

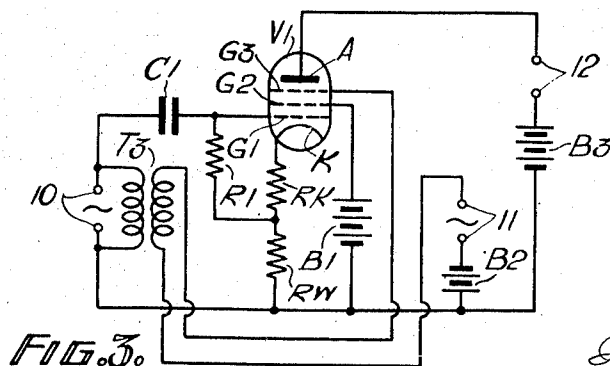
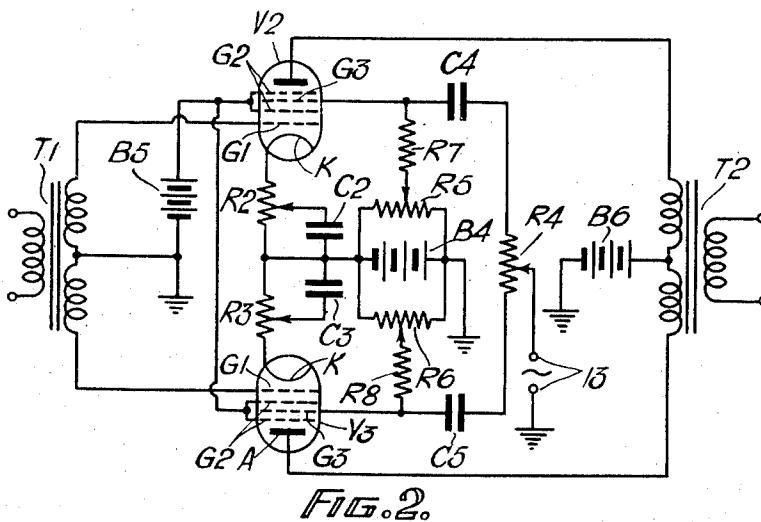
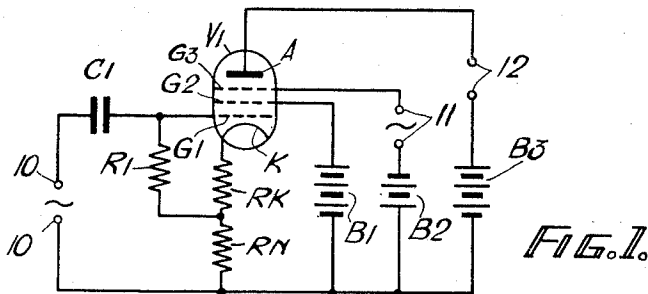
April 18, 1950

J. R. TILLMAN

VALVE MODULATOR

Filed Nov. 13, 1946

2,504,469



Inventor:

John Richard Tillman,

By: Pierce, Scheffler & Parker,
Attorneys.

UNITED STATES PATENT OFFICE

2,504,469

VALVE MODULATOR

John Richard Tillman, North Harrow, England,
assignor to Telephone Manufacturing Com-
pany Limited, London, England

Application November 13, 1946, Serial No. 709,655
In Great Britain November 14, 1945

9 Claims. (Cl. 332-44)

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This invention relates to thermionic valve modulating systems and has for its object to provide an improved form of modulator which is stable in operation and is less dependent upon variations of the supply potentials and ageing of the valves than has hitherto been possible. The invention also has for an object the provision of a system for modulating one signal voltage by a second, in which the results of modulation, other than the sum and difference frequencies, may be largely or completely eliminated from the output of the modulator.

The present invention makes use of a multi-electrode valve of a type in which (a) the cathode current is dependent upon the potentials of two grids with respect to the cathode and substantially independent of the potential of any other electrodes and which varies approximately linearly over at least a portion of the permissible range of variation of voltage of the first grid and (b) the fraction of the cathode current which reaches the anode is dependent on the potential of a third electrode (usually considered as a second control grid) and is approximately linear over at least a portion of the permissible range of variation of this electrode. Most modern multi-electrode valves, with suitable operating potentials, satisfy these two requirements.

With the present invention there is provided a thermionic valve system for modulating together two signal voltages, comprising a thermionic valve of the type described, means for applying said signal voltages to the said control grids, and means for applying a negative feedback voltage of value, whereby the component of the output current of the valve of a frequency the same as that of one of the signal voltages is eliminated.

The invention also comprises a thermionic valve system for modulating together two signal voltages, comprising two thermionic valves of the type described, means for applying one of the signal voltages in phase opposition to the corresponding control grids of said valves, means for applying the other of said signal voltages in the same phase to the other of said control grids of said valves, and means for applying negative feedback to said control grids whereby the operation of said modulator is stabilised.

It is to be understood that modulation comprises broadly the combination of two signal voltages in a manner to produce at least some components of frequencies which are related to the frequencies of both the signal voltages. Thus the term modulation includes, for example, the demodulation of a suppressed-carrier wave signal.

In the accompanying drawing are illustrated certain features of the invention including one practical embodiment thereof. In this drawing, Figure 1 is a simplified circuit arrangement, employing a single valve, from which circuit con-

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siderations may be deduced; Figure 2 is a preferred practical arrangement embodying two valves, and Figure 3 shows a circuit modification.

In the arrangement shown in Figure 1, the valve V1 comprises a cathode K, an anode A, and three interposed grids G1, G2 and G3, although further grids may be included, subject to the conditions set out above that the cathode current is controlled by the potential of grids G1 and G2 with respect to the cathode and is substantially independent of the potential of the grid G3, while the fraction of the space current which reaches the anode is determined by the potential of grid G3, both grids G1 and G3 having a linear rate of control over at least a portion of the permissible range of variations.

The valve V1 may be of the pentode type in which case G1 is the normal control grid, G2 the screening grid and G3 the suppressor grid, but for convenience the suppressor grid may be referred to as the second control grid. If the valve is a hexode or octode valve, the grids G1 and G3 are the two control grids and grid G2 is the screening grid.

The valve V1 is adapted to have a suitable voltage impressed upon the grid G2 from a source B1, upon the grid G3 from a source B2 and upon the anode from a source B3. Signal voltage may be applied from terminals 10 to the grid G1 through a condenser C1. The cathode current of the valve is passed through two serially connected resistances R_K and R_N, and a grid resistance R1 is returned to the junction of these resistances. It is to be noted that the resistances R_K and R_N are not by-passed by condensers and that the input circuit includes both resistances. The valve operates as a negative feedback amplifier for signal voltage E1 impressed across terminals 10 in view of the potential drop established across the resistances by the cathode current component of the signal frequency. A signal voltage may also be applied from terminals 11, in series with the source B2, to grid G3 and the output of the valve may be derived from terminals 12.

Within the linear range of variation of the control grid G1, and with a constant potential V_{G3} impressed on the grid G2 by the source B1, the cathode current I_K is given by:

$$I_K = I_0 + g(V_{G1} - V_1) \quad (1)$$

where V_{G1} is the potential of grid G1 with respect to the cathode, I₀ is the cathode current at a certain reference value V₁ of the potential of grid G1, and g is the mutual conductance of the valve as measured by

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

It follows that

$$I_K = I_0 + g(-R_K I_K - V_1) \quad (2)$$

For simplification we may put $V_1 = -R_K I_0$, and then $I_0 = I_K$.

If now an alternating voltage $E_1 \cos pt$ is applied to terminals 10 in Figure 1, and the frequency $p/2\pi$ is sufficiently high for the impedance of the condenser C1 to be negligible

$$I_K = I_0 + g\{E_1 \cos pt - (R_K + R_N)(I_K - I_0)\} \quad (3)$$

Putting $R_K + R_N = R$

$$I_K = I_0 + g\{E_1 \cos pt - R(I_K - I_0)\} \quad (4)$$

whence

$$I_K = I_0 + \frac{gE_1 \cos pt}{1 + gR} \quad (5)$$

The anode current I_A is related to the cathode current, for given voltages V_A and V_{G2} of the anode and grid G2 respectively by an expression of the form

$$I_A = I_K \left(k + \frac{V_{G2} - V_3}{V} \right) \quad (6)$$

where V_{G2} is the instantaneous potential of the second control grid with respect to the cathode, k is the fraction of the cathode current I_K going to the anode when $V_{G2} = V_3$, V_3 being a constant, and V is a property of the valve. In the case of Figure 1

$$V_3 = (-RI_0 + V_4) \quad (7)$$

where V_4 is the voltage due to the source B2.

If $E_1 = 0$, and a voltage $E_2 \cos qt$ is applied to terminals 11 of Figure 1 it will be seen that

$$V_{G2} = (-RI_0 + V_4 + E_2 \cos qt) \quad (8)$$

and from Equations 6, 7 and 8, it follows that

$$I_A = I_K \left(k + \frac{E_2 \cos qt}{V} \right) \quad (9)$$

If E_1 has a finite value, however

$$I_A = I_K \left\{ k + \frac{E_2 \cos qt}{V} - \frac{(I_K - I_0)R}{V} \right\}$$

Substituting from (5) above:

$$\begin{aligned} I_A &= \left\{ I_0 + g \frac{E_1 \cos pt}{(1 + gR)} \right\} \left\{ k + \frac{E_2 \cos qt}{V} - \frac{RgE_1 \cos pt}{V(1 + gR)} \right\} \\ &= I_0 k + \left(k - \frac{RI_0}{V} \right) g \frac{E_1 \cos pt}{(1 + gR)} + \frac{gE_1 E_2}{2(1 + gR)V} \{ \cos(p+q)t + \cos(p-q)t \} \\ &\quad + I_0 \frac{E_2 \cos qt}{V} - \frac{g^2 R E_1^2 (\cos 2pt + 1)}{2V(1 + gR)^2} \end{aligned} \quad (10)$$

If R is made equal to

$$\frac{kV}{I_0}$$

the term containing pt vanishes, so that the output contains no component of frequency $p/2\pi$.

In a similar way, it can be shown that if the valve V1 is given inputs to its first and second grids respectively of $-E_1 \cos pt$ and $E_2 \cos qt$, the anode current is given by

$$\begin{aligned} I_A &= I_0 k - \frac{gE_1 E_2}{2(1 + gR)V} \{ \cos(p+q)t + \cos(p-q)t \} + \\ &\quad - I_0 \frac{E_2 \cos qt}{V} - \frac{g^2 R E_1^2}{2V(1 + gR)^2} (\cos 2pt + 1) \end{aligned} \quad (11)$$

the term in $\cos pt$ also being reduced to zero if

$$R = \frac{kV}{I_0}$$

If two valves are employed, having anode currents given by (10) and (11) above, and the anode currents are combined in opposition to each other, the resultant current, given by the differ-

ence of the expressions for I_A in Equations 10 and 11 is

$$\frac{gE_1 E_2}{(1 + gR)V} \{ \cos(p+q)t + \cos(p-q)t \} \quad (12)$$

In this way all products of modulation except the sum and difference frequencies can be eliminated.

If the two valves are not identical with respect to

$$\frac{kV}{I_0}$$

complete suppression of the components of the output corresponding to the terms containing $\cos pt$ can be effected by making the value of R for each valve equal to the respective value of

$$\frac{kV}{I_0}$$

If the two valves are not identical with respect to

$$\frac{I_0}{V}$$

complete suppression of the component of the output corresponding to the terms containing $\cos qt$ can be effected by changing the relative values of the signal voltage corresponding to $\cos qt$ applied to the two valves.

If the two valves are not identical with respect to

$$\frac{g^2 R}{V(1 + gR)^2}$$

the component of the output corresponding to the term containing $\cos 2pt$ can still be eliminated by altering the relative values of the signal voltages corresponding to $\cos pt$ applied to the two valves.

By differentiating the coefficient of the terms in $(p+q)t$ and $(p-q)t$ with respect to g , it will be seen that the dependence of the level of the wanted components of the output on changes of

g , due to changes of cathode heater voltage or ageing of the valve is reduced in the ratio of

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$$1: \frac{1}{(1 + gR)}$$

and considerable improvement in the stability of the circuit is thus possible.

A circuit arrangement by which the desired result may be achieved is shown in Figure 2. In this arrangement use is made of two valves V2, V3 of the hexode type, the said hexode sections each comprising a cathode K, first control grid G1, a double screening grid G2, a second control grid G3 and an anode A.

One of the two signal voltages, say that of frequency $p/2\pi$ is applied to the primary winding of an input transformer T1, the secondary windings of which feed the first control grids G1 of the two valves. A suitable potential is applied to the screening grids G2 by means of the source B5 and may be of the order of 100 volts.

The cathode circuits of the valves include two resistances R2 and R3 respectively of each of

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which an adjustable portion may be shunted by condensers C2, C3 respectively; these condensers must have sufficiently low impedance at the working frequencies to ensure that the effective values of the resistances are those of the unshunted portions thereof. The junction of resistances R2 and R3 is connected to the negative terminal of a voltage source B4, of which the positive terminal is earthed. This source may be of the order of 24 volts.

The second signal voltage is applied in parallel, that is, in the same phase, to the two control grids G3 from input terminals 13, the input circuits including isolating condensers C4, C5, and a tapped resistance R4 connected in the manner shown for the purpose of varying slightly the relative inputs to the two valves. The steady potentials upon the second control grids are also made adjustable, in this case by the inclusion of tapped resistances R5, R6 to the taps of which the grids are connected through high resistances R7, R8, the resistances R5 and R6 being connected across the terminals of the source B4.

The anode circuits of the valves are completed through the primary windings of the output transformer T2 of which the secondary winding supplies the load circuit.

It will be understood that the circuit described with reference to Figure 2 is illustrative only, and that it may be modified in details in known manner. In practice, for example, the voltage sources B5 and B6 may be combined into a single source.

In operation, where it is desired to modulate a carrier wave with another signal voltage, for example in a carrier wave telephone system, the carrier wave may be applied either to the transformer T1 or to the terminals 13, the latter being preferred.

The output transformer T2 must be so wound that the two primary windings are as similar as possible and should have the same number of turns in order that the voltages induced in the secondary winding due to the input signal at the second control grids of the valves shall have relative amplitudes and phases which enable sufficiently good balancing of the output signals of the same frequency as that signal ($q/2\pi$) to be achieved.

If this condition is not exactly fulfilled, improvement can be effected by connecting a condenser of suitable value across one or other of the windings.

The primary-secondary turns ratio will be determined by the load requirements.

The ratio of the input transformer T1 will also be determined by the impedance of the primary and secondary circuits. It will be understood that where antiphase signals are available or are derived by other means, the input transformer may be dispensed with. A device other than a transformer may be used to combine the anode currents of the two valves, thereby dispensing with the output transformer T2.

In one arrangement as shown in Figure 2, and using pentode valves, the voltage applied to the input transformer T1 produced at each of the first control grids a voltage of the order of 1.2 volts R. M. S., and the other signal voltage was about 3; the bias on the grids G3 with respect to the cathodes was about 12 volts negative, the potential of grids G2 being 100 volts, as previously described, and that of the anodes 200 volts.

With this particular arrangement, it was possible to obtain an output of the side band components stable to ± 0.1 db. with changes of

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$\pm 20\%$ of the cathode heater voltage of the valves. The unwanted components, of frequency $p/2\pi$ and $q/2\pi$, were each 40 db. below the value of either side band at the optimum settings.

The mathematical treatment given with respect to Figure 1 is subject to the limitation that the applied voltage variations are confined to the limits of linearity of the two control grids. In practice, this is a condition which by suitable choice of valves can be approximated sufficiently closely, particularly as regards the first control grid, for a large number of applications, but if for any reason the magnitude of the signal applied to the second control grid involves operation beyond the linear portion of the curve, the stability of the side-band components and the balancing out of the component of frequency $p/2\pi$ is unaffected.

The operation of the modulator in the non-linear area will give rise, as is well known, to the production of various components of frequencies

$$\left(\frac{np \pm mq}{2\pi}\right)$$

where m and n have a wide range of integral values. If operation is non-linear for the second control grid only, to which is applied the signal of frequency $q/2\pi$, n is largely restricted to the values it has in the analysis given previously. The production of these other components may or may not be useful, and the circuit operated accordingly.

If the signal applied to the second control grid is so large as to drive the grid up to or beyond the point of anode current cut-off or into grid current area, the output level of the side band component is substantially independent of the magnitude of the applied voltage, and despite the additional components produced, this may be of benefit in certain applications. When operating in this manner, the circuit is still very stable, and the component of frequency $p/2\pi$ can still be successfully eliminated from the output, but the component of frequency $q/2\pi$ can be eliminated only by altering the relative value of the components of this frequency in the output for example, by changing the turns ratio of the primary winding of the output transformer.

As described above, the improvement in stability of the desired components of the output obtained by decreasing the dependence upon the mutual conductance of the valve is in the ratio of

$$1: \left(\frac{1}{1+gR}\right)$$

but this improvement may be increased by making R of value greater than

$$\frac{kV}{I_0}$$

as required for the elimination of the output component corresponding to $\cos pt$. Normally this will result in the reintroduction of this component in the output, but this may be again eliminated by introducing a balancing signal into the second control grid.

Such a modification is shown in Figure 3, which corresponds to Figure 1 except for the incorporation of a transformer T3 having its primary winding supplied from terminals 10, and of which the secondary winding is included in series with the input to the second control grid, in the correct phase to cancel the unwanted component in the output.

In this arrangement R may be substantially larger than

$$\frac{kV}{I_0}$$

improving stability but producing in the output a component of frequency $p/2\pi$. By suitable adjustment of the voltage injected into the circuit of the grid G3 however, this component can again be balanced out. If, for any reason, R is required to be less than

$$\frac{kV}{I_0}$$

the transformer T3 may also be used, with the appropriate phase of its secondary winding to effect the desired balancing out of the unwanted signal.

I claim:

1. A thermionic valve system for modulating together two signal voltages, comprising a thermionic valve including a pair of control grids and a third grid cooperating with a cathode and an anode, means for applying said signal voltages to the said control grids, and means to eliminate from the valve output current components of the frequency of one of the signal voltages; said component-eliminating means including means for impressing upon a control grid a negative feedback voltage of the frequency of the signal voltage applied to that grid.

2. A thermionic valve system for modulating together two signal voltages, comprising two thermionic valves each including a pair of control grids and a third grid cooperating with a cathode and an anode, means for applying one of the signal voltages in phase opposition to the corresponding control grids of said valves, means for applying the other of said signal voltages in the same phase to the other of said control grids of said valves, and means for applying negative feedback to said control grids whereby the operation of said modulator is stabilized.

3. A thermionic valve system for modulating together two signal voltages, comprising two thermionic valves each including a pair of control grids and a third grid cooperating with a cathode and an anode, means for applying one of the signal voltages in phase opposition to the corresponding control grids of said valves, means for applying the other of said signal voltages in the same phase to the other of said control grids of said valves, and means for applying individually adjustable negative feedback to the respec-

tive valves whereby the operation of said modulator is stabilized.

4. A thermionic valve system according to claim 2, wherein said negative feedback means includes circuit elements of such value as to eliminate from the output of said valves a component of frequency equal to that of the voltage applied in phase opposition to said valves.

5. A thermionic valve system according to claim 2, wherein means are provided to eliminate, in a common output from said valves, a component of frequency equal to that of the voltage applied to said valves in the same phase.

6. A thermionic valve system according to claim 2, wherein said valves are operated within the limits of linear variation of the anode current by said control grids, and wherein means are provided to substantially eliminate from a common output from said valves all components except those of the sum and difference frequencies of said signal voltages.

7. A thermionic valve system according to claim 1; wherein an output circuit is connected between said cathode and said anode, and said negative feed back voltage means comprises an impedance in said output circuit and connected between said cathode and the control grid upon which is impressed said signal voltage which is eliminated in the output circuit.

8. A thermionic valve system according to claim 2, and comprising means for adjusting relatively the degree of negative feedback applied to said valves, and the amplitude of the signal voltage applied in the same phase to said valves.

9. A thermionic valve system according to claim 3 and comprising means for varying relatively the amplitude of the signal voltage applied in phase opposition to said valves.

JOHN RICHARD TILLMAN.

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