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THERMIONIC VALVE CIRCUIT HAVING A CONSTANT OUTPUT

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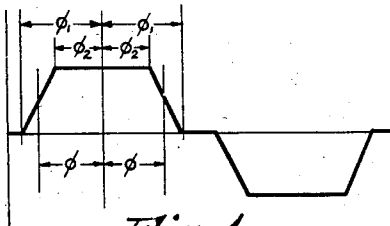


FIG. 1.

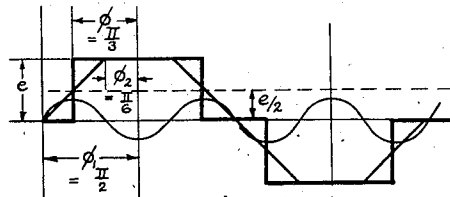


FIG. 2.

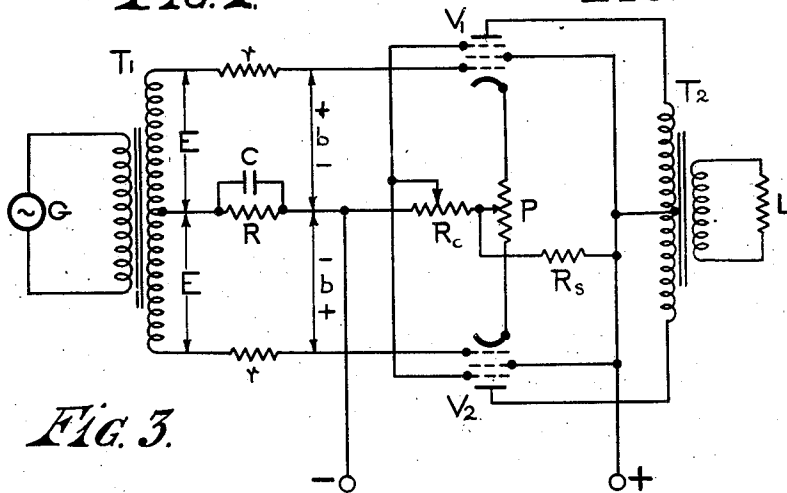


FIG. 3.

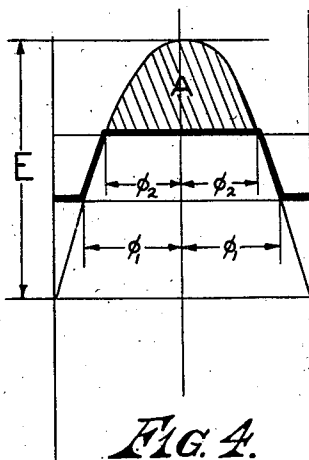


FIG. 4.

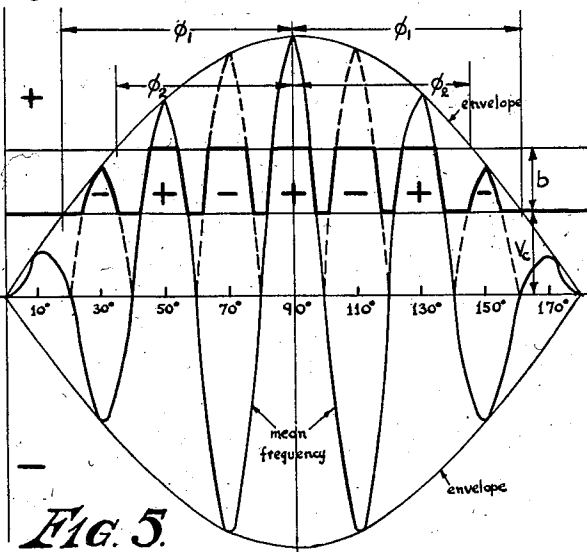


FIG. 5.

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THERMIONIC VALVE CIRCUIT HAVING A
CONSTANT OUTPUT

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7 Claims. (Cl. 250—27)

The present invention relates to thermionic valve circuits and is more particularly concerned with circuits which are adapted to suppress a portion of the input waveform to give an output waveform of trapezoidal shape.

It is known that a recurring waveform containing equal positive and negative trapezoids contains no even harmonics and a minimum of odd harmonics and it is an object of the present invention to arrange for the generation of a trapezoidal wave in which any given odd harmonic may be made negligible and if the given odd harmonic is the third, then the remaining harmonics will not exceed given percentage values.

According to one feature of the invention the thermionic valve circuit is so arranged that for varying amplitudes of the input waveform the amplitude and mean angular displacement of the output trapezoidal waveform remains substantially constant.

According to a further feature of the invention the thermionic valve circuit is so arranged that for varying amplitudes of the input waveform the mean angular displacement of the output trapezoidal waveform remains substantially constant and dependent upon the circuit parameters to enable odd harmonics of any desired order to be suppressed from the output waveform by a suitable choice of said parameters.

According to another feature of the invention the thermionic valve circuit comprises a pair of valves, in the grid circuits of which are provided a parallel connected condenser/resistance combination, a supply resistance, a source of biasing voltage and an input wave source, the thermionic valves being arranged to act as rectifiers and the values of the components being so chosen that for an input which causes grid current to flow the output waveform is of substantially constant amplitude and of trapezoidal shape as determined by the voltage developed across the condenser and by the voltage at which grid current flows and has a mean angular displacement dependent upon the ratio between the two resistances to enable mean angular displacement of the output trapezoidal waveform to remain substantially constant for varying amplitudes of the input.

It is pointed out that the sloping sides of the trapezoidal waveform obtained according to the invention may vary in inclination with variation

of input level but they do so about a point whose amplitude is one half the output amplitude per half cycle and whose time or angular displacement per half cycle is constant and of value dependent on the order of the odd harmonic which is to be made negligible in the output. The trapezoidal waveform is generated per half cycle of the input and in the same sense as the latter, so that the output consists of equal positive and negative trapezoidal waveforms and therefore contains no even harmonic components.

The words "trapezoid" or "trapezoidal" as used in this specification are intended to cover quadrilateral figures with two parallel sides having the ends thereof equally inclined to the parallel sides but in opposite senses, the expression is, however, also intended to cover figures of a very similar shape such as where the end sides are formed of parts of a half sine wave which parts are directly opposite to each other.

The invention will be better understood from the following description taken in conjunction with the accompanying drawing in which

Fig. 1 shows a typical waveform which it is desired to produce,

Fig. 2 shows certain waveforms necessary for an understanding of the invention,

Fig. 3 shows the circuit for obtaining the desired waveform,

Fig. 4 shows certain waveforms necessary for understanding the operation of the circuit and

Fig. 5 shows the manner of operation of the circuit with input waveforms of different frequencies.

It is well-known that a recurring waveform consisting of equal positive and negative trapezoids whose constant amplitude portion extends over an angular displacement of $\pm 30^\circ$ about the quarter cyclic time contains with respect to the fundamental no third harmonic, $\frac{1}{25}$ th of the fifth harmonic, $\frac{1}{49}$ th of the seventh harmonic and so on. Referring to Fig. 1 if $\phi 1$ and $\phi 2$ are defined as being the angular displacements from the quarter cyclic time during which the waveform changes at a linear rate, then $\phi 1$ will be 90° and $\phi 2$ will be 30° for the continuous trapezoidal waveform. The mean angle ϕ (from the quarter cycle) will be 60° , when the waveform has attained one-half its maximum amplitude. It is also well-known that a discontinuous rectangu-

lar wave whose constant output portion extends over $\pm 60^\circ$ about the quarter cyclic time, also contains no third harmonic, $\frac{1}{5}$ th of the fifth harmonic, $\frac{1}{7}$ th of the seventh harmonic, etc., with respect to the fundamental. This latter case may be attained from the former by keeping ϕ (the mean angle) constant and decreasing ϕ_1 to 60° and increasing ϕ_2 to 60° by equal increments, the intermediate waveforms being of the discontinuous trapezoid form. Hence the discontinuous rectangular waveform may be considered as a particular case of the trapezoidal form.

The reason why the two extreme cases of the trapezoidal wave form given above contain no third harmonic is that the mean angle ϕ is 60° (or $\pi/3$). This can be shown as follows:

The mathematical method for determining the amplitude of a given harmonic in a waveform consists of multiplying the expression for the waveform by the expression for the desired harmonic, integrating over 0 to 2π (i. e. one cycle), and dividing by π . For the present types of waveform having constant amplitude portions, the physical application of this method is very quick for demonstrating whether a particular harmonic is present. In performing this method it is best to make the multiplying harmonic commence in phase with the waveform.

To demonstrate this method consider the discontinuous rectangular waveform shown in Fig. 2, where $\phi_1 = \phi_2 = \phi = 60^\circ$, and draw an in phase third harmonic waveform as shown. Then if the latter be multiplied by the former, algebraically, and considering one-half cycle of the former, the first and last quarter cycles of the harmonic waveform contribute nothing, whilst the portion extending over the constant amplitude of the rectangular waveform results also in zero. Consideration of the second half cycle of the discontinuous rectangular waveform will show that a similar result will be obtained. Hence there can be no third harmonic in such a waveform, when $\phi = 60^\circ$ (or $\pi/3$).

Now let the vertical sides of the waveform be inclined about the half maximum amplitude point, so that $\phi_1 = 90^\circ$ and $\phi_2 = 30^\circ$, giving the continuous trapezoidal form. Then from inspection it will be seen that multiplying by the third harmonic will again give zero resultant per half cycle, and so no third harmonic is present. Similarly if the sides are inclined at any intermediate angle such that

$$\frac{\phi_1 + \phi_2}{2}$$

is 60° , again no third harmonic is present.

It will be noticed from the above that the criterion for the suppression of the given odd harmonic is that the mean angle shall represent an integral of the harmonic period with respect to the fundamental period (i. e. $\pi/3$ for the third, $\pi/5$ or $2\pi/5$ for the fifth, $\pi/7$, $2\pi/7$ or $5\pi/7$ for the seventh and so on). Hence making the mean angle equal to these quantities, with respect to the fundamental period, will ensure that these harmonics are respectively eliminated in the resulting waveform.

As regards the remaining harmonic percentages, these are best evaluated by the mathematical method, but in the case where the mean angle is 60° it can be seen that the maximum fifth, seventh, and so on harmonics will be those in the discontinuous rectangular form, which are 20%, 14.3% and so on respectively.

It will thus be appreciated that if such discon-

tinuous trapezoidal waveforms are generated in which the mean angle is kept substantially constant and this angle is given a particular value, a particular odd harmonic may be reduced to negligible proportions in the output. Further by providing means for adjusting the mean angle according to the waveform of the input any desired harmonic may be suppressed in the output.

Referring now to Fig. 3 a specific circuit arrangement will be described.

A full wave rectifying system is employed consisting of an input transformer T1 having a centre tapped secondary winding, the ends of the winding being connected via resistances r to the control grids of a pair of pentode thermionic valves V1 and V2. The cathodes are joined together over a potentiometer P, the tapping point of which is connected via a resistance R_c carrying a biasing current to the negative supply busbar. The polarity of the bias is such as to raise the cathode to a positive potential with respect to the negative busbar. The centre tap on the input transformer is taken via a resistance R shunted by a condenser C also to the negative busbar. It will be assumed that the valves are so biased that no anode current flows when no input is applied (although in practice a small anode current may be allowed to flow). The peak signal voltage between grid and negative busbar necessary just to cause grid current to flow will be termed b volts and is substantially the same as the bias voltage on R_c , and the change of output current for voltages between 0 and b may be made closely linear by suitably choosing R_c so as to give negative feedback. The output transformer T2 is connected in pushpull fashion to the anodes of the valves and feeds a load resistance L . It will be assumed that the change in anode currents for 0— b volts between each control grid and the negative busbar are equal.

The following more detailed analysis of the action of the circuit will be based on the full wave rectifying action of the grid/cathode paths, and it will be assumed as obvious that the production of an alternating output is due to the alternate action of the valves to each half cycle of the input. Referring to Fig. 4, a rectified half cycle of a sinusoidal input is shown, of maximum value E . If the alternating input be large enough to cause grid current to flow, then when a steady state condition is attained, a substantially steady voltage will appear on the condenser C (if the time constant CR is high compared with the periodicity of the input). Such voltage is represented by the line V_c , and the line above represents the operation voltage b of each valve (i. e. the voltage between grid and negative busbar just to produce grid current and hence a maximum change of anode current). The voltage b should be regarded as a battery whose E. M. F. opposes the positive grid voltage from the transformer while using the grid/current path as a rectifier maintains the potential on the condenser C . Since all that part of the input waveform lying outside the two lines defined above is suppressed from the point of the output, the waveform of the latter will be as shown in thick lines for one-half cycle, and is a close approximation to the desired discontinuous trapezoidal form, the condenser voltage being maintained by the flow of grid current over the top "cap" of the alternating input.

The quantity of electricity passing through r per half cycle, is the area A of the shaded top cap divided by r . Hence the mean current per

half cycle is $A/\pi r$ and must equal the steady direct current through R , which is also defined by Vc/R .
Hence

$$A = \frac{\pi r}{R} \cdot Vc = \frac{\pi r}{R} (E \cos \phi_2 - b) \quad (1)$$

But

$$A = 2(E \sin \phi_2 - Vc \phi_2) = 2E(\sin \phi_2 - \phi_2 \cos \phi_2) \quad (2)$$

Hence

$$\frac{\sin \phi_2 - \phi_2 \cos \phi_2}{\cos \phi_2 - \frac{b}{E}} = \frac{r}{2R}$$

This equation defines ϕ_2 but is not in a convenient form for calculation; a better form is

$$\frac{b}{E} = \cos \phi_2 \left(1 - \frac{2R}{\pi r} (\tan \phi_2 - \phi_2) \right) \quad (3)$$

From inspection it will be seen that when b/E becomes zero ϕ_2 is constant for given circuit values. This is termed the ultimate angle and only obtains when the output waveform is of a discontinuous rectangular form. Assuming different values of ultimate ϕ_2 which are known to produce no given odd harmonic, values for r/R can be obtained. For a given ultimate ϕ_2 and hence a given value of r/R , taking various angles for ϕ_2 less than the ultimate will then give corresponding values of b/E , from which graphs may be drawn.

As regards ϕ_1 , this can be derived from a knowledge of ϕ_2 and b/E as follows:

$$Vc + b = E \cos \phi_1 + b = E \cos \phi_2 \quad (4)$$

Hence

$$\cos \phi_1 = \cos \phi_2 - b/E$$

Corresponding graphs for ϕ_1 and b/E may now be drawn, and it will be found for instance when the ultimate angle is 60° that from about a value of 0.8 for b/E the mean angle ϕ is substantially constant and equal to the ultimate angle.

From the above it will be seen that the circuit gives a close approximation to the desired output waveform for all inputs exceeding $b/0.8$ and elimination or reduction of given odd harmonics may be obtained by alteration of the supply resistance r with respect to R , in a known manner, by substitution of the desired ultimate angle for ϕ_2 in equation 3 when $b/E=0$.

A further advantage of the circuit is that it entails little loss of sensitivity. Since it functions over the range of inputs greater than $b/E=0.8$ and the energy content of the output is constant whilst the fundamental only varies by 5% so that as a constant output device it is quite satisfactory.

If the input waveform is not sinusoidal but of known form, such as the isosceles triangular form, a similar method of attack will give the value of r/R for given mean angles of the output waveform. In this connection it is interesting to note that if r/R be 0.667 then the mean angle will be 60° and hence the output will contain no third harmonic. As the input waveform contains 11.1% third harmonic, the circuit has acted as a filter so as to eliminate this harmonic and by mere alteration of the ratio r/R can eliminate any other given odd harmonic. This method could be supplied to any input waveform which has substantially linear rates of change over the selected portion which appears

in the output, and which does not show large re-entrant amplitudes.

The isosceles triangular waveform input is one which is often met in practice, when signalling over telephone lines with A. C. generators of the rotary type. With a linear type of receiver the presence of a large third harmonic in the input signal will adversely affect either the speech guarding or signalling actions, whereas using the present type of circuit as a received level compensating device, neither action will be impaired if adjusted to minimise the third harmonic. For instance if r/R is made 0.55, the output waveform will only contain a maximum of some 5% third harmonic at high input levels, and with either sinusoidal or isosceles triangular waveform input.

The above described embodiment therefore enables trapezoidal waveforms to be generated from a given input according to its waveform with time and a calculated ratio between the supply resistance to a biased full wave rectifier and a resistance shunting a condenser in the output of the rectifier. It follows that the supply resistance may be formed in part by that of the source of alternating voltage, although it is preferred to swamp this by a much larger resistance in practice, in order to have better control of the mean angle. It also follows that any electrical circuit functioning in a similar manner may be used to generate such waveforms.

The above described circuit has been assumed to be composed of perfect components and when commercial apparatus is used certain refinements have to be employed in order to attain the desired mode of operation. The time constant of the condenser C and its shunting resistance R need not be such as to maintain a precisely steady voltage, and up to some 20% ripple can be tolerated in practice. This is because such ripple merely causes the grid circuit to conduct earlier on the positive change of input and to cease conducting earlier on the negative change of input by almost the same time or angular displacement in each case. Hence the output waveform is merely slightly advanced in phase with respect to the input waveform. As the ripple percentage is almost inversely proportional to the time constant $C \cdot R$, this allows the latter to be about two or three times the periodic time of the input (using full wave rectification). The build up and decay of the circuit may therefore be much faster than is normally associated with rectifier systems.

In order that the mean angle of the output waveform may be the same on each half wave of the input when using commercial valves, it is desirable to use negative feedback, which may take the form of separate cathode resistances or a single common cathode resistance R_c since the valves operate alternately. If the valves normally have short grid bases, then this permits the effective grid base to be made much larger and more nearly constant for differing samples of valves. As regards the maximum current output (i. e. during the flow of grid current) this will not be equalised to the same degree, but by using a low resistance potentiometer P connected between the cathodes with the tap taken to the main cathode resistance R_c , the maximum currents can be adjusted to be equal. Alternatively slightly differing screen voltages on the valves will have the same effect.

It should be noted that the static bias on the

valves must be such as to reduce static anode currents substantially to zero less than the maximum value when grid current flows, and this may be effected by feeding a direct current through the main common cathode resistance from a high resistance R_s connected to the positive supply busbar. Theoretical considerations presuppose that the anode current in one valve just starts to flow when the value of the alternating current input is equal to the steady "condenser voltage" V_c in Fig. 4 and ceases when the value of the input is equal to $V_c + b$, that is the bias on the valve is such as just to produce no static anode current. In practice, however, some static anode current can be allowed without seriously altering the action of the circuit. The effect is to retard the alteration in the angle ϕ_1 as compared with ϕ_2 in the anode current output so that for the initial changes in the input level, the mean angle of the output rises slightly above the calculated ultimate value, returning thereto at higher levels. It is found, however, that an initial deviation in the mean angle of say, 5° can be tolerated without producing unmanageable harmonic components, and that not more than this deviation is obtained when the static anode current is not greater than 0.3 times the maximum anode current. This factor allows of considerable latitude in the bias conditions and therefore in the use of valves having widely different tolerances.

It has been assumed in the above description that the resistance of the grid/cathode path is negligible when grid current is flowing, and that no change of output current takes place during this condition whatever the value of the applied voltage. In practice whilst the former may be made true by using a high value for r , the latter is not true, and with increasing input the anode current will show an increase during the passage of grid current, due to the non-linear resistance characteristic of the grid/cathode path. This undesirable effect may be reduced to negligible proportions at all working levels, by applying a portion of the voltage on the cathode resistance R_c to the suppressor grids of the valves as shown in Fig. 3. The suppressor grid/anode characteristic is of similar type to that of the control grid/anode current, except that the slope depends on the control grid voltage and tends towards zero at low suppressor biases for control grid voltages below the grid current value. The voltage waveform produced on the cathode resistance R_c is similar to that normally produced in the anode circuit, and will remain unaltered in waveform and amplitude for a large range of suppressor grid biases, because the total cathode current remains constant. Hence if a portion of this voltage is applied to the suppressor grids, the initial change of cathode current up to the grid current point will have little effect on the anode current change, but increasing grid/cathode voltage changes thereafter will have a more pronounced effect, owing to the increased slope of the suppressor characteristic. As this voltage applied to the suppressor grids acts as a negative bias, the tendency for the anode current to rise during the flow of grid current, can be reduced to negligible proportions.

The above method for obtaining a closer approximation to a flat top waveform in the anode circuit with commercial valves, is suitable when the anode load resistance or impedance is of value such that no non-linear action occurs in the anode circuit, due for instance to the well-

known "knee" in the anode current/anode voltage characteristic of a pentode. This means that the output voltage of the circuit is restricted, as the "knee" voltage becomes larger as the control grid voltage is raised positively. Use may be made of this anode characteristic, however, in order to secure the correct flat topped waveform without resorting to the suppressor grid method, provided the anode load resistance can be stabilised. If the value of the latter be made such that when drawn on the working anode current/anode voltage characteristic for a control grid voltage which just passes grid current, it intersects that characteristic at the "knee" voltage, then further increase of control grid/cathode voltage cannot cause an increase in anode current. Since the desired intersection is governed largely by the initial slope of the anode current characteristic and the slope of the load resistance, and the former is not generally greater than one-fifth of the latter, it will be seen that large variations in the initial slope of the valve have only a reduced effect on the output voltage or current. Hence this method not only gives the desired waveform, but also a maximum of output with constancy as between differing samples of the same type of valve.

In the above description, it has been assumed that the input consists of one frequency of sinusoidal form, or a frequency having low order odd harmonics such as an isosceles triangular form. In certain cases where the arrangement may be used for reception of signalling frequencies at widely differing levels over telephone or telegraph lines, carrier telephone or telegraph channels and the like, it is desired to receive signals consisting of two frequencies of substantially equal amplitudes. The action of the invention to such an input will be somewhat different, but it will be shown that the output, although inferior to the case of a single input frequency as regards low order harmonic products, can be adjusted to be sufficiently good.

An input consisting of the sum of two frequencies of equal amplitudes can be regarded as the product of half the sum and half the difference frequencies. The latter can then be regarded as modulating the former giving an envelope variation as shown in Fig. 5.

The envelopes will of course recur at the periodic time of the difference frequency. The mean frequency alterations on the negative side of the axis have been folded over as indicated by the dotted lines so as to represent the full wave rectifying action of the grid/cathode paths. It will be observed that nine half cycles have been taken, corresponding to the well-known case of frequencies of 600 and 750 cycles per second and their configuration within the envelope is such that one half cycle occurs over the maximum amplitude of the envelope. Regarding the time constant of the resistance R and the shunt condenser C as being high compared to the difference frequency (although this is not essential in practice, for the same reasons as applied to a single frequency input), then the voltage generated on C will be due to the caps of the positive and negative half waves of the mean frequency passed by the grid/cathode paths of the two valves. In the periodic time of the difference frequency, the amplitudes of the positive and negative half waves of the mean frequency will vary sinusoidally from zero to twice the amplitude of each input frequency as shown in Fig. 5. The envelope of these mean frequency half waves can thus be regarded

as being suppressed, from the point of view of the output, when its value is less than the condenser voltage, effective in the output as its value rises towards the grid current voltage of the valves, and suppressed as it rises above the grid current voltage. Hence the envelope of the input will be converted into trapezoidal form, in the same manner as for a single frequency, and the mean angle with respect to the envelope will be determined by the ratio

$$\frac{r}{R}$$

This ratio will, however, be different from that which obtained for a single frequency for the same mean angle, because the condenser voltage is only maintained by the top caps of the mean frequency, instead of the top cap of the envelope. It may be calculated, assuming different configurations of the mean frequency within the envelope, by the same method as before, and it is found that the configuration has little effect. The lines at heights of V_c and $V_c + b$ are similar to those in Fig. 4, whilst the output half cycle waveforms have been drawn in thick lines; it will be understood that each alternate half cycle (positive and negative) is delivered by each valve to the output so that the latter is alternating in character. For the same ratio

$$\frac{r}{R}$$

as was used for a single frequency, the voltage V_c will be smaller with respect to the maximum envelope amplitude, because the condenser voltage is now only maintained by the top caps of the mean frequency instead of the top cap of the envelope. Hence the envelope angles ϕ_1 and ϕ_2 will be larger.

It will thus be seen that the waveform output with time will consist of groups of positive and negative half waves due to the mean frequency, the groups repeating themselves at the periodicity of the difference frequency. The half waves at the mean frequency will approximate to a discontinuous trapezoidal form, whose mean angle will vary over one group according to the instantaneous value of the input and the condenser voltage.

Let the mean frequency be f_1 and the modulating frequency f_2 (i. e. these frequencies are half the sum and difference of the input frequencies). Then the input can be represented as

$$2 \sin f_1 \cos f_2$$

(neglecting the 2π factor). Assuming that only odd harmonics of each of these frequencies are produced in the output (this is not strictly true for the mean frequency) then the output consists of the following: two frequencies represented by $f_1 + f_2$, and $f_1 - f_2$ and therefore correspond to the two input frequencies; on either side of these will be $f_1 + 3f_2$, and $f_1 - 3f_2$; on either side of the latter will be $f_1 + 5f_2$, and $f_1 - 5f_2$ and so on. Then at around $3f_1$ we shall obtain the following: $3f_1 \pm f_2$, $3f_1 \pm 3f_2$, $3f_1 \pm 5f_2$, etc., and at around $5f_1$: $5f_1 \pm f_2$, $5f_1 \pm 3f_2$, $5f_1 \pm 5f_2$ and so on. Thus a whole gamut of frequencies is possible ranging over the whole spectrum and spaced at the difference frequency.

Now since these alien frequencies are due to the product terms of the odd harmonics of f_1 and/or f_2 , then their magnitudes will be very small except when combined with f_1 or f_2 . In other words the important combinations are $f_1 \pm 3f_2$, $\pm 5f_2$, $\pm 7f_2$, etc.; $3f_1 \pm f_2$; $5f_1 \pm f_2$, etc. The combinations of $3f_1$, $5f_1$ and so on with f_2 are not con-

trollable, since the magnitudes depend on the mean angles of the mean frequency half cycles which may vary from one envelope to another if the input frequencies are not multiples of the difference frequency, but they occur so high in the frequency spectrum as to be of negligible effect or can be subsequently eliminated by a simple filter (such as a suitable condenser across a transformer, which incidentally also helps the single frequency case). The combinations of f_1 with the odd harmonics of f_2 are controllable, one at a time, by causing the angles of the envelope function (i. e. f_2) to eliminate or reduce any given odd harmonic in the same way as for a single frequency input.

The method of calculating the angles of the envelope is essentially the same as employed before, in that the areas of the top caps of the mean frequency are summated, but as it is somewhat lengthy will not be given in detail. It is found that r/R must be 0.175 for an envelope angle of 60° , when $3f_2$ vanishes and also all combinations thereof. The nearest alien frequencies are then $f_1 \pm 5f_2$, and hence their magnitude with respect to the desired frequencies will be nearly the same as the amplitude of $5f_2$, which as shown before varies from 4% at low input levels (i. e. trapezoidal form) to 20% at high input levels (i. e. discontinuous rectangular form). Although on a strict comparative basis these figures may seem to compare badly with the "pure" input frequencies, it must be remembered that circuits operating to a compound frequency input must inevitably be designed to cope with the difference frequency products produced by the necessary rectification in order to energise relays, speech biasing circuits and the like. Hence the additional small percentage alien frequencies, separated by at least twice the frequency difference from the fundamentals, does not in practice affect a design which has already coped with the ordinary difference frequency products, since the mean value of the whole may not be substantially greater than that of the latter.

If all the odd harmonic functions of the envelope frequency could be eliminated, then all alien frequency products adjacent to the fundamentals will disappear, as will also all products with the harmonics of the mean frequency. This would leave $f_1 \pm f_2$ (the input frequencies), $3f_1 \pm f_2$, $5f_1 \pm f_2$, etc. The latter could easily be reduced to negligible proportions by a simple filter, thus obtaining a virtually distortionless output. To do this would mean that the envelope of the output would have to be given an approximate sinusoidal formation which would necessitate modulating the output of the present device. Such modulation could be obtained from the input frequency difference, and applied to modulating grids (such as the suppressor grids) with a rough form of limiting action. The gain in distortionless reproduction would however be offset by the additional circuit complication, but the principle might be justified in cases where relaxation of other properties of the circuit could be arranged.

If in practice the input may consist of either single or double frequencies, then a compromise value for r/R can be chosen which while giving reasonably small harmonic products close to the input frequencies when two are employed, also gives small odd harmonics of a single frequency input. Such a value for r/R is about 0.316, giving about 15% at frequencies adjacent to the in-

put frequencies when two are employed, and about 10% third, 25% fifth, and 10% seventh on single frequency inputs.

I claim:

1. A link circuit connecting an input circuit with an output circuit comprising a pair of space discharge devices having cathode grid and anodes, said devices connected in push pull relation, means for supplying an alternating current to the input circuit, means for supplying a fixed potential to the grids of said devices, means having a time constant for applying an additional potential to said grids dependent on the grid current flowing in the grid circuits, additional means for applying an instantaneous grid bias to the active control grid proportional to the grid current flowing in the circuit of the active grid, said grid potential applying means cooperating when properly proportioned to produce in said output circuit a current having a particular trapezoidal wave form in which currents of a particular harmonic are suppressed.

2. A link circuit between an input circuit having alternating current flowing therein and an output circuit, a pair of space discharge devices in said link connected in push pull relation and having grid, cathode and anode circuits, a fixed grid potential source in the grid circuits, said devices rendered alternately active by the alternating current flowing in the input, a resistance condenser combination in the grid circuits for applying additional potential to the grid of the active device, additional means for applying an instantaneous grid bias to the grid of the active device proportional to the current flowing in the grid circuit thereof, said last means and said resistance condenser combination being so proportional as to produce a current in the output circuit of a trapezoidal wave form having a particular amplitude and containing only certain harmonics.

3. A link circuit such as claimed in claim 2 in which each space discharge device has an auxiliary electrode and in which the said grid po-

tential applying means are proportional to each other and to the potentials on the auxiliary electrode potential and the anode potential.

4. A link circuit such as claimed in claim 2 wherein there is an impedance comprising the fixed grid potential source, and means for supplying a potential to the anodes, together with means connecting the plate potential to said impedance in such a manner as to minimize the effect of changes in the cathode current.

5. A link circuit such as claimed in claim 2 in which there is a cathode resistor in the grid circuits for supplying the fixed potential to the grid circuits, said resistor unbypassed and furnishing an inverse feed back from the plate circuit to the grid circuit.

6. A circuit including a pair of space discharge devices connected between an input circuit and an output circuit, each device having a cathode grid and anode and being connected in push pull relation in said circuit, the grid circuits of said devices including a common portion having an impedance therein supplying a fixed grid bias near cut off to each device, means for applying alternating current to the input circuit to render said devices alternately active, a resistance condenser combination in the common portion of said grid circuits and a resistance in each grid circuit in the individual portion, each resistance so proportioned to the resistance condenser combination as to control the grid potential on said devices to cause current of a particular amplitude and of trapezoidal wave form to be produced in the output circuit.

7. A circuit such as claimed in claim 6 in which each device includes a suppressor and a screen grid, said suppressor grids connected to an adjustable point on the impedance in said grid circuits, and said screen grids connected to the source of anode current supply, and in which said resistances are proportioned with the electrode potentials to cause elimination of a particular harmonic in the output circuit.

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