Nov. 28, 1939. R. L. MILLER 2,181,280

ELECTRICAL WAVE PRODUCTION

Filed Dec. 22, 1937

FIG. 1

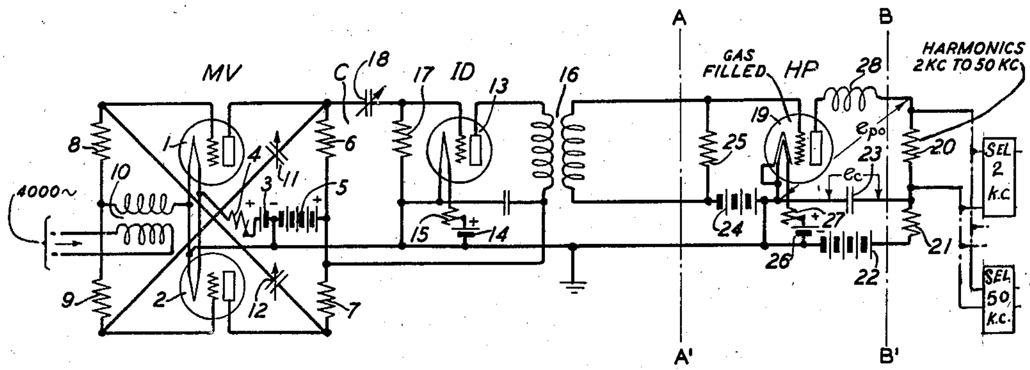


FIG. 1A

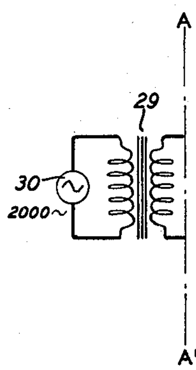


FIG. 1B

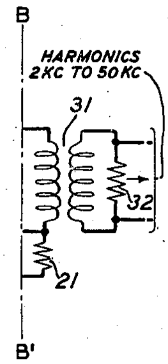


FIG. 2

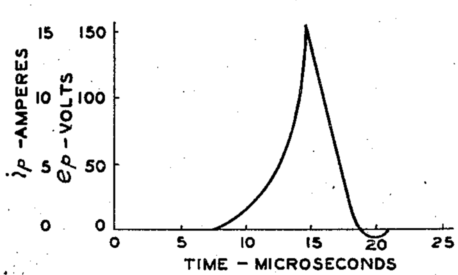
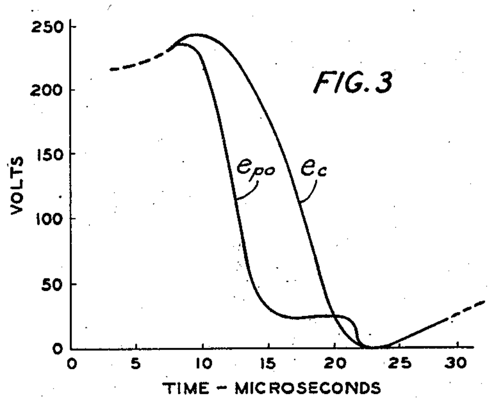


FIG. 3



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ELECTRICAL WAVE PRODUCTION

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7 Claims. (Cl. 250—36)

The present invention relates to the generation of alternating current waves and particularly to the conversion of alternating current waves of one frequency into one or more alternating current waves of other frequencies.

Heretofore, it has been found desirable in transmission systems in which a large number of alternating current waves of different frequencies are required, for example, as the carrier waves for the different channels of a multiplex carrier telephone system, to obtain these waves simultaneously by distorting an alternating current wave of a base frequency by a single wave distorting device. Some systems of the prior art have made use of gas-filled electron discharge devices for this purpose because of the increased power output which can be obtained thereby at ordinary operating voltages. However, gas-filled tubes when used as harmonic or sub-harmonic producers have not proved entirely satisfactory because of large variations in output amplitude and phase, especially at the higher frequencies, due to the arc failing to strike at the same part of each cycle of input.

It is an object of the present invention to produce simultaneously from a single base frequency wave, a large number of waves of harmonically related frequencies which are of substantially equal amplitudes and high power levels, and of constant phase relation over a wide range of frequencies.

In accordance with the invention, this object is obtained in a circuit employing a gas-filled tube as the harmonic producer by so designing the circuit that the output wave is substantially triangular and narrow compared to the whole cycle. In one embodiment the circuit comprises a gas-filled tube with a condenser and resistance in series in its output circuit, the condenser being charged from a source of direct current over a greater part of the cycle and being allowed to discharge through the resistance and the gas-filled tube under control of impulses of the base frequency impressed on the grid of the gas-filled tube. By making the time constant of the resistance and condenser in the output circuit short compared with the time of a cycle of the controlling wave, a relatively sharp impulse wave is obtained in the output circuit.

The various objects and features of the invention will be understood from the following detailed description thereof when read in connection with the accompanying drawing in which:

Fig. 1 shows schematically a frequency conversion circuit embodying the invention;

Figs. 1A and 1B show schmatically circuits which may be substituted for portions of the circuit of Fig. 1 to produce modified forms of the invention; and

Figs. 2 and 3 show curves illustrating the operation of the circuits of the invention.

Fig. 1 shows a frequency converter circuit embodying the invention which was devised to produce simultaneously a group of frequencies ranging from 2,000 to 50,000 cycles per second which are harmonics of 2,000 cycles, to be used as the carrier waves for the different channels of a multiplex carrier telephone system.

Referring to Fig. 1, the circuit comprises a multivibrator unit MV of the well-known Abraham-Bloch type, an intermediate vacuum tube driver stage ID, and a harmonic producer circuit HP.

As indicated, the multivibrator MV which is used to reduce the 4,000-cycle control frequency to 2,000 cycles and to provide an output wave whose shape is desirable to use with the driver stage, comprises two 3-electrode amplifying vacuum tubes **1** and **2**. Heating current of suitable value is supplied in parallel to the cathodes of the two tubes **1**, **2**, from the filament battery **3** through the rheostat **4**. Space current is supplied by the common plate battery **5** to the plates of the multivibrators **1** and **2**, respectively, through the equal high resistances **6** and **7**, which resistances are connected in series between the plates of the two tubes. The control grid-cathode circuits of the two tubes **1** and **2** are connected in push-pull relationship, and the equal resistances **8** and **9** are respectively connected in series in the individual portions of the control grid-cathode circuits of the tubes **1** and **2**. A sinusoidal wave of the control frequency 4,000 cycles is impressed on the common portion of the control grid-cathode circuits of the tubes **1** and **2** through the input transformer **10**, as indicated. The plate of tube **1** is connected directly to the control grid of tube **2** by the variable condenser **11**, and the plate of tube **2** is connected directly to the control grid of tube **1** by the variable condenser **12**.

In such a multivibrator circuit, the time constants of the circuit elements are selected so that the multivibrator oscillates at a fundamental frequency which is approximately that of the frequency desired. Where the multivibrator is used as a step-down frequency converter, the frequency of the injected control oscillations coincides with a harmonic of the multivibrator, or conversely the natural frequency of oscillation of the multivibrator is a sub-harmonic of the frequency of the injected oscillations. In the present case where a wave of 2,000 cycles is desired, the control wave oscillations applied to the input of the multivibrator MV have a frequency of 4,000 cycles, and the value of the condensers and resistances of the multivibrator are selected to make its fundamental frequency of oscillation, 2,000 cycles.

The intermediate driver stage ID comprises a single 3-electrode vacuum tube 13. The cathode or filament of tube 13 is supplied with suitable heating current from the filament battery 14 through the rheostat 15, and space current is supplied to the plate of tube 13 from the plate battery 5 through the primary winding of the output transformer 16. A resistance 17 is connected between the cathode and control grid of tube 13 and the input of that tube is coupled to the output of the multivibrator MV by a resistance-condenser coupling C comprising the shunt resistances 6 and 17 and the series variable condenser 18.

The harmonic producer HP comprises the 3-electrode gas-filled discharge tube 19; the load resistance 20, charging resistance 21 and the plate battery 22 connected in series in the plate-cathode circuit of tube 19; and the condenser 23 shunting the plate battery 22 and the charging resistance 21 in series. The control grid of the tube 19 is negatively biased by the grid battery 24 through the series resistance 25, and the cathode or filament of tube 19 is supplied with heating current from the filament battery 26 through the rheostat 27. The resistance 25 is connected across the terminals of the secondary winding of the output transformer 16 for the intermediate driver tube 13. A small inductance 28 is also preferably inserted in the plate-cathode circuit of tube 19 in series with the load resistance 20 to improve the operation of the harmonic producer circuit, but is not an essential element thereof. The harmonic frequencies produced by this circuit are taken off across the terminals of the load resistance 20, and are separated by suitable selecting circuits or filters connected to that resistance as indicated.

Other characteristics of the circuit of the invention as shown in Fig. 1 in producing a large number of harmonics having equal amplitudes and high power level will be brought out in the following complete description of operation.

In the multivibrator MV as described, the plate circuit of the tube 1 is resistance-capacity coupled to the grid circuit of tube 2 through resistances 6 and 9 and variable condenser 11, and the plate circuit of tube 12 is, in turn, resistance-capacity coupled to the grid circuit of tube 1 through resistances 7 and 8 and variable condenser 12.

A sinusoidal wave of the control frequency, 4,000 cycles per second, is applied to the common portion of the control grid-cathode circuits of the tubes 1 and 2 of the multivibrator through the input transformer 10 so as to apply a series of control impulses of that frequency alternately on the two control grids of the multivibrator tubes 1 and 2. During the greater part of each of half of the multivibrator cycle 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 frequency 2,000 cycles, and a square-topped wave of constant frequency, 2,000 cycles per second, is produced in the output of the multivibrator MV.

This square-topped wave could be directly applied to break down the gas-filled tube 19 of the harmonic producer circuit HP but it would hold the control grid of that tube above the critical voltage for the remainder of a half-cycle so that as the plate voltage builds up the tube would break down again in the same cycle. By using an intermediate driver tube 13 coupled to the output of the multivibrator MV through a condenser-resistance combination C (resistances 6 and 17 and condenser 18) of very short time constant by proper selection of the values of the individual elements in the coupling circuit, triangular-shaped control pulses may be applied to the grid of the gas-filled tube 19. The wave form of the wave which will be obtained in the output circuit of the tube 19 in the manner which will be described below, does not depend to any extent on the applied control wave since the latter determines only the time at which the discharge of tube 19 is started. Each triangular pulse thus impressed by the output transformer 16 of the intermediate driver tube 13 on the control grid-cathode circuit of the gas-filled tube 19 across the resistance 25 will cause the tube to break down so that plate current will flow in the plate-cathode circuit.

In the harmonic producer stage HP, the condenser 23 is normally charged up to the potential of the plate battery 22 through the charging resistance 21, and will discharge through the load resistance 20 and the discharge path of the tube 19 when that tube is rendered operative. As stated above, the starting of the discharge through the tube 19 is controlled by the impulses impressed on the grid-cathode circuit of tube 19 from the output of the intermediate driver stage ID. The control grid-cathode circuit of tube 19 loses control of the plate discharge immediately the tube is ionized and cannot regain control until the voltage between the cathode and plate thereof falls below the ionizing potential of the gas in the tube. The potential will fall below this value because of the oscillatory nature of the discharge circuit consisting of the condenser 23, the load resistance 20 and the inductance in series therewith comprising the effective inductance of the gas-filled tube, which is probably due to the inertia of the ions in the tube, and the small series inductance 28.

By suitable selection of the values of the load resistance 20 and the condenser 23, the time constant of the discharge circuit of tube 19 is made short compared with the time of a cycle of the controlling wave so that the condenser 23 is charged up to the positive potential of the plate battery 22 through the resistance 21 over a greater part of each cycle, and during the remainder of the cycle discharges through the load resistance 20 and the discharge path of the gas-filled tube 19. By this action, a relatively sharp impulse wave is obtained in the load resistance 20. This wave approaches very closely a triangular pulse and contains a large number of harmonics of the frequency 2,000 cycles, which have high power level and substantially equal amplitudes.

A modified method of attaining the sharp pulse necessary to control the gas-filled tube 19 is to use a transformer 29 of the impulse coil (saturable core) type as shown in Fig. 1A of the drawing, as an input transformer for the harmonic producing circuit HP, the primary winding of the coil **29** being supplied from a suitable source **30** with a sinusoidal wave of 2,000 cycles which is of sufficient amplitude to cause saturation of the core. The source **30** and impulse coil **29** would be substituted for the intermediate driver tube **13** and the multivibrator MV to the left of the line A—A'. Since the core of the transformer **29** is saturated over the greater part of a cycle there is no change of flux except as the wave goes through zero, at which point a very short pulse is obtained in the secondary winding of the transformer. This impulse always occurs at the same part of the cycle regardless of the magnitude of input, which is an essential feature.

A transformer **31** having its secondary winding shunted by a resistance **32** may be substituted for the load resistance **20** and outgoing circuit to the right of the dot-dash line B—B' in the system of Fig. 1. This transformer arrangement would be designed to present the same effective resistance as the resistance **20** in the system of Fig. 1.

In order to study the operation of the circuit of the invention, and to more clearly understand the phenomena which take place, measurements of the voltage and current conditions in an experimental circuit substantially as shown in Fig. 1, were taken. The curve in Fig. 2 of the drawing shows the current discharge occurring in the gas-filled tube **19** and the load resistance **20**, or the voltage e_p on the plate of tube **19**, plotted against time. In this case, the circuit constants of the circuit of Fig. 1 were selected so as to give nearly a flat harmonic distribution at the power required for the carrier system with which it was desired to use the circuit of Fig. 1 as the carrier supply. The load resistance **20** was 10 ohms and the value of the condenser **23** was 0.2 microfarad. Inspection of Fig. 2 will show that the peak current obtained under these conditions is about 15 amperes. The curve designated e_{po} in Fig. 3 of the drawing represents the potential variation between the cathode and the plate of the tube **19** in the circuit of Fig. 1 during the discharge, and the curve designated e_c in Fig. 3 shows the potential across the condenser **23**. The difference between the curve e_{po} and the curve e_c represents the voltage variation across the load resistance **20**.

In order for the circuit of Fig. 1 to operate satisfactorily, the tube **19** must ionize in an extremely short time. The curve e_{po} of Fig. 3 shows that the ionization time of the tube **19** is approximately 6 micro-seconds.

Although the deionization time of the tube **19** does not enter to any extent in the sharpness of the pulse which will be obtained in the output circuit thereof, it is important in extinguishing the arc. The deionization of the tube must take place between the time the potential across the cathode to the plate drops below the ionization potential and the point where it charges up to the ionizing potential again through the charging resistance **21**. If this interval is shorter than the deionization time, the tube **19** will continue to conduct current and will not follow the driving tube **13**. The time of this interval depends upon the value of both resistances **20** and **21**. The amount by which the voltage on the condenser **23** drops below zero on the transitory discharge of the condenser is dependent upon the value of the load resistance **20**. The time which it takes to charge the condenser **23** up to the ionization potential from the battery **22** through the charging resistance **21** is directly proportional to its value.

By placing a small inductance **28** in the discharge circuit it was possible to enlarge the control range of the harmonic producer. The small inductance reduces the peak current necessary to obtain the required high power level for the harmonics.

The total energy which may be stored in the condenser **23** in the circuit of Fig. 1 in one cycle is: $W=1/2\ CV^2$ where C is the capacity of the condenser **23** and V is the voltage across it.

The total energy which is stored in the condenser **23** per second, or power, is $P=1/2\ f\ CV^2$, where f is the frequency. Since the values of the frequency f and the voltage V are fixed, then it is evident that the power obtainable is directly proportional to the capacity of the condenser **23**. In order to obtain even distribution of harmonics, the time constant of the load resistance **20** and the condenser **23** must be of fixed value, which definitely fixes the values of the condenser **23** and the load resistance **20** for any given power.

The experiments which have been made on the circuit of the invention as shown in Fig. 1 indicate that a large number of harmonics of substantially equal amplitude and having a large amount of output power may be readily obtained.

Various modifications of the circuits of the invention which have been illustrated and described within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A harmonic producer comprising a gas-filled electron discharge device, an input circuit for said device, an output circuit for said device including a resistive impedance and a capacitor in series, a source of direct current, a circuit for charging said capacitor from said source, means to apply an alternating current control wave of a given base frequency to said input circuit to periodically cause ionization in said device so as to allow said capacitor to discharge through said device and said resistive impedance during a part of each cycle of the applied wave, and means to select from said output circuit a large number of waves of different frequencies harmonically related to said base frequency, the time constant of said output circuit being related to the time of each cycle of said control wave so as to produce an impulse wave in said output circuit, which is relatively sharp and narrow compared to the whole cycle whereby the selected waves of harmonic frequencies obtained from said output circuit are of high power levels and substantially equal amplitudes over a wide frequency range.

2. The harmonic producer of claim 1, in which the time constant of said output circuit is short compared with the time of a cycle of the control wave applied to said gas-filled device.

3. The harmonic producer of claim 1, in which the desired relationship of the time constant of said output circuit and the time of each cycle of said control wave is obtained by making the control wave applied to said device comprise a series of recurring impulses which are substantially triangular and narrow compared to the whole cycle.

4. A harmonic producer comprising a gas-filled electron discharge device having a control electrode, an input circuit including said control electrode, an output circuit including a source of direct current, a resistance and the discharge path of said device in series, a capacitor connected across said source in shunt with said resistance and said discharge path in series, means for

producing an alternating current wave of a desired frequency comprising a series of recurring sharp impulses, means to apply said wave to said input circuit to cause said device to be periodically ionized to discharge said capacitor through said resistance and said discharge path of said device, the time constant of said resistance and said capacitor being short compared to a cycle of the wave applied to said input circuit so that an impulse wave which is substantially triangular and narrow compared to a whole cycle and contains a large number of different harmonics of said desired frequency having a substantial amount of power and of substantially equal amplitudes over a wide frequency range is obtained in said resistance, and means to select the produced harmonics of said desired frequency from said resistance.

5. The harmonic producer of claim 4 in which said means for producing the alternating current wave of said desired frequency comprising a series of recurring sharp impulses, comprises a multivibrator for producing a square-shaped wave of said desired frequency, a second electron discharge device having an output circuit coupled to the input circuit of said gas-filled device, and an input circuit, and a condenser-resistance circuit of very short time constant coupling the output of said multivibrator to the input circuit of said second discharge device.

6. The harmonic producer of claim 4, in which said means for producing said wave applied to the input circuit of said gas-filled device comprises a saturable core transformer having a secondary winding connected to the input circuit of said gas-filled device, and a primary winding and means to impress a sinusoidal wave of said desired frequency on said primary winding of sufficient amplitude to cause periodical saturation of the core of said transformer.

7. A circuit for producing a large number of waves of different frequencies harmonically related to a given base frequency and of high power level and of substantially equal amplitudes over a wide frequency range, comprising a gas-filled electron discharge device having an input circuit, and an output circuit including a resistance and a capacitor in series, a source of direct current, said capacitor being connected across said source so as to be charged therefrom, means to apply an alternating current control wave of said given frequency to said input circuit to periodically cause ionization in said device so as to allow said capacitor to discharge through the discharge path of said device and said resistance during a part of each cycle of the applied wave, the time constant of said resistance and said capacitor being short compared to a cycle of said applied wave so that for each cycle of applied input an impulse is produced in said resistance which is relatively sharp and narrow compared to a whole cycle, means to select the desired waves of different frequencies harmonically related to said base frequency from said resistance, and sufficient inductance in the discharge circuit for said capacitor to reduce the peak current necessary to obtain the required high power level for the harmonics whereby the control range of the harmonic producer is enlarged.

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