

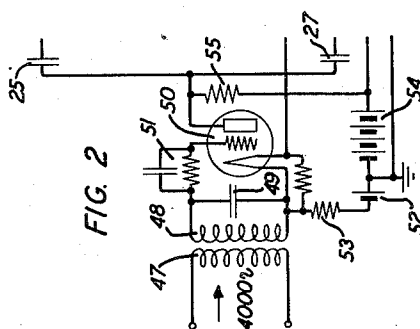
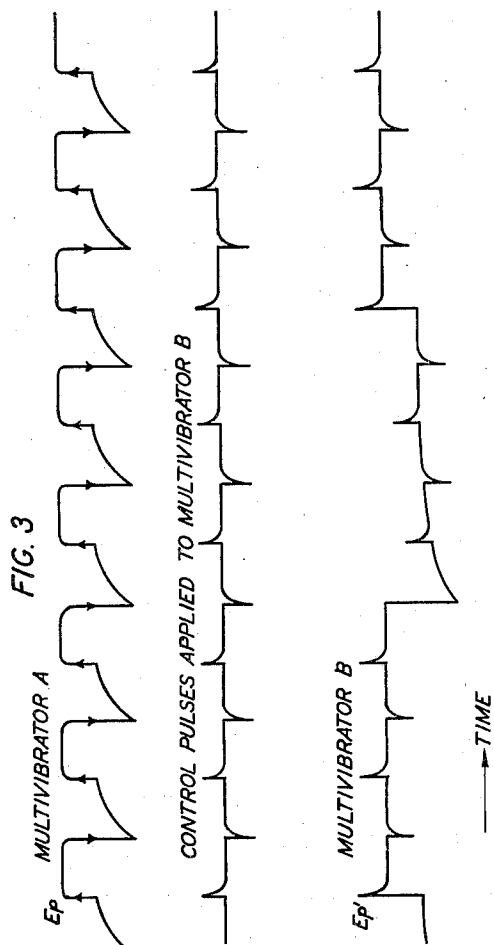
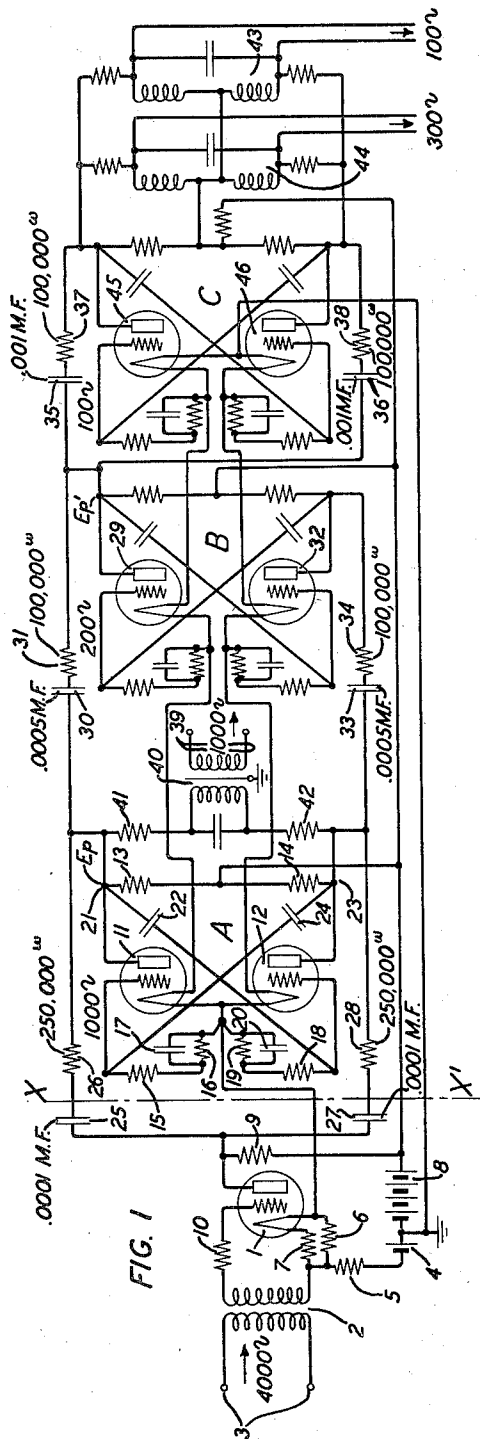
Dec. 3, 1935.

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2,022,969

ELECTRICAL WAVE PRODUCTION

Filed July 7, 1934



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2,022,969

ELECTRICAL WAVE PRODUCTION

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Application July 7, 1934, Serial No. 734,085

6 Claims. (Cl. 250—36)

The present invention relates to electrical wave production and particularly to the conversion of an alternating current wave of one frequency into one or more alternating current waves of other frequencies by wave distorting circuits one example of which is the so-called "multivibrator".

The so-called "multivibrator" is an arrangement of electric space discharge tubes operating as a distorted wave oscillator to produce a discontinuous wave, the frequency of which may be adjusted to have any value within wide limits. In its original form as devised by H. Abraham and E. Bloch and described in an article by them in the *Ann. de Physique*, vol. 12, page 237, 1919, it comprises a two-stage resistance coupled vacuum tube amplifier in which the output is fed back into the input by condensers. The natural frequency of the multivibrator depends primarily upon the time constants of the condenser-resistance combinations in the plate and grid circuits of the tubes. The multivibrator was first used as a rich source of harmonics, in which the fundamental constituent is determined by and maintains a constant phase relation with a low frequency oscillation injected into the plate or grid circuits of the tubes, i. e., as a frequency multiplier or step-up frequency converter. Later, as described in an article by L. M. Hull and J. K. Clapp, published in the *Proceedings of the Institute of Radio Engineers*, vol. 17, No. 2, February 1929, pages 252 to 271, it was used for producing a fundamental frequency which is an integral submultiple of the injected control frequency, i. e., as a step-down frequency converter, in which case the control oscillation coincides with a harmonic of the multivibrator.

An object of the invention is to generate from alternating current waves of one frequency one or more waves of other frequencies.

Another and a more specific object is to improve the stability of operation of circuits employing multivibrators, for producing from a wave of a given frequency one or more waves of frequencies which are desired submultiples of the given frequency.

The circuit of the invention is a submultiple generator comprising a plurality of multivibrator stages and in which exceptional stability of operation is attained in part by employing for

the coupling between stages a circuit which transmits a sharp controlling impulse, and in part by utilizing self-biasing grid circuits for the tubes of the multivibrators which prevent the grids from going far positive thereby prolonging the life of the tubes.

A more complete understanding of the invention together with its various objects and features will be had from the following detailed description thereof when read in connection with the accompanying drawing, in which:

Fig. 1 shows schematically a submultiple generator embodying the circuits of the invention;

Fig. 2 shows schematically an alternative arrangement of a portion of the circuit of Fig. 1; and

Fig. 3 shows curves which will be used to illustrate the operation of the circuits of the invention.

The submultiple generator circuit of Fig. 1 comprises four vacuum tube stages. The first stage is an overloaded amplifier utilized for converting the sinusoidal alternating current waves of the frequency which is to be stepped down to an approximately square wave. This amplifier comprises the single three-electrode space discharge amplifying tube 1, the cathode-grid circuit of which is coupled by the step-up transformer 2 to the input terminals 3 which are adapted to be connected to the source of sinusoidal waves of constant frequency. This source may be, for example, a vacuum tube oscillator controlled by a piezoelectric crystal.

Heating current is supplied to the filament or cathode of tube 1 by current from the battery 4 through resistance 5. The filament is shunted by the resistance 6. Negative bias for the grid of tube 1 is obtained by the voltage drop in the resistance 7 in the filament circuit, the grid being biased to about the mid-point on the vacuum tube characteristic. Space current is supplied to the plate of tube 1 by the plate battery 8 through the resistance 9. The grid circuit of tube 1 also includes the high resistance 10 in series. Thus, when the grid begins to draw grid current, a negative voltage is developed in the resistance 10 which automatically keeps the potential at the grid of the tube 1 from going very far positive. The input of tube 1 by means of the step-up transformer 2 is made large enough so that it

exceeds the points of cut-off in the tube by a large amount. Thus, the output current of tube 1 which is obtained in the resistance 9, and which will be impressed on the coupling circuit to be described later leading to the second multivibrator stage of the system, is approximately a square wave.

The multivibrators A, B and C respectively form the second, third and fourth stages of the submultiple generator. As these stages are identical except for the different values of the resistances and condensers in the grid and plate circuits of the tubes therein, which determine the natural frequency at which each multivibrator vibrates, it will be only necessary to describe one of them, multivibrator A, in detail.

As indicated, the multivibrator A comprises two three-electrode amplifying vacuum tubes 11 and 12, for example Western Electric 101-D tubes. The cathodes or filaments of these two tubes and the cathodes or filaments of the multivibrator tubes in the succeeding stages as well as the cathode of tube 1 in the first stage are supplied with heating current from the filament battery 4 in series with resistance 5. With the connection shown the filament of the amplifier tube 1 would ordinarily carry twice the filament current of the other tubes in the system, but this has been prevented by assigning the proper value to the resistance 6 shunting the filament of tube 1. In order that the grid potentials of the multivibrators may be independent of filament voltages the grid return of each tube is connected directly to its own filament.

Space current is supplied by plate battery 8 to the plates of the multivibrator tubes 11 and 12 respectively through the equal high resistances 13 and 14, which resistances are connected in series between the plates of the two tubes. The grid-cathode circuit of tube 11 comprises in series between the grid and the cathode the resistance 15 and the grid biasing arrangement comprising the resistance leak 16 shunted by the condenser 17. Similarly, the grid-cathode circuit of tube 12 comprises in series between the grid and the cathode the resistance 18 and the grid biasing arrangement comprising the large resistance 19 shunted by the condenser 20. The point 21 between the plate of tube 11 and the resistance 13 is connected directly to the grid of tube 12 by the condenser 22, and the point 23 between the plate of tube 12 and the resistance 14 is connected directly to the grid of tube 11 by the condenser 24.

Except for the grid biasing leak resistance and condenser combinations 16, 17 and 19, 20 in the grid cathode circuits for tubes 11 and 12, respectively, provided for the purpose of preventing the grids of these tubes from going too far positive and thus virtually eliminating grid current, the circuit just described comprises the standard multivibrator circuit such as described in detail in the above mentioned articles by Abraham and Bloch and by Hull and Clapp. The values of the resistances and condensers in the grid and plate circuits of the tubes 11 and 12 primarily determine the natural frequency of vibration of the multivibrator circuit.

The multivibrator A is controlled as a submultiple generator by a controlling wave injected into the plate circuits of the two tubes 11 and 12 over the circuits coupling the output of the first stage amplifier 1 to the plates of tubes 11 and 12, respectively. The controlling wave pro-

vides a series of impulses of frequency f on the two plates of the multivibrator. During the greater part of each half of the multivibrator cycle (which we will assume to have a frequency f/n), these impulses have little effect; but near the end of the half cycle, as the multivibrator approaches the "transient" condition, the margin of stability of the circuit diminishes until finally one of the controlling impulses is sufficient to "trip off" the transient and start a new half cycle. This action being repeated regularly, the multivibrator is held in control at the submultiple ratio $1/n$.

If the controlling impulses are cycles of a sine wave, their control is indefinite in time, and phase shifts in the controlled multivibrator are likely to occur. But if impulses with very steep wave fronts are used (such as may be provided by another multivibrator or other means generating a similar type of wave) the instant of each controlled transient is determined with great precision.

Thus, it appears that if the stages of a train of multivibrators used as submultiple generators are properly coupled, so that the coupling introduces no time lag, each transient of the final multivibrator should occur nearly simultaneously with a corresponding transient of the initial stage. The lag should be not more than a microsecond per stage. Furthermore, changes in operating conditions should not produce phase shifts greater than a fraction of this lag. It has been found in accordance with the invention that the use of coupling circuits between the stages such as shown in Fig. 1 greatly improves the stability of operation of each multivibrator. As indicated, the couplings between the stages of the submultiple generator comprise condensers in series with resistances.

The particular manner of connecting the coupling circuits between stages depends on whether the controlled multivibrator is to be used for producing even order submultiple frequencies or odd order submultiple frequencies. The connections between the first and second stages and between the third and fourth stages of the system of Fig. 1 illustrate the method of connection where the controlled multivibrator is to be utilized for producing even order submultiple frequencies. As shown, in the latter case the plate of tube 29 of the multivibrator B is connected to the plate of the tube 45 in multivibrator C by a circuit comprising the condenser 35 in series with the resistance 37, and also is connected to the plate of the tube 46 of multivibrator C by a separate connection including the condenser 36 in series with the resistance 38 so that voltages of like sign are applied to the plates of both multivibrator tubes. The manner of connection of the multivibrator stages where the controlled multivibrator is to be used for producing odd order submultiple frequencies is indicated by the coupling between multivibrator stages A and B. As shown, the plate of tube 11 in the multivibrator A is coupled to the plate of tube 29 of multivibrator B by the connection including the condenser 39 and the series resistance 31, and the plate of the other tube 12 in the multivibrator A is coupled to the plate of the other tube 32 in the multivibrator stage B by a connection including the condenser 33 in series with the resistance 34, so that the voltages applied to the plates of the two tubes 29

and 30 of multivibrator B are 180 degrees out of phase.

In the first case,

$$\frac{\text{The frequency of C}}{\text{The frequency of B}} = \frac{1}{n}$$

where n is an even integer; whereas in the second case

$$\frac{\text{The frequency of B}}{\text{The frequency of A}} = \frac{1}{n}$$

where n is an odd integer.

In case it is desired to control a multivibrator stage for producing odd submultiple frequencies directly from a preceding stage using an overloaded amplifier, as shown in the first stage of the circuit of Fig. 1, the connection of the coupling circuit would be the same as shown between the first and second stages of Fig. 1, but it would be necessary to use two overloaded amplifier tubes in push-pull arrangement in front of the coupling circuit to give the proper phase relation to the voltages applied to the plates of the controlled multivibrator tubes, or to unbalance the multivibrator by a definite amount.

The manner in which the coupling circuits between stages, as shown in Fig. 1, improve the stability of the submultiple generator will now be described.

As is well known the cycle of a multivibrator, such as used in stages A, B and C, consists of two sections in which currents in the circuit elements change gradually, these sections being separated by transients of very steep "wave-front". The condensers in the coupling circuits between stages, that is, the condensers 25 and 27 in the coupling circuits between the overloaded amplifier 1 and multivibrator A, the condensers 30 and 33 in the coupling circuits between multivibrator A and multivibrator B, and the condensers 35 and 36 in the coupling circuits between multivibrator B and multivibrator C are each given such values as to offer low impedance to the transients produced by the preceding stage, but high impedance to the rest of each cycle. The control waves entering the coupling circuit in the output of each stage, whether it comprises an overloaded amplifier as indicated in the first stage or a multivibrator as used in the remaining stages of the submultiple generator, has a shape which approaches that of a square wave, as indicated by the upper curve in Fig. 2 showing the voltage on the plate of one tube of multivibrator A plotted against time.

The effect of the condenser in each coupling circuit between the stages is to change the shape of the control pulses applied to the plate of the tube in each multivibrator stage from square-shaped pulses to sharp triangular pulses as indicated by the middle curve of Fig. 2. The voltage on the plate of each multivibrator tube is a combination of the sharp control pulses and the square-shaped multivibrator pulses as indicated by the lower curve of Fig. 3 representing the voltage on the plate of one multivibrator tube in stage B plotted against time.

The pulses produced by the multivibrator stage B are also transmitted back to the multivibrator stage A over the coupling circuit therebetween, and the pulses produced by the multivibrator stage C are also transmitted back to the multivibrator stage B over the coupling circuit between the latter stages. However, since multivibrator A is always undergoing a transient

at the instant of multivibrator B's pulse and multivibrator B is always undergoing a transient at the instant of multivibrator C's pulse, these returned pulses have no appreciable effect. Thus, the multivibrator A is left independent of multivibrator B but multivibrator B is controlled in frequency by multivibrator A, and multivibrator B is independent of multivibrator C but multivibrator C is controlled in frequency by multivibrator B.

The resistances 26 and 28 in the coupling circuits between the overloaded amplifier 1 and multivibrator A, the resistances 31 and 34 in the coupling circuits connecting multivibrator A with multivibrator B and the resistances 37 and 39 in the coupling circuit connecting multivibrator B with the multivibrator C are given suitable values to limit the controlling pulses to the proper amplitude.

It has been found that if the condensers are omitted in the coupling circuits between the overloaded amplifier 1 and the multivibrator A or in the coupling circuits between the other multivibrator stages, the stability of the control of the multivibrators is reduced markedly, there being a tendency for each multivibrator to fall periodically in and out of step with its own controlling wave at the frequency of the succeeding multivibrator. This effect is caused by changes of potential on the plates of each multivibrator caused by the voltage on the plates of the succeeding multivibrator acting back through the resistances in the coupling circuit between the two multivibrators.

The submultiple frequency generated by the multivibrator A is picked off in a circuit 39 coupled by the output transformer 40 having a tuned primary winding, across the resistances 13 and 14 in the multivibrator circuit through the series resistances 41 and 42. The series resistances 41 and 42 are made of sufficiently high values so that the circuit 39 will not affect the operation of the multivibrator. The antiresonant circuits 43 and 44 coupled in parallel across the plates of the multivibrator tubes 45 and 46 in multivibrator C have such values for their inductive and capacitive elements respectively to select the submultiple frequency generated by multivibrator C and any desired harmonic thereof, for example the third harmonic.

In the circuit of Fig. 1, the coupling circuits are connected to the several multivibrators in such manner as to apply the controlling pulses to the plates of the tubes therein. Since the plate of each tube in each multivibrator is connected directly to the grid of the other tube of the same multivibrator by a condenser having negligible impedance to the sharp pulses, it is apparent that the control pulses may be applied either to the grids or to the plates of the multivibrator tubes. In either case, the impedance into which the pulses are delivered is something less than the value of the resistance element in the plate circuit of each tube.

In Fig. 3 is shown a circuit arrangement which may be substituted for the portion of the circuit of Fig. 1 shown to the left of the dot-dash line X-X. It comprises a coil 47 adapted to be connected to a source of sinusoidal waves of the constant frequency which is to be stepped down, and inductively connected to the circuit comprising the coil 48 and parallel condenser 49. Across the terminals of the condenser 49 is connected the input circuit of the three-electrode vacuum tube amplifying device 50, which input circuit includes

the parallel resistance-condenser combination 51. The filament of the tube 50 is supplied with heating current from the filament battery 52 through the resistance 53 and space current is supplied to the plate of the tube 50 by plate battery 54 through the resistance 55.

A circuit similar to that shown in Fig. 1 was developed for use in a circuit for stepping down an alternating current wave of the frequency of 4000 cycles per second to submultiple frequencies of 1000, 100 and 60 cycles per second. In this case, the multivibrator stages A, B and C were adjusted to vibrate at a fundamental frequency of 1000, 200 and 100 cycles, respectively, as indicated by the notations opposite these stages on Fig. 1. As indicated in Fig. 1, in the circuit developed the resistances 26 and 28 in the circuits coupling the plate of the overloaded amplifier I to the plates of the tubes in multivibrator stage A had a value each of 250,000 ohms, and the resistances 31 and 34 in the circuits coupling multivibrator stage A to the multivibrator B and the resistances 37 and 38 coupling the multivibrator stage B to the multivibrator stage C each had a value of 100,000 ohms. The condensers 25 and 27 in the circuit coupling the overloaded amplifier I to the first multivibrator A each had a value of 0.0001 microfarad. The condensers 30 and 33 in the circuits coupling the multivibrator stage A to the multivibrator stage B each had a value of 0.0005 microfarad, and the condensers 35 and 36 in the circuits coupling multivibrator stage B to the multivibrator stage C each had a value of 0.001 microfarad.

As indicated, the submultiple frequency of 1000 cycles was taken off by circuit 39 coupled to the output of the multivibrator stage A through the tuned transformer 40, and the submultiple frequency of 100 cycles was picked off from the output circuit of multivibrator C by the anti-resonant circuit 43. Also, the third harmonic of the latter frequency, or 300 cycles, was picked off from the output of the multivibrator stage C by means of the anti-resonant circuit 44 of suitable design. The component of 300 cycles selected from the output of the multivibrator stage C can be used to control an additional multivibrator stage, not shown, similar to the previous multivibrator stages but having a fundamental frequency of 60 cycles through an overloaded push-pull amplifier and a coupling circuit comprising condensers and resistances in a manner similar to that described for the preceding stages.

If the filaments of the tubes in any one multivibrator stage are connected directly in parallel instead of in separate circuits proper biasing of the grids of the tubes in the multivibrator could be obtained by a single parallel condenser-resistance in the common branch of the grid filament circuit instead of the two separate condenser-resistance combinations as illustrated for the present connections.

Among the advantages obtained by the use of the grid biasing leak resistance and condenser with the multivibrator tubes are the following:

- (1) The lives of the multivibrator tubes are increased by virtual elimination of grid current;
- (2) Multivibrators employing the grid bias devices have been found to allow greater variations of plate potential and of circuit elements while still maintaining more stable control than can be obtained with multivibrators with no bias or with fixed bias (battery). This is due to (a) the tubes operating over the lower portion of their

grid potential-plate current characteristic thus using less of their emission and reducing the effect of changes in the filament current; (b) changes in plate potential being compensated for by changes in grid bias; and (c) changes in circuit elements being also compensated for by the changes in grid bias.

It is to be understood that the particular values for frequencies of the waves and the values of the elements in the circuits for coupling the various stages of the circuits of the invention are given by way of example only and are not to be taken as limiting the invention to these particular frequencies and values for the coupling elements. The invention, as described, is of general application and may be used for producing from a wave of any frequency any desired submultiple frequencies. Various modifications of the circuits shown and described within the scope and spirit of the invention will occur to persons skilled in the art. The invention is only to be limited by the scope of the appended claims.

What is claimed is:

1. A submultiple generator comprising a source of alternating current waves of a given frequency and its harmonics, a multivibrator having a natural oscillation frequency which is approximately a desired submultiple of said given frequency, a control circuit coupling said source to said multivibrator and transmitting therebetween waves of said given frequency to control oscillation of said multivibrator at said desired submultiple frequency, means for selecting waves of said desired submultiple frequency from the output of said multivibrator, and means for improving the stability of control of said multivibrator comprising impedance means in said control circuit for transforming the transmitted waves to impulses of approximately triangular form having a steep wave front and of the optimum amplitude for control.

2. The submultiple generator of claim 1 and in which said impedance means includes a series capacitive element providing a high impedance to the lower frequency components of said given wave and a lower impedance to the higher frequency components of said given wave.

3. The submultiple generator of claim 1 and in which said impedance means comprises a capacitive element having a high impedance to the lower frequency components and a lower impedance to the higher frequency components of said given wave, and a resistance element in series therewith.

4. A submultiple generator comprising a source of alternating current waves of a given frequency and its harmonics, a multivibrator comprising two electric discharge devices each having a cathode, an anode and a control electrode, and circuits therefor, resistive means in said circuits, the anode of each device being connected to the control electrode of the other device by a capacitive element, the values of the resistive and capacitive elements in said circuits being such as to cause the multivibrator to oscillate at a natural fundamental frequency which is approximately a desired submultiple of said given frequency, a control circuit coupling said source to the electrodes of said discharge devices and transmitting therebetween waves of said given frequency to control oscillation of said multivibrator at said submultiple frequency, and means for improving the stability of control of said multivibrator comprising a high resistance

shunted by a capacity in the control electrode-cathode circuits of said devices for controlling the bias on the control electrodes of said devices.

5 5. The submultiple generator of claim 4 and in which said control circuit includes between said source and an electrode of each of said devices a series capacitive element of such value as to offer a high impedance to the lower frequency components and a lower impedance to the higher frequency components of the waves from said source.

10 6. A submultiple generator comprising a source of waves of a given frequency and its harmonics, a plurality of multivibrator stages, each including
15 a pair of vacuum tubes each having a plate, cathode and grid electrode and circuits therefor, resistances in the plate and grid circuits of said tubes and a capacitive element connected between the plate of each tube and the grid of the
20 other tube, the resistances and capacitive elements in said circuits having such values as to cause the multivibrator in each stage to oscillate at a natural fundamental frequency which is ap-

proximately a submultiple of said given frequency which submultiple frequency is of lower value for each successive stage, circuits coupling said source to the first multivibrator stage and coupling successive multivibrator stages in such
5 manner as to transmit therebetween a controlling wave which will cause the controlled multivibrator to oscillate at one of said submultiple frequencies, and means for improving the stability of control of said multivibrator stages
10 comprising in each coupling circuit a series capacitive element having a high impedance to the lower frequency components of the waves transmitted from said source or from the preceding
15 stage and a lower impedance to the higher frequency components thereof, a resistive element in each coupling circuit of such value as to limit the amplitude of the transmitted control wave to the optimum value for control, and a high resistance shunted by a capacity in the grid-cathode circuits of the tubes in each stage for controlling the bias on the grids thereof.

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