March 18, 1952 W. A. HIGINBOTHAM 2,589,807

ELECTRICAL INTEGRATION CIRCUIT

Filed Jan. 24, 1945

FIG-1

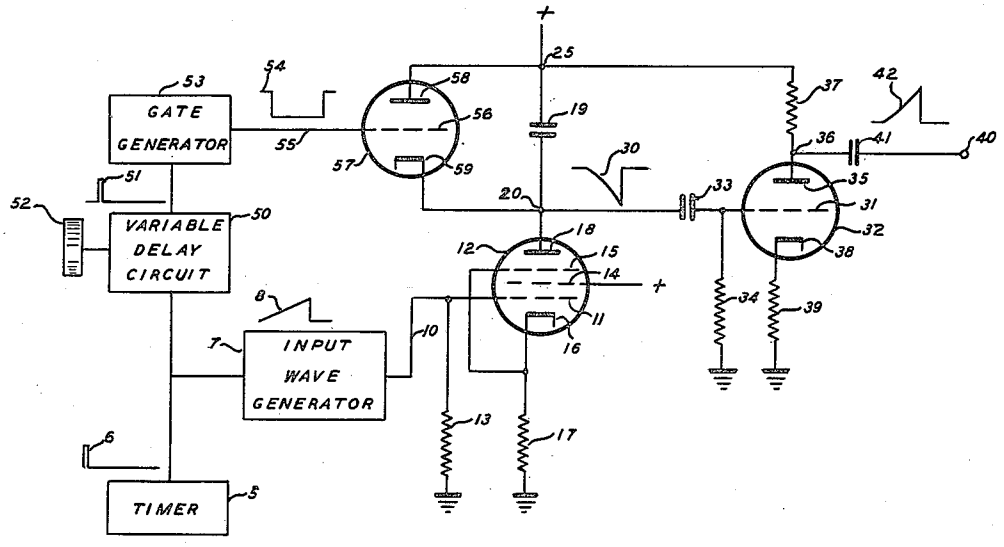


FIG-2

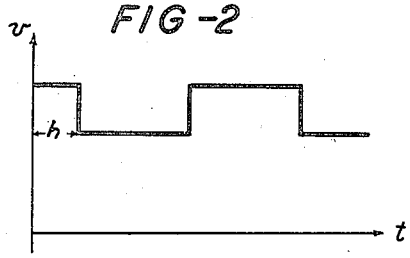


FIG-3

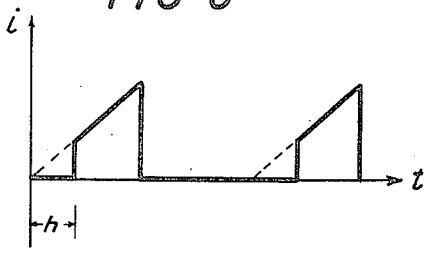
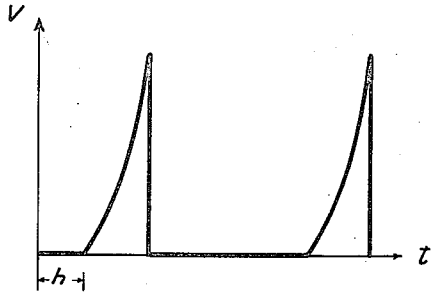


FIG-4



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ELECTRICAL INTEGRATION CIRCUIT

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5 Claims. (Cl. 250—27)

1

This invention relates to an electrical apparatus and more particularly to a wave modifying circuit adapted to perform integration operations. More specifically, the circuit is adapted to develop an output wave form representing an integration of an input wave form.

One object of the invention is to provide such a circuit whereby the output wave form represents an integration of a wave form which is a selected function of an independent variable.

Another object is to provide such a circuit whereby a desired output voltage may be developed.

A further object contemplates the production of such output wave forms between predetermined limits of an independent variable.

The apparatus herein has many applications and, as an example, it may be used in cathode ray tube deflection voltage circuits of radio object detecting and ranging systems.

The apparatus here disclosed operates to generate a recurring output wave in which each wave form represents an integration of an input wave form. Thus, the amplitude of an output wave form at any instant represents an evaluation at that instant of the integration of the input wave form from a lower limit which may be predetermined as will appear hereinafter. The amplitudes of the wave forms are functions of an independent variable which is represented by a time axis, the initiation of each input wave form corresponding to zero value of the independent variable.

A typical use of this integrating circuit may be to generate, as shown in the communication system described in the patent to Luis W. Alvarez, Patent No. 2,480,208, filed June 27, 1944, and issued August 30, 1949, recurring output wave forms each having a voltage which is proportional to the algebraic expression $r^2—h^2$. In this expression, r (range) is the independent variable, and h (height) is a constant whose value may be varied as desired. The expression $r^2—h^2$ is itself proportional to an integration, from a lower limit h, of a voltage which varies linearly with r. As r is represented by time, the voltage of the input wave form used herein varies linearly with time and may be produced by a "saw-tooth" generator.

In the drawing:

Fig. 1 is a diagram, partly in block representation, of a circuit which will perform integrations upon an input wave form;

Figs. 2 and 3 are diagrams showing wave forms present in various parts of the circuit; and

Fig. 4 is a diagram of a typical output voltage wave form produced by the circuit from a selected input wave form.

Referring now to Fig. 1, the present integrating circuit includes several components which are

2

well known to the art and are therefore represented in block form. Such components will not be dealt with in detail except insofar as is necessary to describe the present invention. Reference numeral 5 designates a timer which produces recurring trigger voltage pulses 6 of relatively short duration, for example, 2 or 3 microseconds. These trigger pulses are applied to an input wave generator 7 to time or trigger the production of voltage waves having a predetermined form. Such an input wave form may, as mentioned above, have a voltage which varies linearly with time as shown at 8.

The wave forms shown on the diagram in Fig. 1 are drawn in their relative positions along a common time base. For example, wave form 8 is shown as initiated at the instant of occurrence of a trigger 6. The repetition rate of the trigger pulses 6 and the time duration of the input waves 8, if desired, may be such as to space the input waves along the time axis by a time duration equal to or greater than the duration of an input wave.

A lead 10 from input wave generator 7 applies the voltage wave form 8 to a control grid 11 of a vacuum tube 12. The control grid 11 is connected through a resistance 13 to a ground point of the circuit. The tube 12 may be of pentode type as shown, having a screen grid 14 to which is applied a positive voltage of constant value. A suppressor grid 15 and a cathode 16 are connected together and through a biasing resistance 17 to ground. Plate 18 of the tube 12 is connected to one terminal of a relatively large capacitance 19 at a junction 20, the other terminal of the capacitance being connected to a junction 25. A positive voltage of constant value is applied, as shown, to the junction 25 from a source having a low impedance to ground for alternating voltage components.

During circuit operation, a recurring unidirectional current is produced in the plate 18-capacitance 19 circuit due to the recurring input voltage applied to the control grid 11, and to the periodic discharge of the capacitance 19, as will be presently described.

As will appear hereinafter, the plate potential at the junction 20 undergoes variations which, however, are small compared to the constant voltage applied to the junction 25. The tube 12 is of the "constant current" type whose characteristic is that, despite such variations of plate potential, the plate current is substantially dependent only upon the voltage applied to the control grid 11. The operating conditions of the tube 12 are such as to secure a linear relation between its plate current and control grid voltage, the variation of plate voltage having negligible effect on this relationship over the range of operation. Thus, the varying current produced in the

plate circuit of the tube 12 has a wave form which is similar in shape to that of voltage 8 formed by the input wave generator 7.

The varying plate current which passes through the capacitance 19 acts as a charging current to develop a voltage across said capacitance. The voltage developed across the capacitance is proportional to the charge placed upon it, the charge in turn being proportional to the time integral of the charging current. Thus, the voltage wave 8 applied to the control grid 11 causes a corresponding electron current wave to flow in the cathode-plate circuit of tube 12. As will appear hereinafter, a selected time-portion of this current flows through the integrating capacitance 19 in the direction of junction 20 to junction 25, resulting in an integration voltage wave at the terminal 25 with respect to terminal 20. Junction 25 is effectively at ground potential so far as varying voltages are concerned, so that a voltage wave 30, which is an inversion of the desired integration wave form, is present at terminal 20.

The voltage wave 30 appearing at the junction 20 is communicated to a control grid 31 of an amplifier vacuum tube 32 through a coupling capacitance 33. The control grid 31 is connected through a resistor 34 to ground. Vacuum tube 32 may be of triode type as shown, having a plate 35 which is connected to a junction 36 and thence through resistance 37 to the positive potential at the junction 25. Cathode 38 of the vacuum tube 32 is connected through a biasing resistance 39 to ground. The operation of the vacuum tube 32 is linear, and the varying potential developed at the junction 36 is an inverted replica of the voltage wave 30 applied to the grid 31. Junction 36 may be connected, as shown, to an output terminal 40 through a coupling capacitance 41.

A voltage wave 42 at the terminal 40 is thus the desired integration of the input voltage wave form applied to the control grid 11 of the tube 12.

As mentioned previously, the capacitance 19 is periodically discharged and maintained in a short-circuited condition for a predetermined time interval in order that recurring waves of voltage may be formed at the junction 20. Additionally, by causing the capacitance to become unshorted at a selected time after initiation of each input wave form, the output voltage wave will represent an integration of the input wave from a lower limit represented by that selected time. This is accomplished in the following manner.

The trigger pulses 6, in addition to being applied to generator 7, are also applied to a variable delay circuit 50. Here a selected time delay, representing, for example, the quantity h previously mentioned, is imposed on the trigger pulses 6 resulting in time-displaced trigger pulses 51. The time interval between the original and delayed trigger pulses may be varied as desired by a control 52, which adjusts circuit constants within the said variable delay circuit 50 to produce the predetermined time delay. The said control 52 may be adjustable manually, or automatically, in response to some condition. As shown in the previously mentioned copending application, for example, such apparatus may be mounted in an aircraft, and a height-responsive device may, by suitable linkage, position the control 52.

The delayed trigger pulses 51 are applied to a gate generator 53 to time or trigger the cycles of a rectangular wave 54, said rectangular wave

therefore having the same frequency as the input voltage 8. The relatively negative and positive portions of rectangular wave 54 may have equal time durations (or they may have unequal time durations), and these portions will hereinafter be termed negative and positive gates, respectively. The gate generator is so designed that the leading edge of a negative gate is produced by, and is thus in time-phase with, a delayed trigger pulse 51.

A lead 55 from the gate generator 53 applies the rectangular wave 54 to a control grid 56 of a vacuum tube 57. Tube 57 may be of triode type as shown, having a plate 58 and a cathode 59 connected to the junctions 25 and 20, respectively, of the capacitance 19. The potential of the control grid 56 with respect to the cathode 59 determines whether or not the tube 57 forms a short circuit across the integrating capacitance 19, and the tube 57 is therefore referred to as a switch tube.

Thus a positive gate of wave 54 causes the tube to conduct and effectively short circuit capacitance 19. A negative gate portion of the rectangular wave causes removal of the effective short circuit across the integrating capacitance, and the plate current of the tube 12 will at such time become a charging current for the integrating capacitance.

This condition is shown in greater detail in Figs. 2 and 3, in which a rectangular wave applied to switch tube 57, and a charging current of capacitance 19, respectively, are drawn to the same time scale indicated by the horizontal axes designated t. The vertical axes of Figs. 2 and 3 represent voltage and charging current, respectively, so designated by reference characters v and i.

Referring again to tube 12, there is at all times during the time of an input wave 8 a continuous path for current flow through said tube, the plate circuit being completed either through switch tube 57 during the time of a positive gate, or through capacitance 19 during the time that switch tube 57 is open-circuited by a negative gate. The dotted line of Fig. 3 represents that time-portion of plate current of tube 12 which is bypassed around capacitance 19 by switch tube 57 during the delay time interval corresponding, in the example given, to the quantity h. The occurrence of the leading edge of a negative gate (positioned along the time axis by variable delay circuit 50) thus determines the lower limit of the integration operation performed by the present circuit.

The resultant voltage developed, in this instance, across capacitance 19 is shown in Fig. 4, in which the axis designated V is a voltage axis. The wave form shown is proportional to an integration of the input wave form from the preselected lower limit h and is thus proportional, as stated above, to the desired expression r^2-h^2. This is also the wave form of the output voltage appearing at the terminal 40 as explained heretofore.

While there has been illustrated and described herein, but rather it is to be taken as defined it is apparent that variations and modifications may be made by those skilled in the art. It is to be understood that the scope of the invention is not to be limited to the precise details disclosed herein one embodiment of the present invention, by the following claims.

I claim:

1. A voltage generator including a source of

recurring input voltage waves, each input voltage wave representing a function of an independent variable, a vacuum tube having at least a cathode, control grid and anode, an output circuit for said vacuum tube, said output circuit including a capacitance and normally closed switch means connected in parallel therewith, said source being connected to said control grid whereby input voltage waves are applied to said control grid, said vacuum tube being adapted to provide a recurring current wave in said output circuit, said current corresponding in form to said input voltage wave, a timing means, said timing means connected to said source and adapted to initiate each input wave, a variable delay circuit connected between said timing means and said switch means, said variable delay circuit cooperating with said timing means to open-circuit said switch means at a predetermined time after initiation of each input voltage wave, whereby a recurring output voltage wave is developed across said capacitance, said output voltage wave representing a definite integration of said function, the lower limit of integration corresponding to said predetermined time after initiation of each input voltage wave.

2. A voltage generator including a source of recurring input voltage waves, each input voltage wave representing a function of an independent variable, a vacuum tube having at least a cathode, control grid and anode, an output circuit for said vacuum tube, said output circuit including a capacitance and normally closed switch means connected in parallel therewith, said source being connected to said control grid whereby input voltage waves are applied to said control grid, said vacuum tube being adapted to provide a recurring current wave in said output circuit, said current wave corresponding in form to said input voltage wave, and means for opening said switch means after a predetermined time interval to permit a recurring output voltage wave to be periodically developed across said capacitance, said output voltage wave representing a definite integration of said function, the lower limit of integration corresponding to said predetermined time interval.

3. In an electronic integrating circuit of the character described having applied thereto a recurring input voltage wave, a vacuum tube having at least a cathode, control grid and anode, an output circuit for said vacuum tube, said output circuit including a capacitance and switch means connected in parallel therewith, said control grid having applied thereto said input voltage wave, said vacuum tube being adapted to provide a recurring output current wave in said output circuit, said current wave corresponding in form to said input voltage wave, means for causing said switch means to short said capacitance until a predetermined time after initiation of each input voltage wave and to be unshorted during the remaining time of each input voltage wave, whereby a recurring output voltage wave is developed across said capacitance, said output voltage wave representing an integration of said input voltage wave from a lower limit corresponding to said predetermined time after initiation of each input voltage wave.

4. A voltage generator including a source of recurring input voltage waves, each input voltage wave representing a function of an independent variable, a first vacuum tube having at least a cathode, control grid and anode, an output circuit for said vacuum tube, said output circuit including a capacitance and normally closed switch means connected in parallel therewith, said switch means comprising a second vacuum tube having at least a cathode, a control grid and an anode, the said capacitance being connected between said cathode and said anode, said source being connected to the control grid of said first vacuum tube whereby input voltage waves are applied to said control grid, said first vacum tube being adapted to provide a recurring current wave in said output circuit, said current wave corresponding in form to said input voltage wave, a timing means, said timing means being connected to said source and adapted to initiate each input wave, a gate generator having its output connected to the control grid of said switch means and a variable delay circuit connected between said gate generator and said timing means, said variable delay circuit cooperating with said timing means and said gate generator to open-circuit said switch means at a predetermined time after initiation of each input voltage wave, whereby a recurring output voltage wave is developed across said capacitance, said output voltage wave representing a definite integration of said function, the lower limit of integration corresponding to said predetermined time after initiation of each input voltage wave, and a vacuum tube amplifier having at least a cathode, a control grid and an anode, the said capacitance being connected in the grid-anode circuit of said amplifier, whereby the said output voltage wave may be amplified.

5. In an electronic integrating circuit of the character described having applied thereto a recurring input voltage wave, a vacuum tube having at least a cathode, control grid and anode, an output circuit for said vacuum tube, said output circuit including a reactance and switch means connected in parallel therewith, said control grid having applied thereto said input voltage wave, said vacuum tube being adapted to provide a recurring current wave in said output circuit, said output current wave corresponding in form to said input voltage wave, means for causing said switch means to short said reactance until a predetermined time after initiation of each input voltage wave and to be unshorted during the remaining time of each input voltage wave, whereby a recurring output voltage wave is developed across said reactance, said output voltage wave representing an integration of said input voltage wave from a lower limit corresponding to said predetermined time after initiation of each input voltage wave.

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