positive and negative pulses will be generated. It is pointed out, however, in the application of Wrathall referred to above, that to obtain a phase modulated wave it is necessary to suppress the pulses of the one sign. So in connection with this circuit, if it is desired to use a signal biasing voltage at Q for the purpose of obtaining a phase modulated wave, then it will be necessary to suppress the peaks of one sign by some means such as a rectifier 21 suitably introduced, as disclosed in the application of Wrathall.

It is apparent from the description given above that other high vacuum tube circuits which give rise to a series of pulses in synchronism with a base frequency may be used either as a frequency

multiplier of high efficiency or as a phase modulating circuit in the manner disclosed.

While the invention has been described primarily in terms of producing a phase or a frequency modulated wave it is to be understood that in a reciprocal manner it will serve as a demodulator, the incoming frequency modulated wave modifying the rate at which pulses are generated, which pulses are then integrated in any suitable manner to reproduce the desired signal.

What is claimed is:

1. A space discharge device comprising a primary electron section and a secondary electron emission section, said primary electron section including an electron-emitting cathode, an anode and a control grid, a source of base frequency waves coupled to said grid, an output circuit connected to said anode, means admitting electrons from said primary electron section under control of said grid to said secondary electron section to initiate secondary emission in the latter section, circuit connections for causing a voltage variation resulting from secondary electron emission in said latter section to react upon the grid in regenerative phase, whereby upon initially driving the potential of said grid positive the current in said primary section quickly rises to a maximum value under the influence of said secondary emission section to produce a sharp impulse of current in said output, and means comprising a source of signaling waves connected to a grid in said primary electron section for varying the phase in the cycle of said base frequency wave at which said impulse is produced, as a function of said signaling wave amplitude.

2. The combination defined in claim 1 including a condenser and resistance in series in said output circuit, between said cathode and anode, means to charge said capacity to place a positive potential on said anode prior to the production of said impulse, and means to discharge said condenser through the space path between said cathode and anode to produce said impulse, said discharge acting to reduce the anode potential to a value to interrupt passage of electrons into said secondary emission section.

3. A phase modulating system comprising a

source of high frequency waves whose phase is to be modulated and a source of signaling waves, means under control of said high frequency wave for producing a sharp impulse of current per cycle of said high frequency wave, said means comprising a grid controlled space discharge device having a main space discharge space and having a secondary electron emission electrode, means controlled by said grid for driving electrons against said electrode for producing secondary emission therefrom thereby to vary the potential of said electrode, a circuit causing the potential changes of said secondary emission electrode to react in regenerative phase upon said grid to increase the space current whereby said sharp impulse of current per cycle of said high frequency wave is produced, and means causing said signaling wave to exercise a control upon the space current to vary the timing within the high frequency cycle at which said sharp impulse of current is produced, dependent upon the instantaneous amplitude of signaling wave, whereby the phase of said high frequency wave is modulated by said signal wave.

4. In a modulating system, a source of high frequency waves to be modulated, a source of signal waves, a controlled oscillator comprising a space discharge device having a main discharge space, a control grid and an output circuit, said device having also a secondary emission electrode positioned to receive emission from said main discharge space, a circuit causing the potential changes of said secondary emission electrode produced by changes in secondary emission therefrom to react upon the grid in phase with the impressed grid potential, means to impress said high frequency waves upon the grid to control the current in the output circuit, said grid and secondary emission electrode cooperating to build up the current, once started, to a sharp impulse in the output circuit, once per cycle of said high frequency wave, and means causing said signal wave to vary the internal impedance of said discharge space at signal frequency to vary in accordance with signal amplitude the timing of said impulse within the high frequency cycle, whereby the phase of the output high frequency wave is modulated by the signal wave.

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