July 27, 1948. M. M. LEVY 2,445,785

MEANS FOR GENERATING RECTANGULAR ELECTRICAL IMPULSES

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FIG. 1.

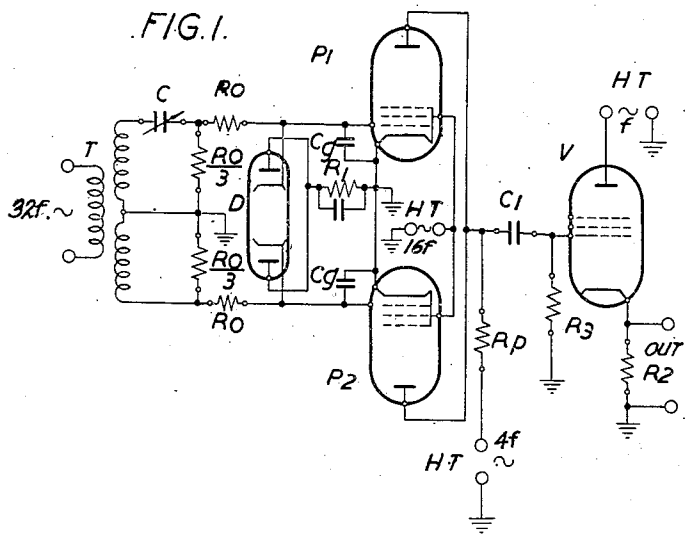
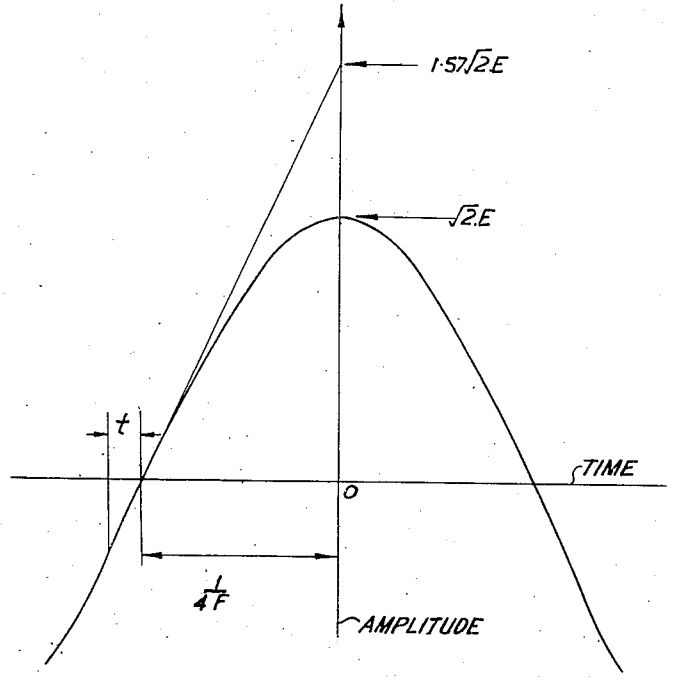


FIG. 2.



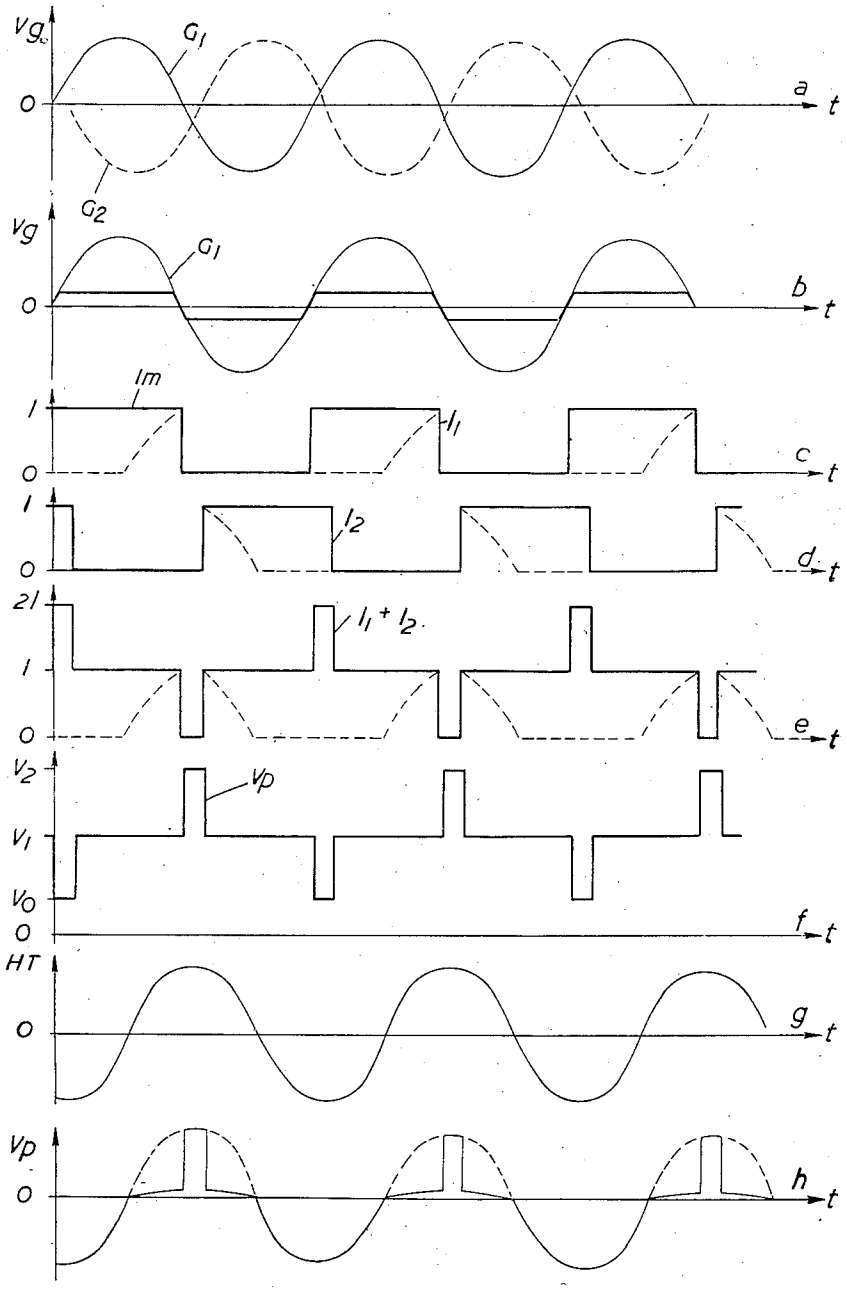
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MEANS FOR GENERATING RECTANGULAR ELECTRICAL IMPULSES

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FIG. 3.



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FIG. 4.

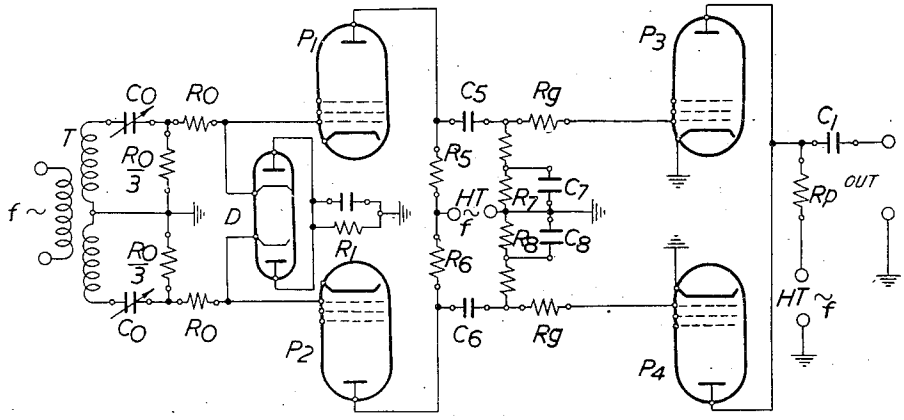
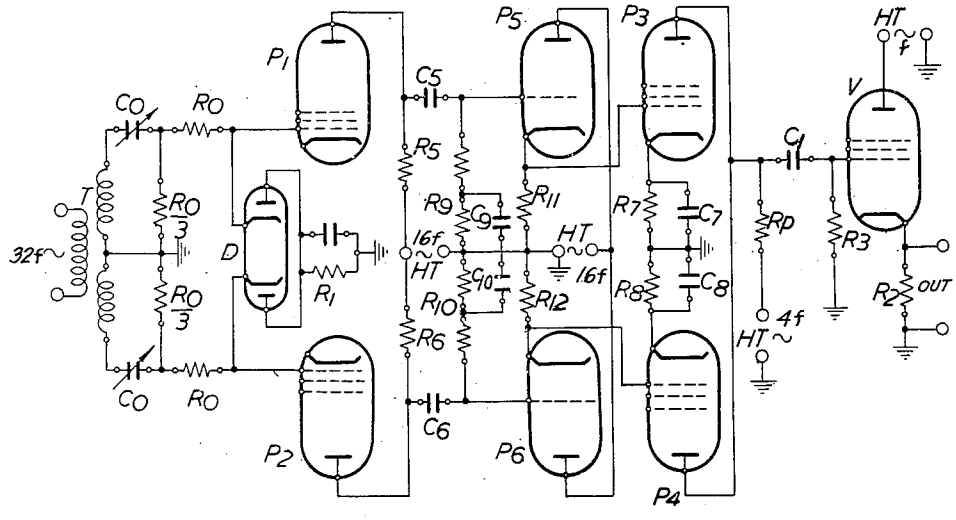


FIG. 6.



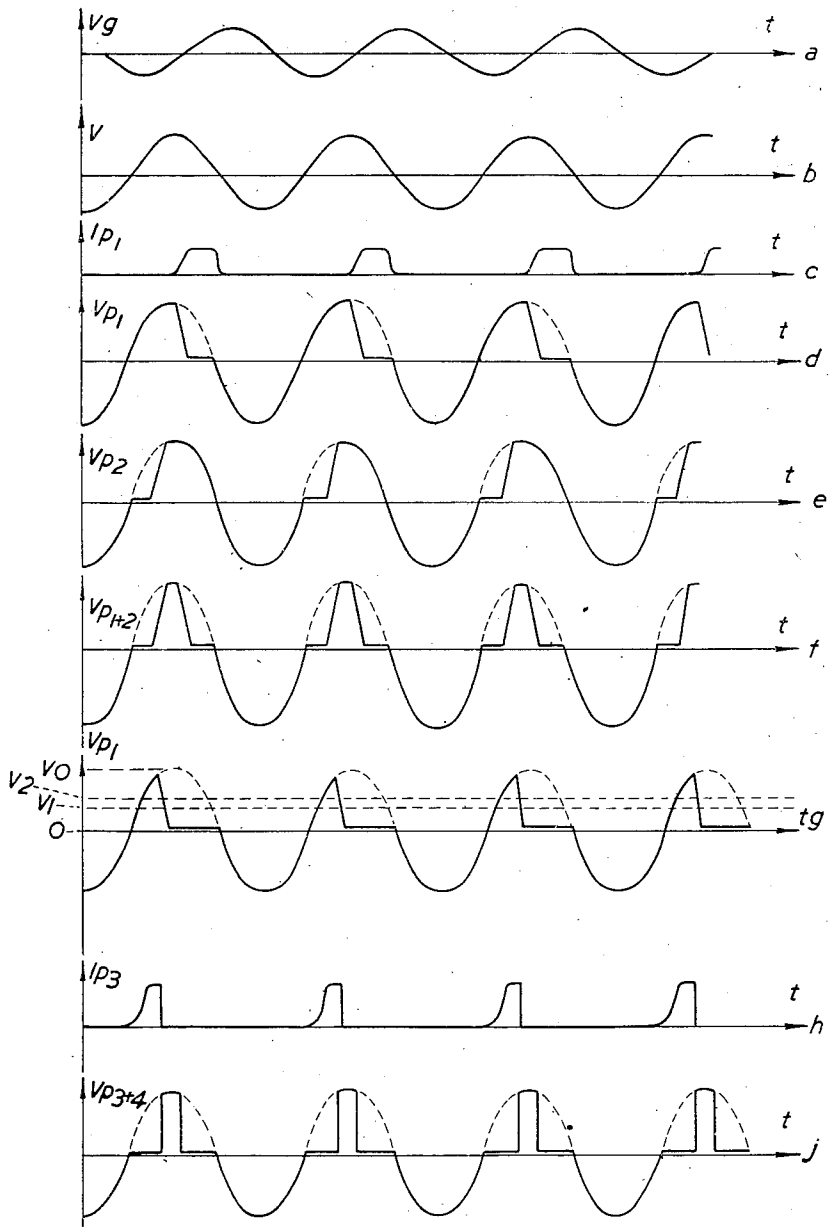
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MEANS FOR GENERATING RECTANGULAR ELECTRICAL IMPULSES

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FIG. 5



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Patented July 27, 1948

2,445,785

UNITED STATES PATENT OFFICE

2,445,785

MEANS FOR GENERATING RECTANGULAR ELECTRICAL IMPULSES

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Application September 11, 1942, Serial No. 458,059
In Great Britain May 27, 1941

Section 1, Public Law 690, August 8, 1946
Patent expires May 27, 1961

12 Claims. (Cl. 250—27)

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The present invention concerns improvements in methods for generating rectangular electrical impulses having very steep initial slopes, with special reference to the production of impulses of very short duration.

These methods are of particular importance in connection with systems for obstacle detection, television testing and the like, where periodically repeated impulses of very short duration, and of very high peak power, are required.

The generation of impulses whose amplitude needs to be established within periods of the order of 1 microsecond or less, presents some considerable difficulty, especially when such impulses are required to have considerable peak voltages and peak power. Orthodox methods which have been used up to the present have tended to require complicated assemblies of high power valves, the efficiency of which was likely to be extremely poor because the valves would dissipate considerable power in the periods between the impulses, which periods might easily occupy 99% or more of the total time.

The principal object of the present invention, therefore, is to provide a system for generating substantially rectangular electrical impulses of considerable peak power and of very short duration from a source of alternating potential, using circuits involving thermionic valves, the plate circuits of some or all of which are fed with alternating polarising potential whose frequency is a submultiple of that of the source from which the impulses are generated.

According to the principal feature of the invention, impulses are generated from a sinusoidal source in a circuit of a type already known containing thermionic valves the plate circuits of which are fed with alternating potential, of a frequency which is a sub-multiple of the frequency of the source from which the impulses are generated. By this means the impulses are produced at a frequency which is a multiple of the desired frequency of repetition, the impulses not required being eliminated as a result of the lower frequency alternating plate voltage. The sides of the impulses are thereby made steeper because they are generated at a frequency which is higher than the frequency of repetition.

According to another feature, the generator is provided with a number of stages of amplification, in which the plate circuits of the valves are fed with alternating potentials, the frequency of which, at any stage, may be a sub-multiple of the frequency of the preceding stage.

According to another feature, arrangements

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are provided for efficiently reducing the duration of the impulses, whereby the initial and final slopes are produced in separate valves and are separately made steeper by other valves before being combined to form the complete impulse.

According to another feature, a cathode follower stage is used to enable the time constant of the circuit to be reduced so that it may be able to transmit impulses of extremely short duration.

The above objects and features will be more clearly understood from the following detailed description and by reference to the accompanying drawings, in which:

Figure 1 shows the schematic circuit of an impulse generator in accordance with the invention;

Figure 2 shows a geometrical construction used in the explanations;

Figures 3 and 5 show wave form diagrams;

Figure 4 shows a schematic circuit of a generator employing amplification in accordance with a feature of the invention;

Figure 6 shows another schematic circuit exhibiting an additional feature of the invention.

In the schematic circuits shown in the various figures listed above, the cathode heating circuits of the valves and various other well understood operating arrangements have been omitted for clearness. It should be assumed, therefore, that these arrangements would actually be included in the practical working of the circuits.

Figure 1 shows the circuit of a known type of impulse generator, by which rectangular impulses of short duration may be produced from an alternating current source. The method of operation of this generator will be described as an introduction to the explanation of the working of the system which forms the subject of the present invention.

An important feature of this generator is that it is adaptable for producing impulses of high maximum voltage and peak power by the use of low rated valves. This is possible because, as the impulses are very short, they occupy a very small fraction of the time during which they are being generated. It is then practicable to arrange for the valves to be operated with abnormally high plate voltages, so long as the power dissipation during the periods between the impulses is reduced to a very small amount. The valves are then able to generate considerable amounts of power just at the moments of the impulses without any harmful effects. As will be explained, one of the means by which the dissipation during

the intervals is reduced is by the use of alternating plate potentials, the maximum values of which are much higher than the potentials specified for the normal operation of the valves. By operating the valves in this way, a much improved power efficiency is obtained, because in more usual circuits the power rating of the valves would have to be of the same order as the peak power of the impulses, and they would accordingly be consuming large amounts of power during the intervals when nothing is being produced.

With this arrangement it is possible, for example, to obtain a peak power of over 500 watts developed in resistance Rp (7000 ohms) using valves rated at only about 12 watts, or of over 1,500 watts developed in resistance R2 (1500 ohms) using a valve V rated at 25 watts.

According to the arrangement of Fig. 1, alternating current having a frequency equal to the desired frequency of impulse repetition feeds the primary winding of a transformer T. The secondary windings feed the grids of two pentodes P1, P2, and are connected so as to supply voltages which are practically in phase opposition. A small condenser C permits the voltages to be displaced slightly in phase from exact phase opposition.

The secondary windings of transformer T supply very high voltages, 1000 volts, for example, so that the valves P1, P2 are saturated very suddenly, but each voltage is transmitted to the grid through the medium of a very high resistance R0, which limits the positive voltage applied to the grid. The negative voltages are also limited by a diode D which connects the grids to earth or other point of stable potential, each cathode of the diode being connected to the grid of the corresponding pentode, and the plates of the diode to earth through a biassing resistance R1. The plates of the two pentodes are connected together and are fed from a very high tension source, perhaps several thousand volts, through a resistance Rp.

The operation of the portion of the circuit so far described will now be explained with reference to the wave-form diagrams of Fig. 3.

In Fig. 3*a* is shown the two sinusoidal waves transmitted to the grid circuits. These waves are very slightly displaced with respect to each other in relation to phase opposition.

One of the waves is shown in light line in Fig. 3*b*. As its amplitude is very high, a small fraction only is actually transmitted to the grid, the remainder appearing at the terminals of the resistance R0 in the form of a drop in potential alternately produced by the grid current and the diode current. The wave actually transmitted to the grid is shown by the heavy line in Fig. 3*b* and takes the form of a series of practically rectangular trapeziums, the slopes of the sides of which will be very steep if the amplitude of the wave is sufficiently great.

The plate currents I1 and I2 of the two pentodes take the form of rectangles as shown in Figs. 3*c* and 3*d*, respectively, in the thick continuous lines. These rectangles are in phase opposition with a slight angular displacement. The resulting current which flows in the common resistance Rp takes the form shown by the continuous lines in Fig. 3*e*, and is obtained by adding together the ordinates of the two curves of Figs. 3*c* and 3*d*. It will be seen that the resultant current is in the form of positive and negative impulses.

The plate voltage has the inverse form of the resultant current. It is a maximum when the current is zero and a minimum when the current is a maximum, as indicated in Fig. 3*f*. If, for example, the potential applied to the resistance Rp is 2000 volts the amplitude of the impulses can be (say) 1500 volts if the value of the resistance Rp has been made sufficiently high, account being also taken of the grid current of the following valve V which is not negligible.

If the valves used in the type of circuit just described are operated in the conventional manner, the resistance Rp will need to be very high in order that the fall of the potential therein due to the plate current may be sufficient to produce the desired amplitude of the impulse. Moreover, since the plate voltage during the intervals between the signals (that is for perhaps 99% of the time) is, in the example just chosen, about 1000 volts, the valves will be dissipating considerable power nearly all the time. This will clearly prevent the use of low power valves operated with abnormally high plate voltages which, as already explained, is desirable in order to obtain a high efficiency. If, however, alternating potential be applied to the resistance Rp instead of a constant potential these objections can be largely overcome, because by this means the power consumption in the periods between the impulses can be appreciably reduced, as will now be explained.

The alternating voltage applied to the plate resistance Rp is shown in Fig. 3*g*. As shown, it should be practically in phase quadrature with the voltages applied to the grids of P1 and P2, and it should be a positive maximum when the resultant plate current, as shown in Fig. 3*e*, is zero. In Figs. 3*c* and 3*d* the dotted lines show the plate currents of the valves P1 and P2 respectively, when the alternating voltage of Fig. 3*g* is applied to resistance Rp instead of the constant voltage. The peak voltage of the wave of Fig. 3*g* is equal to that constant voltage, and since the peaks occur at the same times as the impulses, the currents I1 and I2 will have approximately the same values at these times as when constant voltage was used. Since the alternating voltage falls to zero at times halfway between the impulses, the plate currents I1 and I2 must also both fall to zero at these same times and must accordingly follow the dotted curves in Figs. 3*c* and 3*d*. During the alternate half periods when the applied alternating voltage is negative, the plate current will be zero. Thus the total plate current $Ip=I1+I2$ flowing through Rp will take the form shown by the dotted lines of Fig. 3*e*, obtained by adding the ordinates of the dotted lines in Figs. 3*c* and 3*d*. The negative impulses at the intermediate half periods disappear because the plate voltage is then negative. The total plate current is accordingly zero for the period of the positive impulses and for the whole of the periods during which the applied alternating voltage is negative.

The plate voltage is shown in Fig. 3*h* in which the dotted line shows the applied alternating potential. It is negative or a maximum when the total plate current is zero and may be made to have a very low value as indicated in Fig. 3*h* during the periods when any current flows, by making the resistance Rp great enough.

It is advisable that the feed to the screening grids should also be alternating. The voltage applied to the screening grids should be in phase with the voltage applied to the plate circuit. The amplitude of the voltage applied to the screen-

ing grids should, however, be of the same order of magnitude as the normal voltage with continuous current operation.

The present invention is a further development of this circuit. It will be noted that a distinctive feature is the use of alternating potential instead of constant potential for supplying the plates of the valves whereby the effective potential is at a maximum only at the times of the production of the impulses.

Now, if the frequency of the alternating supply to the transformer T be doubled while the plate supply frequency remains the same, double the number of impulses will tend to be produced in the same time. Referring to Fig. 3*h*, extra impulses will tend to be produced midway between those which are shown in the figure. These, however, will not actually be transmitted because the plate voltage is then negative. In other words, these impulses will be missed out. Similarly, if the frequency supplied to the transformer T is three times or four times the frequency of the plate supply, two, or three, intermediate impulses will tend to be produced during the period when the plate potential is negative and these impulses will also be missed out. It is not, however, possible to multiply the frequency of the supply to the transformer any further, because some of the extra impulses would then occur during the time when the plate voltage is positive and would tend to be transmitted though with reduced amplitude.

The significance of this is that it is possible to increase the steepness of the sides of the impulses by increasing the frequency of the generating sinusoidal wave.

Referring to Fig. 3*b*, it will be seen that the time taken by the grid voltage to reach the cut-off points represented by the horizontal portions of the trapeziums will depend upon the steepness of the slope of the wave where it crosses the axis. When the maximum amplitude is fixed, it is obvious that the steepness of this slope will be proportional to the frequency of the wave. Accordingly, if it is desired to produce impulses with a given repetition, the steepness of the sides of these impulses may be multiplied up to four times by producing them from an alternating supply having a frequency four times that of the potential applied to the plates of the valves.

As has been explained, the unwanted impulses are missed out so that the desired repetition is actually obtained.

Fig. 1 shows the valves P1 and P2 followed by an amplifying stage consisting of a valve V connected as a cathode follower. It is coupled to the plates of the previous valves through a condenser C1 and a resistance R3, and R2 is the resistance connected in the cathode circuit of the valve V. The output may be taken from the terminals of resistance R2, as shown. The primary function of this stage is to increase the power of the impulse without increasing their voltage.

A further steepening of the slopes of the impulses can now be obtained in a similar way, by applying the same process again. A frequency sixteen times that of the desired repetition will be supplied to the transformer T. The plate circuits of the valves P1, P2 will be supplied with a frequency four times that of the desired repetition, while the plate circuit of the valve V will be supplied with a frequency equal to that of the desired repetition. In this case the slope of the impulses will be multiplied by sixteen, and three out of every four impulses will be missed out in the stage corresponding to the valves P1, P2, and of those which remain again three out of every four will be missed out in the stage corresponding to the valve V. It is evident that this process could be repeated as often as desired by providing further stages of amplification and also it is not necessary that multiplication at each stage should be four. As already explained, it can be two or three.

Some idea of the advantage which can be derived from this process may be obtained from the following numerical results.

With the generator in its original form, that is, when the plate voltages supplied have the same frequency as the alternating current from which the impulses are produced, it is possible to obtain impulses in which the time taken for the maximum amplitude to be reached is perhaps 0.0005 times the period of repetition. For example, if it is desired to produce impulses repeated fifty times per second, then such impulses will be established in about 10 microseconds. By the use of the principles of the present invention, however, and assuming that a multiplication of sixteen is obtained in two stages, as explained, it is possible to produce impulses repeated fifty times per second, which are established in perhaps 0.7 microsecond.

It will be convenient to express the time in seconds taken by the impulses to be established by the following formula:

$$t=\frac{0.0005}{Kf}$$

where f is the desired frequency of repetition of the impulses and K is the total multiplication produced in the manner explained. In the numerical example just given K will be equal to 16.

It will be appreciated that since the time taken for the impulses to be established is of the order of 1 microsecond, it is necessary to consider what limitations to the elements of the circuit will be set by the time constants associated with these elements. It is clear that if these time constants are too large it will not be possible to establish the impulses within the desired time.

The principal reason for a low time constant will be the stray capacity C*g* which is effectively connected between the grid of each of the valves P1 and P2 and earth, as shown in Figure 1, with which is associated the resistance R0, which, as already explained, will be large. In order that the time taken for the impulses to be established shall not be appreciably affected by the time constant of this circuit, it is desirable that it should not be greater than about $t/5$. We have, therefore, the limitation that the product C*g*.R0 must not be greater than $t/5$.

Now it is possible to limit C*g* to a value not greater than $20\mu\mu$F. It follows, therefore, that R0 must not exceed $t\times 10^{10}$ ohms.

In order to prevent the output of each secondary winding of the transfer T from being appreciably affected by the sudden appearance and disappearance of the grid and diode currents, it is desirable to limit the resistance which shunts each of these secondary windings to a relatively small value, which may, for example, be taken as equal to R0/3. It is also desirable to obtain the highest possible voltage across the secondary windings. This will be limited by power available for supplying the transformer. Suppose, therefore, that this power is of the order of a 100 watts: then the effective voltage E across each secondary winding will be given by

$$E=\sqrt{\frac{50.R0}{3}}=4\sqrt{R0} \text{ approximately.}$$

The grid of each of the valves P1 and P2 takes a time t to pass from the cut-off to the limiting positive voltage or vice versa. If valves having a high slope are used the cut-off voltage may be, for example, about —3 volts and the limiting positive voltage is in the neighborhood of zero if R0 is large.

From Fig. 2 it can be seen that this time t is given by

$$t=\frac{3}{1.57.\sqrt{2E}}.\frac{1}{4F}$$

By substituting the value of E given above it follows that

$$t=\frac{0.085}{F\sqrt{R0}}$$

and by replacing R0 by its limiting value $t\times10^{10}$ given above we obtain $t=F^{-2/3}.10^{-4}$, approximately.

In the above formulae F is the frequency of the alternating current supplied to the transformer T. By substituting for F its value Kf, the final value of t is obtained as follows:

$$t=(Kf)^{-2/3}.10^{-4} \text{ seconds, approximately}$$

This formula gives the order of magnitude of the shortest time in which the impulses can be established in the circuit of Figure 1.

It is also necessary to show that the efficiency of the circuit for transmitting these very steep impulses will not be diminished. In order that they shall not be appreciably distorted it is necessary that none of the time constants in the circuit must exceed $t/5$.

Referring to Figure 1 it must be assumed that the plate resistance Rp will be shunted by a stray capacity due to circuit wiring, etc., which will be denoted by Cp. Again, Cp need not exceed $20\mu\mu$F, and by making the product Cp.Rp not greater than $t/5$ we obtain the maximum value of Rp of about 10,000 ohms, when t is put equal to 1 microsecond.

In the example given in connection with the circuit of Fig. 1, the value of Rp was about 7,000 ohms, and any other resistances which affect the time constant in any succeeding stages of amplification will generally be less than this, if cathode follower stages are used. Accordingly it is possible with the circuit of Figure 1 to produce impulses in which the time of establishment can be as low as about 1 microsecond.

The impulses produced in this circuit will actually be shaped like symmetrical trapeziums, of which the bases are longer than the crests by twice the time interval needed for establishing the maximum amplitude. The width of the impulses may be measured by the length of the base, and may be adjusted by means of the small condenser C in Fig. 1. This adjustment changes the phase difference from opposition of the two grid voltage waves Vg in Fig. 3a, and thus the widths of the rectangular peaks in Fig. 3h. It will be clear that in the example given the width cannot be reduced below 2 microseconds without also reducing the amplitude. The maximum width will be determined by the deformation caused by the rounded crest of the potential supply wave to the plates of P1 and P2, and if the deformation be limited, for example to 1% of the maximum amplitude, this will permit a width of the impulse of about 5% of the period of repetition of the impulses. This leads to a value of about 60 microseconds for the maximum width when K=16.

The valves P1 and P2 shown in Figure 1 have been indicated as pentodes, but this is not essential, and any of the valves may be triodes or may have any number of electrodes, as may be found convenient. It is also possible to use further stages of amplification as desired, and also, the total multiplication is not necessarily limited to sixteen, but can have any value so long as the multiplication per stage does not exceed 4. Also, although in the example given above, the frequency of repetition of the impulses was taken as 50 per second, this is not essential, and any desired frequency could be used, so long as the other conditions are such that the time constants of the circuit do not introduce limitations.

Fig. 4 shows a circuit in which the steepness of the sides of the impulses can be still further increased. The impulses, however, are not amplified in the ordinary way by means of an amplifying stage connected in cascade immediately after the generator. Whilst this would be possible it would result in a rather inefficient arrangement, which would prevent the use of low power valves, because the valves would be unavoidably dissipating power during the periods between the impulses, which, as already stated, may be 99% of the time.

By the method of Fig. 4 the slopes of the sides of the impulses are separately steepened before they are combined to produce the complete impulses.

In Fig. 4 two valves P1 and P2 are shown connected to a transformer T by an arrangement practically the same as that of Fig. 1, except that for convenience the small variable condenser C has been replaced by two condensers C0, one connected to each secondary winding of the transformer. The plates of the valves P1 and P2 are, however, fed through separate resistances R5 and R6 and the valves are coupled separately to two other similar valves P3 and P4 through condensers C5 and C6. The plates of the valves P3 and P4 are connected to a common plate resistance Rp through which they are fed from the HT supply. The grids of the valves P3 and P4 are provided with shunted biasing resistances R7, C7 and R8, C8 and each grid is connected to the corresponding coupling condenser by a high resistance Rg. The output is taken from the plate resistance Rp through a blocking condenser C1. The combination of the plate currents to form the complete impulses takes place in the resistance Rp.

In Fig. 5 some curves are given somewhat similar to those of Fig. 3 for the purpose of explaining the action of this circuit.

With reference first of all to the circuit of Fig. 4, the grid voltage applied to the valve P1 is shown in Fig. 5a, and Fig. 5b shows the potential V applied to the plates of the valves P1 and P2. The corresponding plate current of the valve P1 flowing through R5 is shown in Fig. 5c. This plate current will be zero until the grid voltage Vg rises above the cut-off and this is arranged to occur when the plate potential V has practically reached its maximum. The plate current then continues to rise until the grid voltage becomes zero, or very slightly positive, being limited by the high resistance Rg. From that point the plate current remains approximately constant until it is cut off by the plate potential V falling to zero. During the whole of the period when the plate potential V is negative and until the grid voltage Vg again rises above the cut-off the plate current of valve P1 will be zero. These variations are as shown in

Fig. 5c. Fig. 5d shows the corresponding plate voltage of the valve P1. As soon as the plate current starts to increase from zero the plate voltage drops and will fall steeply as shown, if the resistance R5 is large enough. Thus, in Fig. 5d is shown the right-hand portions of impulses such as are shown in Fig. 3h. Similarly, Fig. 5e shows the left-hand halves of the impulses which are produced by the valve P2 in combination with its plate resistance R6. Now, if it be assumed that the two plates are connected directly together, thus connecting R5 and R6 in parallel, the arrangement becomes similar to Fig. 1, with the parallel combination of R5 and R6 represented by Rg. The effect will be to combine the two curves Figs. 5d and 5e in the common resistance Rg, and the resulting completed impulses will be as shown in Fig. 5f. These are really the same as those shown in Fig. 3h, except that the steepness of the sides has been shown much less for the purpose of explanation.

In the circuit of Fig. 4, however, the voltage variations of the valves P1 and P2 shown in Figs. 5d and 5e, are separately produced across resistances R5 and R6 and before combination in a common resistance are applied to the grids of the following valves P3 and P4 through the coupling circuits already explained.

In Fig. 5g is shown the plate voltage of valve P1 which is applied to the grid of P3, but the steep drop of plate voltage has been arranged to occur somewhat earlier by suitably adjusting the phase relations of Vg and V in Figs. 5a and 5b. In Fig. 5g, V1 and V2 indicate the voltages corresponding to the cut-off and zero voltages of the grid of P3, which has been suitably biassed by means of the circuit R7, C7.

The difference V2—V1 will usually be a few volts. In Fig. 5h is shown the corresponding plate current of the valve P3, assuming that the plate of this valve is fed with a voltage in phase with V in Fig. 5b. It has the same general character as Fig. 5c, but the initial rise is very much steeper because the grid voltage has changed from the cut-off to zero in a very much shorter time than did the grid voltage of valve P1. It follows, therefore, that the slope of the corresponding plate voltage will be very much steeper than before, and Fig. 5j shows the result obtained when the plate currents P3 and P4 are combined in the resistance Rp, which result may be compared with Fig. 5f. It should be pointed out first that the left-hand side of the impulse is now produced by valve P3, and the right-hand side by P4.

Referring again to Fig. 5, the steepness of the sides of the impulses will be increased approximately in the ratio

$$\frac{VO}{V2-V1}$$

assuming, for the moment, that no account is taken of the time constants of the circuit. This ratio can easily be of the order of several hundred. If, therefore, the original impulses, which would have been produced by the valves P1 and P2 alone, are established in 10 microseconds, the type of amplification just described can produce impulses which are established within 0.1 microsecond, or less.

With impulses of this kind, however, the difficulty with the time constants of the circuit will be considerably increased. By applying the same limits as given above, namely that the product $Rp \cdot Cp$ must not exceed $t/5$, it results that the value of Rp is limited to about 1000 ohms when C_1 is taken as 20$\mu\mu$F. Further, owing to the stray capacity Cg which effectively shunts the resistance Rg, and which cannot usually be reduced below 10$\mu\mu$F, the value of Rg will also be limited to a very low value, i. e., 2000 ohms when t=0.1 microsecond. If still steeper impulses involving still lower values of t are required, Rg and Rp become limited to such small values that valves of much higher power must be used for P3 and P4 to produce impulses of the same peak power as before. This results also in a considerable reduction in the efficiency.

The use of high power valves can, however, be avoided by means of a stage consisting of a pair of valves connected as cathode followers which will be inserted between the two stages of Fig. 4, and also by following the valves P3 and P4 by one (or possibly more) stages of cathode follower valves.

In this way the circuit of Fig. 6 will be obtained, in which the cathode follower valves are P5 and P6. The grids of these valves are connected through the condensers C5 and C6 to the plates P1 and P2, and the grids of P3 and P4 are connected to the cathode resistances R11 and R12, as shown. The grids of P5 and P6 are provided with biasing circuits R9, C9 and R10, C10, and the valves P3 anod P4 are followed by a cathode follower stage similar to that shown in Fig. 1. The designations of all the other elements which have not been mentioned are the same as those in Figs. 1 and 4. With this arrangement R5 and R6 may be, for example, several thousand ohms and R11 and R12 might be perhaps 500 ohms, and approximately the same voltage will be produced across R11 and R12 as was produced across R5 and R6. The stray grid capactly Cg which effectively shunts R11 and R12, will now produce a time constant sufficiently small to enable impulses established in perhaps 0.03 microsecond to be transmitted.

The plates of all the valves in the circuit will be supplied with alternating potential, and the arrangement described in connection with Figs. 1 and 4 may be used, whereby the frequency applied to each stage is a sub-multiple of that of the preceding stage It must be noted, however, that when the plates of any pair of valves are not connected to the same plate resistance, the corresponding sub-multiple cannot exceed 2.

This can be understood with reference to Figs. 5a, 5b and 5c. If the frequency of Vg in Fig. 5a be supposed to be multiplied by four, for instance, there will be four times as many peaks in the plate current curve of Fig. 5c which corresponds to the valve P1. It is clear that two of them must occur while the voltage V in curve 5b is still positive, so that only two out of the four peaks will be missed out instead of three. A similar consideration holds when the frequency of Vg is multiplied by three. If, however, the frequency of Vg is multiplied by two, the extra peak produced in Fig. 5c will occur when the voltage V in Fig. 5b is zero and changing to negative, and it will accordingly be missed out.

Thus, for example, in the circuit of Fig. 6 it would be possible to supply the transformer T with a frequency 32f, the valves P1 and P2 and P5 and P6 with 16f, the valves P3 and P4 with 4f and the cathode follower valve V with f, where f is the desired frequency of repetition of the impulses. Any other arrangement of frequencies involving a multiplication not greater than 2 in the case of stages in which the plates of the corresponding pair of valves are not directly connected together, or not greater than 4 in the

case of other stages, could, of course, be adopted; and also, if found convenient, the plates of some of the amplifying stages need not be fed from an alternating supply at all, but the more usual continuous potential could be used.

It will be appreciated that the various figures and circuit details quoted above have been given for purposes of example and explanation, and that various other arrangements in accordance with the principles of the invention will be possible and will occur to those skilled in the art. It is not intended, therefore, that the invention should be limited to the examples given.

What is claimed is:

1. A system for producing high voltage impulses having a duration short compared with their period of repetition comprising a source of impulses, a pair of electron discharge devices each having a cathode, a control electrode and an anode, means for applying impulses from said source to the said respective control electrodes with a phase difference slightly displaced from exact phase opposition, and a source of alternating high-tension voltage connected in parallel to said anodes said alternating voltage having a frequency which is an integral submultiple of the frequency of said source of impulses.

2. A system for producing high voltage impulses having a duration short compared with their period of repetition comprising a source of sinusoidal waves, a pair of electron discharge devices each having a cathode, a control electrode and an anode, means for applying waves from said source to the said respective control electrodes with a phase difference slightly displaced from exact phase opposition, and a source of alternating high-tension voltage connected in parallel to said anodes said alternating voltage having a frequency which is an integral submultiple not greater than the fourth of the frequency of said source of sinusoidal waves.

3. A system for producing high voltage impulses having a duration short compared with their period of repetition comprising a source of impulses, first and second stages each comprising pairs of electron discharge tubes each having a cathode, a control electrode and an anode, means for applying impulses from said source to the respective control electrodes of the tubes of said first stage with a phase difference slightly displaced from exact phase opposition, a source of alternating high-tension voltage of a frequency which is an integral submultiple of the frequency of said source of impulses, individual anode circuit impedances for said tubes of said first stage, means for connecting said source of alternating voltage to the anodes of said last-mentioned tubes through said individual impedances, means for coupling the anodes of the tubes of said first stage respectively to the control electrodes of the tubes of said second stage and output circuits connected to the anodes of the tubes of said second stage.

4. A system for producing high voltage impulses according to claim 3 wherein the frequency of said alternating high-tension source is one-half the frequency of said source of impulses.

5. A system for producing high voltage impulses according to claim 3 wherein the anodes of the tubes of said second stage are fed from an alternating high-tension source the frequency of which is an integral submultiple of the frequency of said source of impulses.

6. A system for producing high voltage impulses according to claim 3 wherein the anodes of the tubes of said second stage are fed from an alternating high-tension source the frequency of which is an integral submultiple of the frequency of the high tension source which feeds the anodes of said first stage.

7. A system for producing high voltage impulses according to claim 3 wherein said means for coupling the anodes of said first stage to the control electrodes of said second stage comprises a further pair of electron discharge tubes connected to operate as cathode followers.

8. A system for producing high voltage impulses according to claim 3 further comprising resistances inserted in the conductors of the control electrodes of the tubes of said first stage and diodes connected between said control electrodes and a point of stable potential.

9. A system for producing high voltage impulses having a duration short compared with their period of repetition comprising a source of impulses, first and second stages each comprising pairs of electron discharge tubes each having a cathode, a control electrode and an anode, means for applying impulses from said source to the respective control electrodes of the tubes of said first stage with a phase difference slightly displaced from exact phase opposition, a source of alternating high-tension voltage, individual anode circuit impedances for said tubes of said first stage, means for connecting said source of alternating voltage to the anodes of said last-mentioned tubes through said individual impedances, means for coupling the anodes of the tubes of said first stage respectively to the control electrodes of the tubes of said second stage and output circuits connected to the anodes of the tubes of said second stage.

10. A system for producing high voltage impulses according to claim 9, further comprising resistances inserted in the conductors of the control electrodes of the tubes of said first stage and diodes connected between said control electrodes and a point of stable potential.

11. A system for producing high voltage impulses having a duration short compared with their period of repetition, comprising a source of impulses of a single frequency which is a multiple of the desired repetition frequency of the impulses to be produced, a stage of amplification comprising a vacuum tube having a cathode, a control electrode and an anode, means for applying impulses from said source to said control electrode, a source of alternating high tension voltage connected to said anode, the frequency of said alternating voltage being an integral submultiple of the frequency of said source of impulses, and means connected to said anode for deriving said high voltage impulses.

12. A system for producing high voltage impulses having a duration short compared with their period of repetition, comprising a source of sinusoidal waves of a single frequency which is a multiple of the desired repetition frequency of the impulses to be produced, a stage of amplification comprising a vacuum tube having a cathode, a control electrode and an anode, means for applying waves from said source to said control electrode, a source of alternating high-tension voltage connected to said anode, the frequency of said alternating voltage being an integral submultiple of the frequency of said source of sinusoidal waves, and means connected to said anode for deriving said high voltage impulses.

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