July 25, 1950 J. R. TILLMAN 2,516,812

ELECTRON DISCHARGE TUBE CIRCUITS

Filed Nov. 12, 1946 2 Sheets-Sheet 1

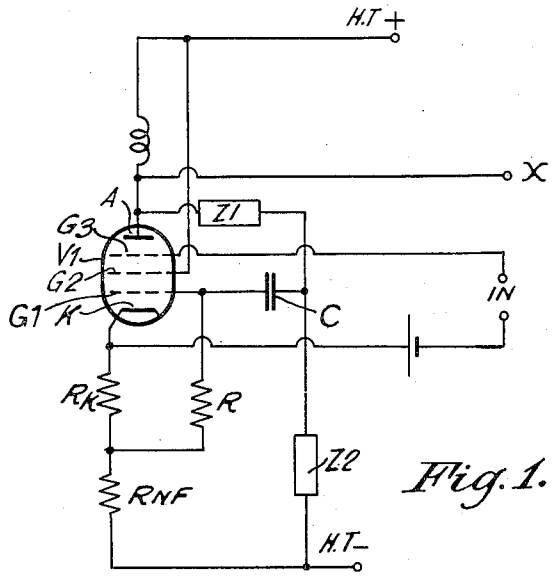


Fig. 1.

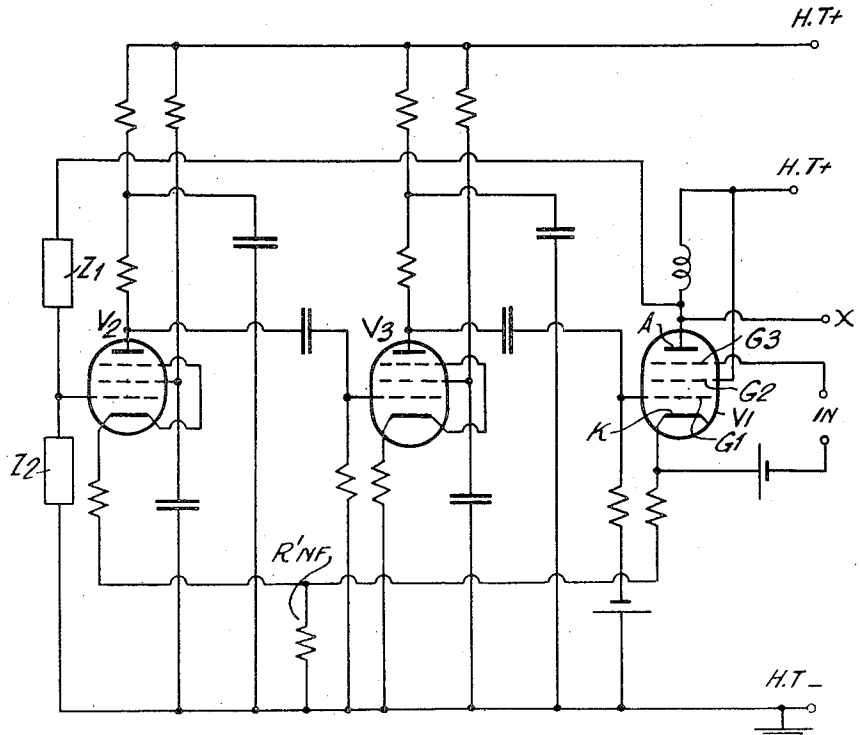


Fig. 2.

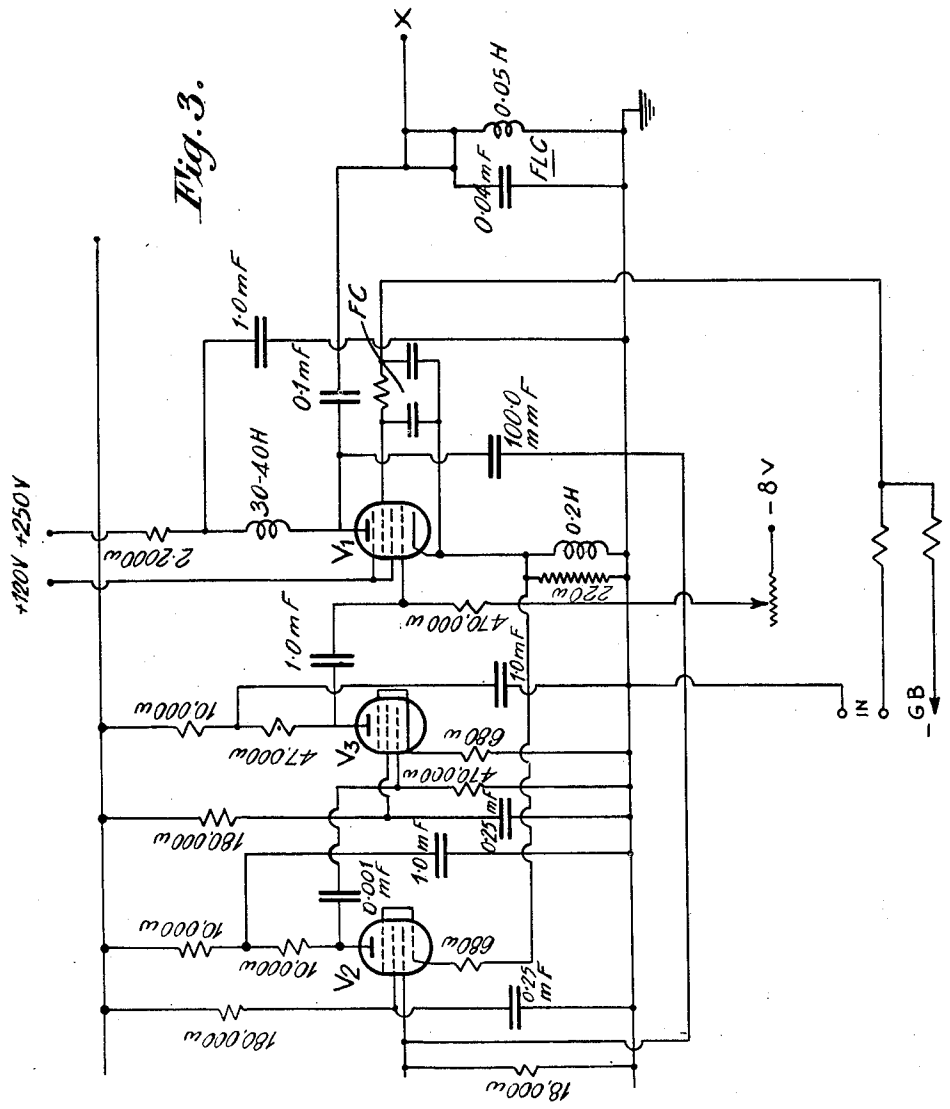
INVENTOR
JOHN RICHARD TILLMAN,
Chas. M. Candy
ATTORNEY

July 25, 1950 J. R. TILLMAN 2,516,812

ELECTRON DISCHARGE TUBE CIRCUITS

Filed Nov. 12, 1946 2 Sheets-Sheet 2

Fig. 3.



INVENTOR

JOHN RICHARD TILLMAN,

Chas. M. Candy

ATTORNEY

Patented July 25, 1950 2,516,812

UNITED STATES PATENT OFFICE

2,516,812

ELECTRON DISCHARGE TUBE CIRCUITS

John Richard Tillman, North Harrow, England

Application November 12, 1946, Serial No. 709,339
In Great Britain November 14, 1945

2 Claims. (Cl. 332—28)

1

This invention relates to variable impedance electron discharge tube circuit arrangements that is to say to discharge tube circuit arrangements in which one or more discharge tubes is or are employed to act as variable impedance means presenting variable impedance (usually though not necessarily variable reactance) of a value which is controlled in dependence upon a control signal.

The use of a discharge tube as a variable reactance is well known and a number of circuits in which a tube is so employed has been proposed.

There are numerous practical applications for a variable impedance discharge tube circuit, one of the most important being that in which the circuit is utilised to effect frequency modulation. In such an application the tube which is to present variable impedance is usually arranged to provide part of the reactance in a frequency determining circuit of an oscillator and the reactance so provided is caused to vary in dependence upon the instantaneous amplitude of a modulating wave so that the frequency of the oscillator is modulated in accordance with the said modulating wave.

In one well known form of variable reactance electron discharge tube circuit arrangement the variable reactance is obtained between the anode and cathode of the tube and, where the tube is to be employed to control the frequency of an oscillator, these electrodes are connected across the normally provided parallel tuned circuit of said oscillator so that the effective reactance presented between them is included therein. A voltage, nominally in quadrature with that between anode and cathode of the tube is applied between the control grid and the cathode and a modulating or other control voltage. is superimposed upon the said voltage in series in the same grid circuit. The effect of the modulating voltage is to vary the operating conditions of the grid circuit and therefore the instantaneous value of the mutual conductance of the tube, thereby varying the reactance (more strictly the susceptance) between anode and cathode and consequently the operating frequency of the oscillator. Over some limited range (depending upon the tube and circuit parameters) the relationship between susceptance and modulating voltage amplitude is substantially linear—a common requirement.

In another known type of variable reactance electron discharge tube circuit arrangement a multi-electrode tube, e. g. a pentode or hexode, is employed and the quadrature and modulating or controlling voltages are applied to different grids instead of to the same grid, the quadrature voltage being applied to one control grid and the modulating voltage being applied to another grid

2

which is nearer the anode so as to serve to control the proportion of the total emitted cathode current reaching the anode.

These and other known variable reactance electron discharge tube circuit arrangements have the important defect of lacking stability or constancy of performance, the reactance presented for a given amplitude of modulating or control voltage being by no means always the same in a given circuit. Even in the absence of any control or modulating voltage the change of anode current with respect to change of voltage on the grid receiving the quadrature voltage is dependent, inter alia, on the H. T. voltage, the L. T. voltage and ageing of the tube and the susceptance manifested is therefore similarly dependent on these factors. Although the adverse results of this can be reduced by stabilising the H. T. and L. T. voltages, stabilisation of L. T. voltage is often difficult and there still remains inconstancy due to tube ageing. It has been proposed to meet the difficulty by providing additional circuits for stabilising the center frequency but such proposals obviously involve additional circuit complexity and, moreover, are not suitable for application in the not uncommon case in which the modulating or control voltage includes a unidirectional component.

The present invention seeks to avoid these defects and to provide relatively simple variable impedance discharge tube circuits of high stability.

According to this invention a variable impedance discharge tube circuit arrangement comprises a tube having at least a cathode, two control electrodes and an output electrode; means for subjecting one of said control electrodes and said output electrode to voltages which are in predetermined phase relation (in quadrature where pure reactance is required) means for applying a controlling voltage to another of said control electrodes; and means for applying degeneration of said one control electrode so as to make the change of cathode current with respect to the potential on said one control electrode approximately independent of its value in the absence of degeneration, said other control electrode having little effect on the total cathode current but serving to control the proportion of said current reaching the output electrode.

The degeneration may be applied directly across the tube or it may be applied by means of additional discharge tube circuits provided for the purpose.

Where the tube is a pentode the controlling voltage is preferably applied to the suppressor grid and the other input voltage (the phase voltage) to the control grid. Where the tube is a hexode or tube including still more electrodes

the latter voltage is preferably applied to the first control grid and the controlling voltage to the second control grid. In either case the screen grid (between the two input grids) is held at some anchored potential in the ordinary way.

It will be seen that, with an arrangement in accordance with this invention, although the proportion of cathode current reaching the output electrode and determined by the controlling voltage is dependent upon the geometry of the tube (which is a relatively stable factor) and on the operating potentials of the electrodes subsequent to the first input grid it is substantially independent of the magnitude of the cathode current. Thus, if I_A is the output electrode (normally the anode) current; V_G is the voltage on the control electrode (normally the first control electrode) receiving the phased voltage; I_K is the total cathode current; and ρ the fraction of the total cathode current reaching the anode. (This varies substantially linearly with the voltage on the second input grid.)

$$\frac{dI_A}{dV_G}=\rho\frac{dI_K}{dV_G}$$

and, in the presence of the applied degeneration will be substantially independent of I_K and of the value of

$$\frac{dI_K}{dV_G}$$

in the absence of degeneration.

The invention is illustrated in the accompanying drawings which show, by way of example, three circuit embodiments in accordance therewith, for providing variable reactance.

Fig. 1 discloses a pentode tube arranged in a circuit so as to act as a variable reactance tube, with degeneration applied to the control electrode to give high stability.

Fig. 2 is a modification of Fig. 1 in that two amplifier tubes are included in the degeneration and phase shifting circuits.

Fig. 3 shows a practical electrical circuit utilizing the invention.

Referring to Fig. 1 a pentode V_1 having a cathode K, three grids G1, G2, G3 and anode A is employed as a variable reactance tube to manifest controllable reactance between a terminal X connected to the anode and earth. Anode and screen grid potentials are applied from a stabilised source (not shown) connected between H. T.+ and H. T.—. The cathode leg of the tube contains two series resistances R_K and R_{NF} of values represented by these references and the anode-earth circuit contains two series impedances Z_1Z_2 dimensioned in accordance with well known principles. The control grid G1 is connected to the junction point of Z_1Z_2 through the condenser C and also to the junction of the resistances R_KR_{NF} through the resistance R. In this way the grid G1 receives quadrature voltage (i. e. voltage in quadrature with that on the anode A) and is also subjected to negative feed back or degeneration. A modulating or other controlling signal wave is applied at terminals IN between the suppressor grid G3 and the cathode, the lead to the latter electrode including a bias source if required.

With this arrangement g_K is the value of

$$\frac{dI_K}{dV_{G1}}$$

(where V_{G1} is the voltage on the grid G1) in the

presence of degeneration—i. e. with the circuit as shown; and g_{KO} is the value when degeneration is removed—i. e. when R_K+R_{NF} is made effectively equal to zero (e. g. by by-passing these resistances with a large capacity) then

$$g_K=\frac{g_{KO}}{1+g_{KO}(R_K+R_{NF})}$$

By making $(R_K+R_{NF})\ g_{KO}$ large as compared to unity g_K may be made to approach closely to the value

$$\frac{1}{R_K+R_{NF}}$$

with obviously greatly improved stability as compared with g_{KO}.

A defect of the circuit shown in Fig. 1 is that the application of any considerable amount of degeneration results in a low value for g_K and, for some purposes, this may be a serious disadvantage. In such cases the defect may be avoided by modifying the circuit by providing for voltage step-up between Z_2 and G1, e. g. by replacing the condenser C by a step-up transformer or coupling Z_2 to G1, through a stable amplifier. If the signal input circuit connected at IN is required to have one side "earthy" the resistances R_KR_{NF} should be shunted by an inductance of high inductive value and low ohmic resistance, and a low pass filter or some equivalent arrangement provided to pass the desired input to the second input grid while excluding undesired high frequency input thereto.

In the modification shown in Fig. 2 two additional tubes V_2V_3 are provided for applying degeneration and the quadrature voltage, taken as in Fig. 1 from across Z_2 is applied to the first grid of tube V_2 and thence via V_3 to the grid G1 of V_1. As will be apparent the negative feed back loop includes the cathode circuit of V_1 and the circuits of the tubes V_2 and V_3 to the grid G1 of tube V_1. If, when the resistance R'_{NF} is reduced to zero, i. e. in the absence of degeneration, the voltage gain from the first control grid of V_2 to G1 of V_1, is μ; g_0 represents

$$\frac{dIk}{dV_{G1}}$$

(for tube V_1) under these conditions; and

$$\frac{dIk}{dV_{G12}}$$

is the rate of change of cathode current of V_1 with change of voltage on the first grid of V_2; then, the value g of

$$\frac{dIk}{dV_{G12}}$$

when the resistance R'_{NF} is inserted is given by

$$g=\frac{\mu g_0}{1+\mu g_0 R'_{NF}}$$

If

$$\mu g_0 R'_{NF}$$

is much larger than unity g becomes nearly equal to

$$\frac{1}{R'_{NF}}$$

and

$$\frac{dIk}{dV_{G12}}$$

becomes very nearly equal to

$$\frac{1}{R'_{NF}}$$

and is substantially independent of the cathode current I_K of tube V_1 whence it follows that the required stabilisation is obtained.

Although the introduction of the additional tubes V_2V_3 introduces new variables, notably variation of μ with tube ageing, the stability of the susceptance produced is still very high because all the components likely to vary with time are in the feed back loop. As before the circuits of the grids G_2 and G_3 and of the anode A of tube V_1 are not in the feed back loop. If desired negative feed back may be applied to either or both of the tubes V_2V_3, either separately or across them both, in addition to the overall feed back illustrated.

With this arrangement, as the amount of degeneration is increased from zero the stability improves until a maximum is obtained after which additional degeneration produces no further improvement. This limiting value occurs by reason of the fact that the magnitude of I_K has some influence on ρ the influence being less the smaller the value of I_K. As I_K is reduced to overcome this effect g_0 also becomes smaller and accordingly a larger gain is required from V_2 and V_3 (for a given degree of stability) to maintain a given amount of degeneration without the value of g becoming smaller. In practice it is unnecessary to reduce I_K indefinitely to secure maximum stability for if the current is controlled in some way, e. g. by providing a control of the bias voltage of V_{G1} in tube V_1 and there is a moderate amount of feedback, e. g. 10–30 times it will be found that it is possible to adjust I_K to a value such that the residual dependence of g on cathode emission changes (due for example to ageing of the tube) is balanced by the dependence of ρ on I_K. It is therefore preferred to provide for manual adjustment of the (steady) cathode current of I_K for by operating such adjustment it is possible, by trial and error, to achieve a very high degree of stability, g_0 and g falling (to an extent reduced by the degeneration) as the cathode emission falls (with ageing) but ρ increasing therewith.

Fig. 3 shows a practical circuit in which the invention is employed for frequency modulation. In view of the description of Fig. 2 it is thought that Fig. 3 will be largely self explanatory. Modulating potentials are applied at IN to the second input grid of tube V_1 through a filter circuit FC the components of which are chosen to suit the frequency range of the modulating signals and exclude the high frequency. For the sake of giving maximum information suitable values of components are indicated in the figure but it is, of course, to be understood that these are by way of example only. It will be noted that control is provided of the bias voltage for V_1. The inductance in the cathode lead of this tube should be of low ohmic resistance and the bias applied at —GB should be sufficient to operate the grid G_3 of V_1 about the middle of the substantially linear range of control. The terminal X is connected to the drive circuit (not shown) of the oscillator to be frequency modulated the fixed elements of the frequency determining circuit of which are shown at FLC. A circuit as represented in Fig. 3 can be designed for any of a wide range of modulating signals, either alternating or D. C. (telegraphic) signals.

If, for any reason, it is not desired to obtain the required variable reactance directly from between anode and cathode of a reactance tube connected in accordance with this invention, a load, preferably resistive, may be connected in the anode circuit and a highly degenerated amplifier coupled thereto, the quadrature voltage being then derived from the output current of the amplifier tube and the variable reactance (susceptance) being obtained from its output circuit. Any of the illustrated embodiments can be modified in this way.

The invention is not limited to the particular circuits shown and many modifications may be made without departing from the scope thereof. Moreover, although the invention has been particularly described as applied to the provision of a variable reactance electron discharge tube circuit for frequency modulation purposes, it will be apparent that the said invention is not limited to this application but has numerous other applications, e. g. for automatic tuning purposes.

In the description of the drawings reference has been made throughout to variable reactance tube circuit arrangements and to the application of a quadrature input voltage. The invention is obviously not limited to arrangements in which a pure reactance is manifested and if desired a reactive impedance effect may be provided, i. e. the "reactance tube" may be arranged to provide a resistive as well as a reactive component. In such a case the "quadrature input" will not be quadrature but will be at a phase angle removed from 90° by an amount dependent on the resistive component required.

I claim:

1. In a frequency modulating system, an electronic discharge device connected to comprise a part of the impedance of the frequency determining circuit of an oscillator, an anode, a cathode and a plurality of grids in said device, a circuit connected between said cathode and anode including a pair of impedance devices and a pair of resistances, a connection including a third resistance from a point between said pair of resistances to the control grid of the device, a second connection including a condenser from a point between said impedances to said control grid, and a modulating circuit connected between the cathode and another grid to vary the gain of the device to in turn vary the frequency of the oscillator.

2. A frequency modulating system as claimed in claim 1 wherein said first connection includes additional discharge devices serving as amplifiers.

JOHN RICHARD TILLMAN.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,255,746	Brailsford	Sept. 16, 1941
2,279,661	Crosby	Apr. 14, 1942
2,382,436	Marble	Aug. 14, 1945
2,445,508	Beleskas	July 20, 1948

FOREIGN PATENTS

Number	Country	Date
450,136	Great Britain	July 6, 1936