Nov. 27, 1945. A. H. BARTELS 2,389,948

FREQUENCY COMPARISON APPARATUS

Filed April 30, 1943 2 Sheets-Sheet 1

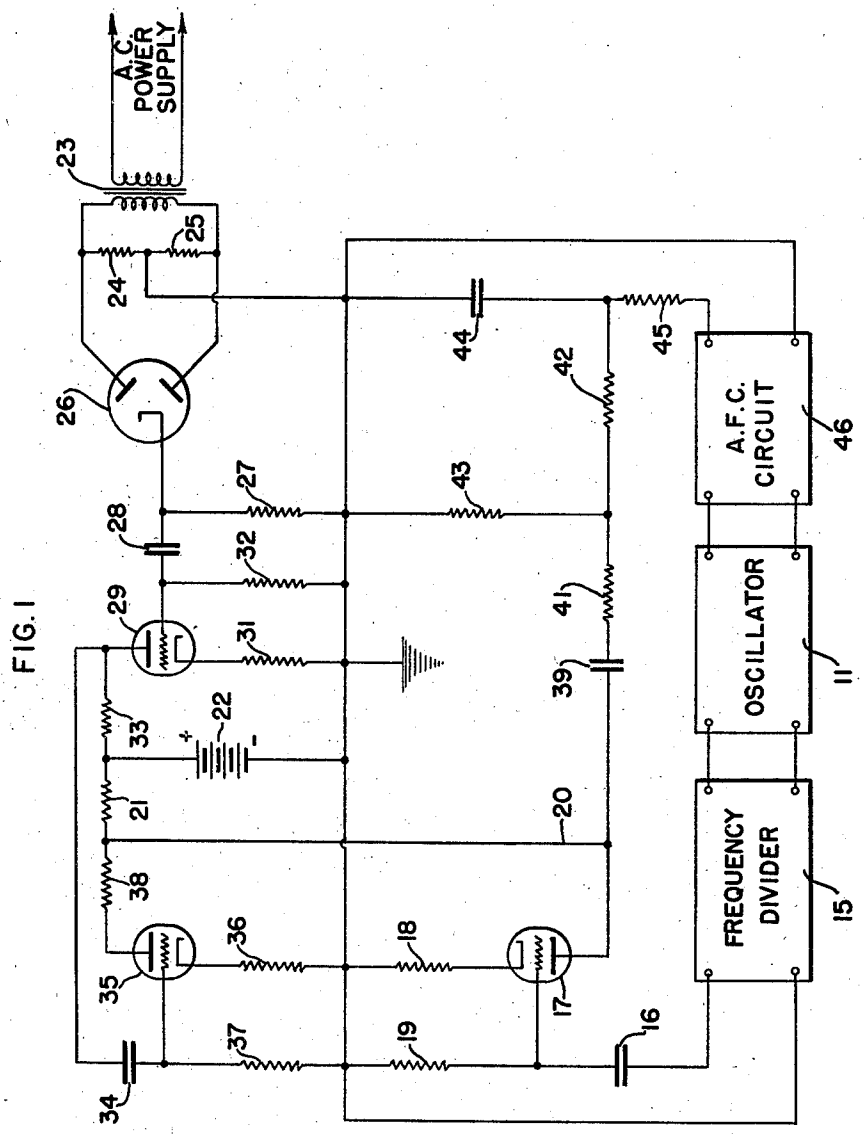



FIG. 1

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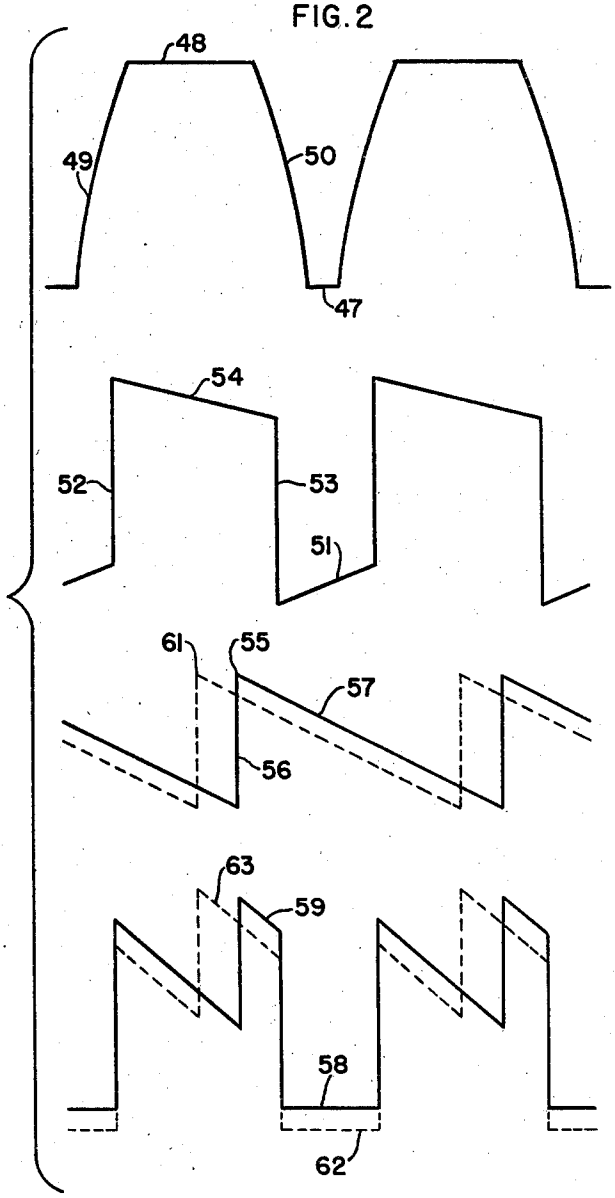
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FREQUENCY COMPARISON APPARATUS

Filed April 30, 1943 2 Sheets-Sheet 2

FIG. 2




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# UNITED STATES PATENT OFFICE

2,389,948

## FREQUENCY COMPARISON APPARATUS

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Application April 30, 1943, Serial No. 485,205

13 Claims. (Cl. 250—36)

This invention relates to frequency control apparatus and particularly to apparatus for controlling the frequency of an oscillator used in a television timer.

According to conventional television practice the synchronizing signal generator and the transmitter scanning generators are operated in a definite time relation to a source of standardizing frequency which usually is a commercial alternating current power supply. This relationship is attained by the use of so-called timer apparatus which includes a high frequency oscillator and a timer chain or frequency divider, whereby the scanning and synchronizing signal frequencies are produced. A submultiple frequency of the high oscillator frequency is compared with the alternating current power supply frequency to generate a control voltage representative of the frequency comparison. This voltage is employed to control the operation of an automatic frequency control circuit, whereby the oscillator frequency may be locked in a harmonic relation with the source of standardizing frequency.

As is well understood in the art, the control voltage generally is in the form of a series of spaced impulses. In order to utilize these impulses they are passed through a filtering network to produce a voltage which approximates a steady direct voltage. It is necessary to provide filtering for the control impulses in order to prevent the frequency of the oscillator from changing between successive impulses. Also, since the standardizing frequency is most conveniently a source of 60 cycle alternating current the control impulses are generated at a 60 cycle rate. The amount of filtering necessary to approximate the desired steady direct current control voltage from 60 cycle impulses has the disadvantage that the response by the oscillator to a detected frequency deviation is relatively slow.

An object of the present invention, therefore, is to provide improved automatic frequency control apparatus for a television timer which will obviate the objectionable feature referred to.

Another object of the invention is to provide, in automatic frequency control apparatus for a television timer, means whereby to minimize the filtering necessary to convert a series of control impulses into an approximation of a steady direct current control voltage.

A further object of the invention is to provide, in automatic frequency control apparatus for a television timer, means whereby to maintain synchronism between an oscillator and a source of standardizing frequency, irrespective of substantial fluctuations of the voltage of the standardizing source.

In accordance with the present invention, there is provided a novel circuit for producing a voltage representative of the phase relation between impulses derived from two periodic sources. This circuit includes a means for deriving from one of the sources a series of impulses having a frequency which is a harmonic of the frequency of the source from which it is derived. Additional means is provided for deriving from the other of the two sources, a series of impulses also having a frequency which is a harmonic of the frequency of the first of the two sources. The frequencies of the two series of impulses are preferably but not necessarily the same harmonic of the frequency of one of the sources. There also is provided, means for combining the two series of impulses in a manner to produce a composite wave which has pedestal portions representative of the phase relation between the two series of impulses. The novel circuit also includes a means for developing from the composite wave substantially continuous unidirectional voltages which have magnitudes corresponding to the energy content of the pedestal portions.

More specifically, in accordance with the illustrated embodiment of the invention, there is provided an automatic frequency control system having means for converting a standardizing alternating current into a series of steep sided impulses having sloping crests at a harmonic frequency of the alternating current. There also is provided, means for deriving from the television timer oscillator a series of substantially saw-toothed impulses. These two series of impulses are combined to form a composite wave having pedestal portions. The peak amplitudes and the widths of the pedestal portions are representative of the phase relation between the two series of impulses. There also is provided an integrating means, whereby energy derived from the pedestal portions is utilized to produce a control voltage which approximates a steady direct voltage. The control voltage is applied to an automatic frequency control circuit, whereby to effect a change in the frequency of the oscillator derived impulses in accordance with changes in the control voltage.

By reason of the wave shapes of the two series of impulses a slight phase change of one series with respect to the other is manifested by a

change in the peak amplitudes of the composite wave pedestals and also by a pronounced change in the widths thereof. Consequently, the manner of combining the two series of impulses to form the composite wave provides a means for generating impulsive energy which represents very slight frequency deviations of one series of impulses with respect to the other. Also, since the energy impulses are generated at a rate which is a multiple of the stadardizing frequency the integrating network is provided with smaller storage facilities than have been possible heretofore. The control voltages generated as a result are much more responsive to frequency changes and thus, the frequency stability of the oscillator is considerably improved by virtue of the fact that a differential control voltage is applied oftener in a given time interval than was possible in prior art systems.

For a better understanding of the invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is a partially schematic circuit diagram of automatic frequency control apparatus embodying the invention; and

Fig. 2 is a series of graphical representations of wave forms of the voltages appearing in various circuits of the apparatus which are of assistance in explaining the operation of the apparatus.

Referring now more particularly to Fig. 1 of the drawings, there is shown schematically an oscillator 11 which may be any conventional type of oscillator. The oscillator is designed to generate oscillations at a relatively high frequency. These oscillations are impressed upon a conventional timer chain or frequency divider 15 whereby to subdivide the oscillator frequency so as to produce impulses at the desired synchronizing and scanning frequencies. The components of the frequency divider may also be conventional blocking oscillators, multivibrators or the like. There also is derived from the frequency divider 15, impulses of a predetermined frequency which are employed in a manner to be described subsequently to assist in the generation of an automatic frequency control voltage.

The relatively low frequency impulses derived from the last stage of the frequency divider 15 are coupled by means of a condenser 16 to the control grid of an amplifier tube which is illustrated as a triode 17. The cathode of the tube 17 is connected through a biasing resistor 18 to ground. There also is provided a leak resistor 19 for the control grid of the tube 17. The coupling circuit including the condenser 16 and the resistor 19 is designed to have a relatively small time constant for a purpose to be described. As disclosed herein, this result is achieved by the use of a relatively small condenser, but, obviously, the use of a relatively small resistor will accomplish the same result. The anode of the tube 17 is connected by a conductor 20 and a resistor 21 to the positive terminal of a source of direct current energy such as a battery 22. The negative terminal of this battery is connected directly to ground.

Because of the relatively low capacity of the coupling condenser 16 the impulses derived from the frequency divider 15 are converted in the output circuit of the tube 17 into substantially saw-toothed voltage waves which appear at the anode of the tube.

Such impulses are utilized for the purpose of comparing the frequency thereof with a source of standardizing frequency. Such a source may be a commercial alternating current power supply which is connected to the primary winding of a transformer 23. The secondary winding of the transformer is shunted by a series arrangement of two resistors 24 and 25. These resistors are for the purpose of placing the center of the winding at ground potential and may be omitted, if desired, where the winding itself may be center tapped. The terminals of the secondary winding are also connected to the anodes of a twin diode rectifier tube 26. The cathode of this tube is connected through a load resistor 27 to the grounded junction point of resistors 24 and 25. The rectifier tube and its associated circuits functions as a frequency multiplier. While obviously not limited to any particular multiplication of the power supply frequency, as disclosed herein for illustrative purposes only, the apparatus serves to double the power supply frequency.

The double frequency voltage appearing across the resistor 27 is coupled by means of a condenser 28 to the control grid of an amplifier tube illustrated as a triode 29. The cathode of this tube is connected through a self-biasing resistor 31 to ground, and to the grounded terminal of the rectifier load resistor 27. A leak resistor 32 is provided for the control grid of the tube 29. Space current for the tube 29 is supplied from a source of direct current energy such as the battery 22, the positive terminal of which is connected to the anode of the tube through a resistor 33. The magnitude of the voltage applied to the control electrode and the biasing of the input circuit of the tube 29 is of such a nature that the tube operates in the anode-to-cathode current saturation region during a portion of the input cycle. As a result, the wave form of the voltage appearing at the anode of the tube 29 is substantially flat topped and the slopes of the sides of the wave are relatively steep.

The voltage developed at the anode of the tube 29 is coupled by means of a relatively small condenser 34 to the control grid of another amplifier tube which is illustrated as a triode 35. The cathode of this tube also is connected through a biasing resistor 36 to ground. A leak resistor 37 is provided for the control grid of the tube 35. This coupling circuit is designed to have a relatively small time constant which, alternatively, may be attained by the use of a relatively small resistor 37, in the manner indicated in connection with the description of the coupling circuit for the tube 17.

The anode of the tube 35 is connected through resistors 38 and 21 to the positive terminal of the battery 22. The tube 35 also is biased for operation in the anode-to-cathode current saturation region during a portion of the input cycle.

Consequently, the wave form of the voltage developed at the anode of the tube 35 has leading and trailing edges which are substantially perpendicular. Also, the tops or crests of the voltage wave are sloping. The sloping crests of the voltage wave are produced by the relatively small capacity of the coupling condenser 34 so that the result is a wave having an amplitude which decreases from the leading to the trailing edges thereof.

The frequencies of the sloping crested wave derived from the alternating current power sup-

ply and the substantially saw-toothed wave derived from the frequency divider 15 during normal operation of the apparatus are identical. It is contemplated to be within the scope of this invention that these frequencies may be any desired harmonically related frequencies. The composite wave produced by the combination of the two series of impulses which appears at the junction point of resistors 38 and 21 has pronounced pedestal portions recurring at the frequency of the impulses.

The composite wave is applied to an integrating circuit whereby to convert the impulsive energy into substantially direct current energy. The integrating circuit comprises a series arrangement of a condenser 39 and a resistor 41. This series arrangement is connected to a series parallel arrangement of resistors 42 and 43 and the condenser 44. The energy of the impulses of the composite wave form is converted into a unidirectional voltage which appears across the terminating condenser 44 of the integrating network.

The unidirectional control voltage is applied through a resistor 45 to the input terminals of an automatic frequency control circuit 46. The output terminals of the A. F. C. circuit are connected to the frequency determining circuit of the oscillator 11, whereby to control the frequency thereof in accordance with the control voltage developed across the condenser 44.

Referring to Fig. 2, typical wave forms of the voltages appearing in different parts of the circuit of Fig. 1 are shown. The curve 47 illustrates approximately the wave form of the voltage appearing at the anode of the tube 29. It is noted that, because of the operation of the tube in the anode-to-cathode current saturation region during a portion of each cycle, the voltage impulses have substantially flat crest portions 48. Also, the leading and trailing edges 49 and 50 respectively, of each impulse are relatively steep. This is also the result of the operation of the tube 29 in the saturation region.

The voltage having a wave form such as the curve 47 is converted, by the tube 35 and its external circuit elements, into a voltage having substantially the form shown by the curve 51. Since this tube also is operated in the anode-to-cathode current saturation region, during a portion of each cycle, the leading and trailing edges 52 and 53 respectively, of each impulse are substantially perpendicular. Also each impulse has a sloping crest portion 54. It is noted that the crest portion slopes somewhat downward from the leading edge to the trailing edge of the impulse. The form of this portion of the impulse results from the employment of the coupling circuit with small time constant which includes the relatively small capacity condenser 34.

The curve 55 illustrates the wave form of the impulses applied to the input circuit of the tube 17. Each impulse, as derived from the frequency divider 15, has a steep leading edge 56 and, as impressed upon the grid of the tube 17, has a sloping trailing edge 57. The configuration of the trailing edge is produced by the employment of the coupling circuit with small time constant which includes the relatively small capacity condenser 16 as one of the coupling elements between the frequency divider 15 and the tube 17. Thus, the impulses derived from the frequency divider have wave shapes which are substantially saw-toothed in form.

The voltage having the wave form such as illustrated by the curve 51 and the voltage having the wave form such as illustrated by the curve 55 are combined in the interconnected output circuits of the tubes 35 and 17. The resulting composite voltage which appears at the junction point between resistors 38 and 21 has a wave form similar to that illustrated by the curve 58. It is seen that each impulse of the combined voltage wave has a pedestal portion 59. The pedestal portion is produced by the super-position of the peak portion of the saw tooth wave 55 upon the sloping crest portion 54 of the voltage wave 51.

Referring now to the operation of the apparatus illustrated in Fig. 1, assume that the frequency of the oscillator derived impulses is the same as that of the impulses derived from the alternating current power supply. If the power supply has the usual frequency of 60 cycles per second, the frequency of the impulses derived therefrom and also the frequency of the oscillator derived impulses will be 120 cycles per second. This is a result of the operation of the full wave rectifier including the tube 26 as a frequency doubler. Under the assumed conditions the oscillator derived impulses illustrated by the curve 55 of Fig. 2 are related in phase to the impulse derived from the alternating current power supply illustrated by the curve 51, as indicated in Fig. 2. The resulting composite voltage wave represented by the curve 58 is filtered by means of the described facilities to produce a normal control voltage which has a substantially constant unidirectional value. This voltage appears at the terminals of the condenser 44 and is applied to the input terminals of the automatic frequency control circuit 46 by means of which the frequency of the oscillator 11 is locked in predetermined harmonic relation with the alternating current power supply.

If, now, the frequency of the oscillator derived impulses increases slightly with respect to the frequency of the impulses derived from the alternating current power supply, the saw-toothed voltage wave 55 of Fig. 2 will lead in phase the voltage wave 51. This condition is illustrated by the broken line curve 61. When such a voltage wave is combined with the voltage wave 51 there is produced at the junction point between resistors 38 and 21 a composite wave having the form illustrated by the curve 62. It will be noted that the pedestal portion 63 of the impulsive voltage is slightly increased in its peak value due to the sloping crest 54 of the voltage wave 51. Also, the width of the pedestal portion 63 is increased by an amount corresponding to the phase shift. When a series of such impulses is filtered by means of the facilities provided for such purpose there is produced a voltage across the condenser 44 which is representative of the sense of the frequency deviation and the magnitude thereof. When this voltage is applied to the automatic frequency control circuit 46, a correcting reactance is injected into the frequency controlling elements of oscillator 11, whereby the frequency thereof is altered in a sense and in an amount corresponding to the correcting voltage to restore the frequency of the oscillator derived impulses to the predetermined phase relation to the impulses derived from the alternating current power supply.

Obviously, if the frequency of the oscillator 11 tends to decrease with respect to the predetermined relation with the standardizing frequency, there is produced a phase shift of the

saw-toothed wave 55 of Fig. 2 in a sense opposite to that described. As a result of such a phase shift the pedestal portion 59 of the composite voltage wave 58 is changed correspondingly whereby to produce a representative voltage across the condenser 44 of Fig. 1. When this voltage is applied to the automatic frequency control circuit 46, the oscillator 11 is corrected to restore the frequency of the impulses derived from the frequency divider 15 to the predetermined relation with the standardizing frequency.

It is important to note that the frequency comparison circuit in accordance with the instant invention provides a means for maintaining synchronism between the oscillator and the source of standardizing frequency even though the voltage of the latter fluctuates over a rather wide range. This performance feature is obtained by the operation of the tubes 29 and 35 in the respective anode-to-cathode current saturation regions. Since these tubes are operated at saturation for a substantial portion of each alternating current cycle, it is evident that the peak amplitudes of the alternating current wave may vary appreciably without having any noticeable influence upon the output voltage of the tubes 29 and 35. As a result, substantially large variations of the alternating current power supply voltage may occur without affecting the capability of the system to maintain the desired synchronism.

While it will be understood that the circuit specifications of the desired apparatus may vary according to the design for any particular application, the following circuit specifications for a frequency comparator employed for the purpose described are included by way of example only:

| | |
|---|---|
| Condenser 16 | 0.01 microfarad |
| Tube 17 | ½ of 6SN7 |
| Resistor 18 | 1,000 ohms |
| Resistor 19 | 270,000 ohms |
| Resistor 21 | 10,000 ohms |
| Battery 22 | 325 volts |
| Resistor 24 | 10,000 ohms |
| Resistor 25 | 10,000 ohms |
| Tube 26 | 6H6 |
| Resistor 27 | 100,000 ohms |
| Condenser 28 | 0.5 microfarad |
| Tubes 29 and 35 | 6SN7 |
| Resistor 31 | 1,000 ohms |
| Resistor 32 | 270,000 ohms |
| Resistor 33 | 10,000 ohms |
| Condenser 34 | 0.03 microfarad |
| Resistor 36 | 1,000 ohms |
| Resistor 37 | 270,000 ohms |
| Resistor 38 | 15,000 ohms |
| Condenser 39 | 0.25 microfarad |
| Resistor 41 | 100,000 ohms |
| Resistor 42 | 100,000 ohms |
| Resistor 43 | 680,000 ohms |
| Condenser 44 | 0.1 microfarad |
| Resistor 45 | 10,000 ohms |

Thus, there is provided by the novel phase comparator described, a means for applying a corrective voltage to the A. F. C. circuit, whereby the frequency determining circuit of an oscillator is maintained in a predetermined harmonic relation with a standardizing frequency. The apparatus, in accordance with the present invention, produces greater stability of synchronization than is obtainable by prior art devices. This result is achieved in part by generating the impulses representative of the frequency comparison at a higher frequency than usually is the practice, whereby to permit a decrease in the amount of filtering necessary to produce the necessary control voltages. Also, by reason of the descibed shaping of the impulses derived from the source of standardizing frequency, there is provided an output voltage which is substantially constant over the range of line voltage fluctuations which are customarily encountered in practice. Moreover, as a further result of the impulse shaping, synchronization of the apparatus is achieved in approximately thirty seconds after the power is initially applied to the apparatus.

While there has been described what, at present, is considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and therefore, it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, means for producing from said source of standardizing frequency a first series of steep sided impulses at a harmonic of the standardizing frequency, means for producing from said oscillator a second series of substantially saw-toothed impulses, each having one edge of relatively great slope and the other edge of relatively small slope, means for combining said steep sided impulses and said saw-toothed impulses to produce a composite wave having pedestal portions, of substantially unvarying amplitudes and varying widths representative of the phase relation between said two types of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

2. A circuit for producing a voltage representative of the phase relationship between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, means to produce a first series of impulses at a harmonic of the standardizing frequency, means for converting said first series of impulses into steep sided impulses, means for producing from said oscillator a second series of impulses at a harmonic of the standardizing frequency, means for converting said second series of impulses into saw-toothed impulses having leading edges of relatively great slopes and trailing edges of relatively small slopes, means for combining said steep sided impulses and said saw-toothed impulses to produce a composite wave having pedestal portions of varying amplitudes and widths representative of the phase relation between said two types of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

3. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a frequency multiplier to produce a se-

ries of impulses at a harmonic of the standardizing frequency, first electronic means coupled to said frequency multiplier for converting the impulses derived therefrom into a series of steep sided impulses, a frequency divider connected to said oscillator for producing a series of impulses at a harmonic of the standardizing frequency, second electronic means coupled to said frequency divider for imparting to said oscillator derived impulses saw-toothed wave forms having leading edges of relatively great slopes and trailing edges of relatively small slopes, means for combining said two series of impulses, whereby to produce a composite wave having pedestal portions of varying amplitudes and widths representative of the phase relation between said two series of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

4. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequencies comprising, a frequency multiplier connected to said source of standardizing frequency to produce a first series of impulses having a frequency harmonically related to the standardizing frequency, an electron discharge device for converting the impulses derived from said frequency multiplier into a series of steep sided impulses, a first coupling circuit having a relatively small time constant linking said multiplier with said electron discharge device for shaping said steep sided impulses to have sloping crests, a frequency divider connected to said oscillator for producing a second series of impulses having a frequency harmonically related to the standardizing frequency, a second electron discharge device associated with said frequency divider, a second coupling circuit having a relatively small time constant linking said frequency divider with said second electron discharge device for shaping said oscillator derived impulses to have saw-toothed wave forms, means for combining said two series of shaped impulses, whereby to produce a composite wave having pedestal portions occurring at the frequency of said oscillator derived impulses, said pedestal portions having energy contents representative of the phase relation between said two series of shaped impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

5. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a frequency multiplier connected to said source of standardizing frequency to produce a series of impulses having a frequency harmonically related to the standardizing frequency, a vacuum tube capacitatively coupled to said frequency multiplier for converting the impulses derived therefrom into a series of steep sided sloping crested impulses, a frequency divider connected to said oscillator for producing a series of impulses having a frequency harmonically related to the standardizing frequency, a second vacuum tube capacitatively coupled to said frequency divider for imparting saw-toothed wave forms to said oscillator derived impulses, means for combining said two series of impulses, whereby to produce a composite wave having pedestal portions occurring at the frequency of said oscillator derived impulses, said pedestal portions having energy contents representative of the phase relation between said two series of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

6. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a frequency doubler connected to said source of standardizing frequency to produce a series of impulses of twice the standardizing frequency, a vacuum tube coupled to said frequency doubler for converting the impulses derived therefrom into a series of steep sided impulses, a relatively small capacity coupling condenser associated with said tube for imparting sloping crests to said steep sided impulses, a frequency divider connected to said oscillator for producing a series of impulses having twice the standardizing frequency, a second vacuum tube coupled to said frequency divider, a relatively small coupling condenser associated with said second vacuum tube for imparting saw-toothed wave forms to said oscillator derived impulses, a common output circuit for said vacuum tubes for combining said two series of impulses, whereby to produce, a composite wave having pedestal portions, said pedestal portions having energy contents representative of the phase relation between said two series of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

7. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a rectifier tube connected to produce a series of impulses of twice the standardizing frequency, a vacuum tube coupled to said rectifier for converting the impulses derived from said rectifier into a series of steep sided impulses, a relatively small capacity coupling condenser associated with said vacuum tube for imparting sloping crests to said steep sided impulses, a frequency divider connected to said oscillator for producing a series of impulses having twice the standardizing frequency, a second vacuum tube coupled to said frequency divider, a relatively small coupling condenser associated with said second vacuum tube for imparting saw-toothed wave forms to said oscillator derived impulses, a common output circuit for said vacuum tubes for combining said two series of impulses, whereby to produce a composite wave having pedestal portions, said pedestal portions having energy contents representative of the phase relation between said two series of impulses, and an integrating network for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

8. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a full wave rectifier tube connected to said source of standardizing frequency and hav-

ing circuits to produce a series of impulses of twice the standardizing frequency, a vacuum tube coupled to said rectifier and operated in the space current saturation region thereof for converting the impulses derived from said rectifier into a series of steep sided impulses, a relatively small capacity coupling condenser associated with said vacuum tube for imparting sloping crests to said steep sided impulses, a frequency divider connected to said oscillator for producing a series of impulses having twice the standardizing frequency, a second vacuum tube coupled to said frequency divider, a relatively small coupling condenser associated with said second vacuum tube for imparting saw-toothed wave forms to said oscillator derived impulses, a common output circuit for said vacuum tubes for combining said two series of impulses, whereby to produce a composite wave having pedestal portions, said pedestal portions having widths representative of the phase relation between said two series of impulses, and an integrating network for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

9. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, a full wave rectifier tube connected to said source of standardizing frequency and having circuits to produce a series of impulses of twice the standardizing frequency, first and second tandem connected vacuum tubes coupled to said rectifier and operated in the space current saturation regions thereof for converting the impulses derived from said rectifier into a series of steep sided impulses, a relatively small capacity coupling condenser associated with the second of said vacuum tubes for imparting sloping crests to said steep sided impulses, a frequency divider connected to said oscillator for producing a series of impulses having twice the standardizing frequency, a third vacuum tube coupled to said frequency divider, a relatively small coupling condenser associated with said third vacuum tube for imparting saw-toothed wave forms to said oscillator derived impulses, a common output circuit for said second and third vacuum tubes for combining said two series of impulses, whereby to produce a composite wave having pedestal portions, said pedestal portions having peak amplitudes and widths representative of the phase relation between said two series of impulses, and an integrating network for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

10. In automatic frequency control apparatus for a television timer, a source of alternating current, an oscillator having an output to be maintained in harmonic relation to said alternating current source, means for converting said alternating current into a series of impulses having sloping crests, means for deriving from said oscillator a series of substantially saw-toothed impulses, each of said saw-toothed impulses having one edge of relatively great slope and the other edge of relatively small slope, means for combining said two series of impulses to form a composite wave having pedestal portions, said pedestal portions having widths representative of the phase relation between said two series of impulses, and means controlled by energy derived from said pedestal portions to maintain the output frequency of said oscillator in said harmonic relation to said alternating current source.

11. In automatic frequency control apparatus for a television timer, a source of alternating current, an oscillator having an output to be maintained in harmonic relation to said alternating current source, means for converting said alternating current into a series of steep sided impulses having sloping crests, means for deriving from said oscillator a series of substantially saw-toothed impulses having leading edges of relatively great slopes and trailing edges of relatively small slopes, means for combining said two series of impulses to form a composite wave having pedestal portions, said pedestal portions having peak amplitudes and widths representative of the phase relation between said two series of impulses, and means controlled by energy derived from said pedestal portions to maintain the output frequency of said oscillator in said harmonic relation to said alternating current source.

12. A circuit for producing a voltage representative of the phase relation between impulses derived from two periodic sources, means for deriving from one of said sources a first series of impulses, means for deriving from the other of said sources a second series of impulses having a substantially saw-toothed wave form, one edge of each of said saw-toothed impulses being of relatively great slope and the other edge of relatively small slope, means for combining said two series of impulses to produce a composite wave having pedestal portions of varying widths representative of the phase relation between said two series of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

13. A circuit for producing a voltage representative of the phase relation between impulses derived from an oscillator and impulses derived from a source of standardizing frequency comprising, means for deriving from said source of standardizing frequency a first series of impulses, means for deriving from said oscillator a second series of impulses having a substantially saw-toothed wave form, one edge of each of said saw-toothed impulses being of relatively great slope and the other edge of relatively small slope, means for combining said two series of impulses to produce a composite wave having pedestal portions of varying widths representative of the phase relation between said two series of impulses, and means for developing from said composite wave substantially continuous unidirectional voltages having magnitudes corresponding to the energy content of said pedestal portions.

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