

Nov. 25, 1969

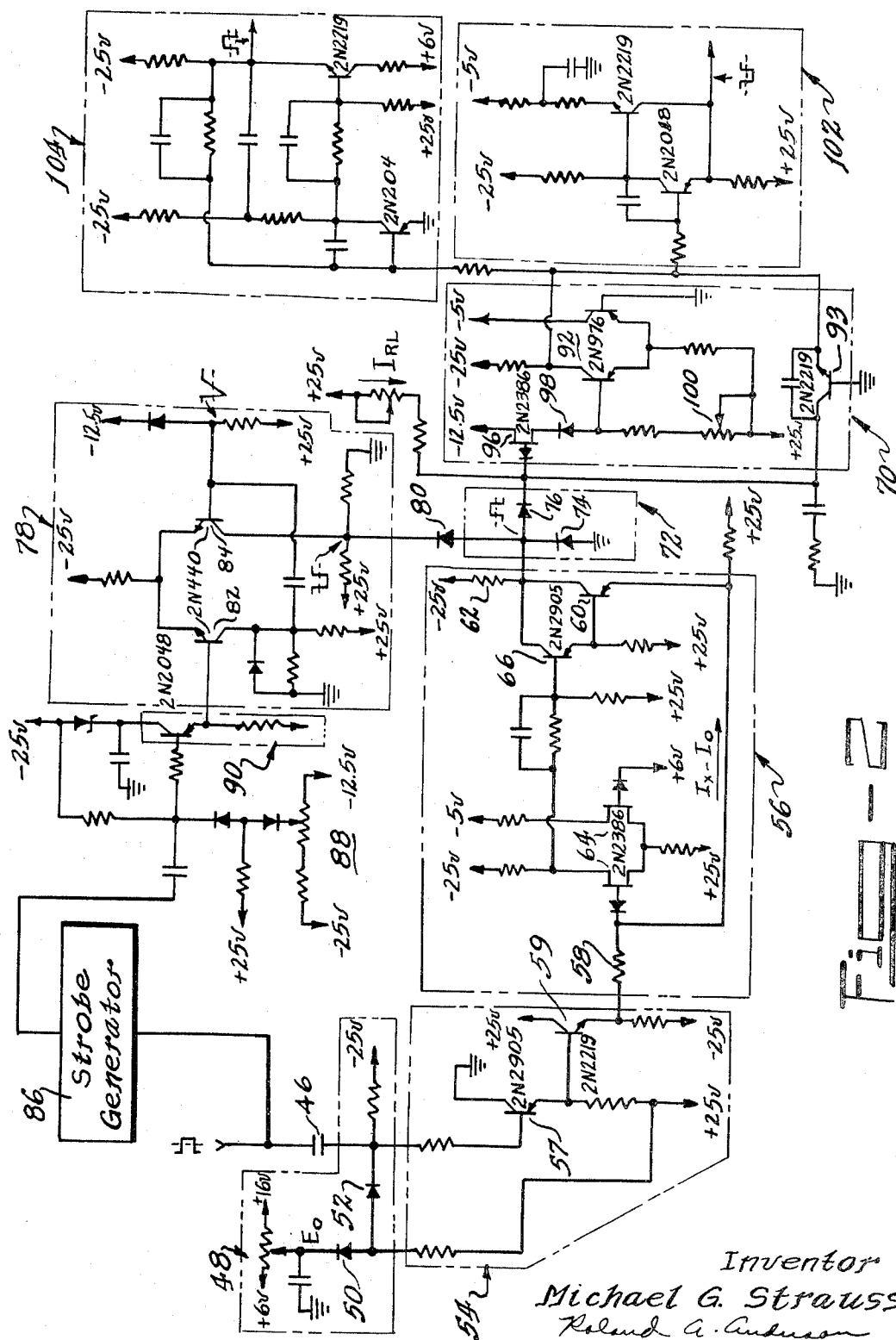
M. G. STRAUSS

3,480,793

LOGARITHMIC FUNCTION GENERATOR

Filed Aug. 2, 1966

2 Sheets-Sheet 2



21

Inventor
Michael G. Strauss
Roland A. Anderson
Attorney

1

3,480,793

LOGARITHMIC FUNCTION GENERATOR

Michael G. Strauss, Downers Grove, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Filed Aug. 2, 1966, Ser. No. 569,761

Int. Cl. G06g 7/24

U.S. Cl. 307—229

6 Claims

ABSTRACT OF THE DISCLOSURE

The circuit produces an output signal which is a logarithmic function of pulsed input voltage signals. A voltage-to-current converter changes the applied input pulse to a current pulse which is coupled by way of a gate to a logarithmic function generator. The applied input pulses also generate control signals for actuating the gate so that an output signal is produced only when an applied input pulse is present.

The invention described herein was made in the course of, or under, a contract with the United States Atomic Energy Commission.

This invention relates to logarithmic function generators and more particularly to generators for generating the logarithm of pulsed input signals.

Logarithmic function generators are useful circuits often employed in computers to perform arithmetic operations. In the prior art, logarithmic conversion of D-C signals is obtained by connecting a transistor as a feedback element in an operational amplifier. The D-C voltage input signal is coupled to the generator through a series-connected resistor. The output of the amplifier, that is, the emitter-base voltage of the transistor, is proportional to the logarithm of the collector current of the transistor, and therefore to the logarithm of the input voltage. When this function generator is to be used with input pulses rather than D-C signals, a coupling capacitor is used and a quiescent reference current must flow through the feedback transistor. Base-line shifts due to the random rate of the pulsed input signals and the input coupling capacitor modulate this quiescent reference current and a slight base-line shift is sufficient to cause a significant change in the quiescent current and a considerable error in the output signal of the function generator.

When multiple logarithmic function generators are employed in a computer with the pulses applied to each generator being in fixed time relationship with each other but at random repetition rates, a problem exists in generating the logarithm for each of the pulses thereof so that they may be subsequently combined in a meaningful manner. It is necessary that all of the output signals of the logarithmic function generators, to be combined, be exactly coincident in time and duration.

It is also desirable in a logarithmic function generator to be able to add a positive or negative constant to each input signal before logarithmic conversion is effected. This positive or negative constant may be useful for such functions as compensating for energy loss in the window of a nuclear particle detector or backing of a target. Further, the insertion of a constant permits the reciprocal function $1/X$ to be calculated, since the variable X may then be divided into the constant E_0 which is proportional to $1/X$.

It is therefore one object of the present invention to provide an improved logarithmic function generator for a pulsed input signal.

It is another object of the present invention to provide for pulsed input signals a logarithmic function generator which is more accurate than heretofore.

2

It is another object of the present invention to provide for pulsed input signals a logarithmic function generator which is not affected by base-line shifts caused by the random rate of input pulsed signals.

It is another object of the present invention to provide for pulsed input signals a logarithmic function generator wherein a positive or negative constant may be added to each input signal before the logarithmic conversion thereof is accomplished.

It is another object of the present invention to provide logarithmic function generators wherein, for pulses applied thereto which are in fixed time relationship with respect to each other but at random repetition rates, each generator generates an output pulse proportional to the logarithm of the input signal coincident in time and duration, wherefrom they may be subsequently combined in a meaningful manner.

Other objects of the present invention will become apparent as the detailed description proceeds.

In general in the present invention a voltage-to-current converter changes an applied input voltage pulse to a current pulse. Means are provided to generate an electrical signal responsive to the occurrence of the applied input voltage pulse. A linear gate responsive to the generated electrical signal couples the current pulse to a logarithmic function generator comprising an operational amplifier having a transistor as a feedback element therein. The output of the operational amplifier, the emitter-base voltage of the transistor, is proportional to the logarithm of the applied input voltage pulse.

Further understanding of the present invention may best be obtained from consideration of the accompanying drawings wherein:

FIG. 1 is a simplified schematic drawing of an embodiment according to the present invention and

FIG. 2 is a detailed schematic of an embodiment according to the present invention.

Turning to FIG. 1 wherein is shown a logarithmic function generator in simplified form constructed according to the present invention, a pulsed input signal is capacitively coupled to a D-C restorer 10. The output of the D-C restorer 10 is transmitted through an emitter follower 12 to a voltage-to-current converter 14 wherein the voltage input pulse is converted to a current pulse. The current pulse output of the converter 14 is then transmitted through a linear gate 16 comprising diodes 18 and 20 to a logarithmic function generator 22.

The input voltage pulse is also used to drive a conventional strobe generator 24 which provides an output pulse for each input pulse. The output of the strobe generator 24 is capacitively coupled to a D-C restorer 26 which is followed by emitter follower 28 and a linear gate control univibrator 30. The output of the control univibrator 30 is connected to linear gate 16.

The logarithmic generator 22 is a conventional logarithmic generator comprising an operational amplifier 32 with a transistor 34 connected to form a feedback element therewith. The logarithmic reference current I_{RL} is provided through a variable resistor 36. The output of the logarithmic function generator 22 is connected to both a White emitter follower 38 and an operational amplifier inverter 40, wherefrom logarithmic output signals of opposite polarities are obtained.

In operation, the logarithmic function generator 22 is isolated from the input circuitry by the linear gate 16, diode 18 being normally conducting and diode 20 being normally nonconducting. Resistor 36 is adjusted to provide the correct quiescent logarithmic reference current I_{RL} for the transistor 34. This current must be stable and hence the voltage driving source for resistor 36 must be a constant stable voltage source.

The input signal, when capacitively coupled to the D-C restorer 10, loses its D-C level. The D-C restorer 10 establishes the D-C level of the input signal according to the voltage E_0 obtained by adjusting the variable resistor 42 connected across a voltage source as shown. By adjusting the value of E_0 a constant may be inserted to add to or subtract from the input pulse signal prior to the logarithmic conversion thereof being effected. This added or subtracted constant may be used to compensate for energy loss in the window of a nuclear particle detector or be used so that a function proportional to the reciprocal $1/X$ may be calculated.

The output voltage pulse of the D-C restorer 10 is coupled via emitter follower 12 to the voltage-to-current converter 14. The fixed resistor 44 in the voltage converter 14 transforms the voltage input pulse to a current input pulse. It is to be noted that the logarithmic generator 22 of the present invention adds the quiescent reference current I_{RL} to any input current applied thereto. To compensate for the addition of current I_{RL} , the value of voltage E_0 of D-C restorer 10 is adjusted so that it contains a component wherefrom a current I_0 is generated by the voltage-to-current converter 14 which is equal to the value of the quiescent reference current I_{RL} . Thus, the output current pulse signal from the voltage-to-current converter 14 is equal to the current generated by the input signal (I_X) minus the current generated by the D-C restorer voltage E_0 (I_0).

As previously stated, the application of a pulsed input signal to the D-C restorer 10 is accompanied by an output from the strobe generator 24. The output from the strobe generator 24 triggers the gate control univibrator 30 to bias the diode 18 off and the diode 20 on. Thus, the output current $I_X - I_0$ from converter 14 is coupled through diode 20 to the input of the logarithmic generator 22 wherefrom the logarithmic function of I_X is obtained. The quiescent reference current I_{RL} is added to the input current $I_X - I_0$ to give an effective current I_X which flows through the transistor 34. The flow of the current I_X through the transistor 34 causes a change in the emitter-base voltage of transistor 34, which change is equal to

$$\begin{aligned}\Delta N_{\text{emitter-base}} &= \frac{kT}{q} \ln \frac{I_X}{I_{RL}} \\ &= 2.3 \frac{kT}{q} \log \frac{I_X}{I_{RL}} \\ &= c \log X\end{aligned}$$

where:

k =Boltzmann constant $=1.381 \times 10^{23}$ joule/ $^{\circ}$ K.

T =temperature in $^{\circ}$ K.

q =electronic charge $=1.6 \times 10^{-19}$ coulomb

I_X =value of input current pulse

I_{RL} =value of quiescent reference current

c =proportionality constant

The White emitter follower 38 and inverter 40 connected to the output of the logarithmic function generator 22 provided logarithmic pulse outputs from the system which are of opposite polarities.

It is to be noted that for the practice of the present invention a gating device such as that of linear gate 16 is necessary to disconnect the logarithmic generator 22 from the input circuitry, whereby base-line variations due to the random input pulse rate and the coupling capacitor are avoided. Base-line fluctuations are greatly reduced by the use of the D-C restorer 10. However, the imperfections in the D-C restorer 10 as well as thermal drift do not eliminate the fluctuations completely and the small remaining base-line fluctuations are sufficient so that they will modulate the quiescent reference current through the logarithmic transistor 34. Since the quiescent reference current I_{RL} is generally only 1% of the maximum input signal current I_X , a slight base-line shift is

enough to cause a significant change in the quiescent current I_{RL} and therefore a considerable error in the output signal from the logarithmic function generator 22. For example, if I_{RL} changed due to base-line shift from 1 to 2%, the resulting error will be as significant as if the input signal current was reduced by a factor of 2. Thus, the normally closed linear gate 16 (diode 20 biased off, diode 18 biased on) disconnects the logarithmic function generator 22 from the input circuitry, so that even the remaining small base-line fluctuations do not affect the logarithmic reference current I_{RL} which remains virtually constant independent of the counting rate or thermal drift at the input.

As stated, by adjusting the value of E_0 , a constant may be added to the input voltage pulse prior to logarithmic conversion so that a reciprocal function proportional to $1/X$ may be calculated. To effect this, it is necessary that two logarithmic generators of the type shown in FIG. 1 be used. No input signal is applied to the input of one of the generators and strobing of the logarithmic generator will give an output therefrom $+\log E_0$. The variable X signal is applied to the other generator to give $-\log X$. By summing the outputs $+\log E_0$ and $-\log X$ of the two generators the logarithm of the ratio E_0/X is obtained therefrom. It is noted that E_0/X is proportional to $1/X$.

It is to be further noted that the device of the present invention is such that the output logarithmic pulses from different generator are exactly coincident in time and duration, whereas the input pulses applied thereto have a fixed time relationship to each other and random repetition rates. When coincident operation is desired, one pulse input is applied to the strobe generator 24 to generate output pulses as described. These output pulses are then applied to the D-C restorer circuits 26 in each of the logarithmic generators so that coincidence is effected in the triggering of the linear gates 16 thereof. It is to be noted that the output pulses of the strobe generator 24 may be adjusted in time and width so that gating is accomplished on the flat top portions of the input pulses thereby avoiding perturbations in rising and trailing edges of the output pulses after they are meaningfully combined.

Turning to FIG. 2, a detailed schematic is shown of a preferred embodiment for the present invention. In this embodiment, a pulsed signal input from 0 to +10 volts is coupled through a .01 microfarad capacitor 46 to D-C restorer circuit 48. The voltage swing of the restorer voltage E_0 is from +6 to +16 volts. The D-C restorer circuit 10 of FIG. 1 is adequate for positive input pulses except for noise and possible undershoot following an input pulse. These tend to charge the coupling capacitor so that the input pulses are restored to the negative peak noise or undershoot level. In FIG. 2, the diodes 50 and 52 of D-C restorer circuit 48 establish the baseline of the input pulse at the average noise level which fluctuates far less than the peak noise amplitudes. Further, the D-C restorer 48 is not affected by signal undershoot as it restores bipolar as well as unipolar input pulses. For equal response in the two polarities, the current in diodes 50 and 52 should be equal. In the circuit illustrated, the equilibrium is upset to permit the voltage E_0 to cover the full 10 volt input range. Drifts due to the temperature coefficients of the diodes 50 and 52 tend to cancel each other.

The output voltage from the D-C restorer 48 is fed through an emitter follower 54 to a voltage-to-current converter 56. The transistors 57 and 59 of emitter follower circuit 54 are, like diodes 50 and 52, essentially mutually self-canceling for drifts due to the emitter-base temperature coefficients. Thus, the potential at the voltage-to-current converter 56 is, to a first approximation, temperature-independent.

Resistor 58 and transistor 60 form the path for original current I_X to flow through the voltage-to-current con-

verter 56. The quiescent emitter current of transistor 60, which is partially controlled by the value of E_0 , is routed via the collector thereof to resistor 62. The difference between the constant current through resistor 62 and the quiescent emitter current is I_0 which is subtracted from or added to the signal current I_x . The output of the difference amplifier 64 in the voltage-to-current converter must be stable and therefore independent of circuit components. Since the collector of transistor 60 is outside of the feedback loop, the output signal of the voltage-to-current converter 56 is dependent upon the alpha of transistor 60. This alpha dependence is virtually eliminated by using a cascaded emitter follower amplifier (Darlington pair) comprising transistors 60 and 66. The fraction of the emitter current of transistor 60 which flows to the base is routed to the collector via transistor 66 so that virtually all the feedback stabilized emitter current of transistor 60 appears at the output of the converter 56. Alpha variations in transistor 66 are insignificant since the contribution of transistor 66 to the output of converter 56 is much less than transistor 60.

The output from the voltage-to-current converter 56 is coupled to the logarithmic generator 70 via a linear gate 72 comprising diodes 74 and 76. The current through diode 74 is greater than the maximum signal current; thus, the linear gate 72 is normally closed. When the gate control univibrator 78 is triggered, the current through diode 74 is discontinued and the input signal is transmitted via diode 76 to the logarithmic generator. Diode 80 permits rapid opening of the linear gate 72 since it is considerably faster than the two transistors 82 and 84 of univibrator 78. The transistors 82 and 84 are selected for their high reverse emitter-base voltage rating. The univibrator gate control circuit is, as for the FIG. 1 embodiment, actuated by an output pulse from strobe generator 86 which is transmitted thereto via D-C restorer 88 and an emitter follower 90.

The operational amplifier 92 of the logarithmic generator 70 does not need a high gain since the signal is applied via a high impedance source, namely, the collectors of transistors 60 and 66. The logarithmic generator 70 operates similarly as described for the embodiment of FIG. 1 to provide an output signal which corresponds to the logarithm of the input pulse signal. It is to be noted that to prevent forward biasing of the collector of the logarithmic transistor 93 and the diode 76, or change the reference current I_{RL} , appreciably, the potential at the virtual ground (gate of transistor 96) should not drift excessively. This potential is stabilized by diode 98 which, to a first approximation, compensates for the thermal drift of the gate-source junction of transistor 96. Since the gate-source bias for a given source current varies appreciably from device to device, a bias control 100 is provided to adjust for zero volts at the gate.

The output from the logarithmic generator is transmitted through a White emitter follower 102 and an inverter 104 to provide opposite polarity logarithmic outputs of the pulse input signal.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A device for generating the logarithm of a voltage pulse comprising means for converting said voltage pulse to a current pulse, means responsive to said voltage pulse for generating an electrical signal, transistor means for generating a signal proportional to the logarithm of an applied current pulse, and means responsive to said generated electrical signal for electrically connecting the current pulse of said current pulse converting means to said transistor means only during the occurrence of said voltage pulse.

2. The device according to claim 1 further including means for adding a constant to said voltage pulse prior to the logarithmic conversion thereof.

3. The device according to claim 1 wherein said current converting means comprise a D-C restorer circuit; means for capacitively coupling said voltage pulse to said D-C restorer circuit; a resistor; an emitter follower electrically connecting the output of said D-C restorer circuit to one terminal of said resistor; a difference amplifier having one input thereof electrically connected to the other terminal of said resistor; a voltage source electrically connected to the other input of said difference amplifier; a cascaded emitter follower amplifier comprising first and second triode transistors; the input of said cascaded emitter follower amplifier being connected electrically to the output of said difference amplifier, the output stage emitter thereof electrically connected to the said other terminal of said resistor and the output stage collector thereof electrically connected to the input of said electrical connecting means.

4. The device according to claim 1 wherein said electrical signal generating means and said electrical connecting means comprises a strobe generator having the input thereof connected to receive said voltage pulse; a univibrator; means for electrically connecting the input of said univibrator to the output of said strobe generator; and a linear gate electrically interconnected of said voltage pulse converting means, said transistor means and the output of said univibrator; said linear gate responsive to the output of said univibrator transmitting the output of said current pulse generating means to said transistor means.

5. The device according to claim 4 wherein said linear gate comprises a first diode having the anode thereof electrically grounded; a second diode having the anode thereof electrically connected to the cathode of said first diode, the output of said voltage pulse converting means, and the output of said univibrator; the cathode of said second diode being electrically connected to the input of said transistor means; said first and second diodes being biased in a nonconducting and conducting state respectively only in the presence of an output pulse from said univibrator.

6. A device for generating the logarithm of a voltage pulse comprising a first D-C restorer; means for capacitively coupling said voltage pulse to said first D-C restorer; a first emitter follower; a resistor having one terminal thereof electrically connected through said first emitter follower to the output of said D-C restorer; a difference amplifier having one input thereof electrically connected to the other terminal of said resistor; a voltage source electrically connected to the other input of said difference amplifier; a cascaded emitter follower having the input thereof electrically connected to the output of said difference amplifier; the output stage emitter of said cascaded emitter follower amplifier being electrically connected to the said other terminal of said resistor; a strobe generator electrically connected to receive said voltage pulse; a second D-C restorer; means for capacitively coupling said second D-C restorer to the output of said strobe generator; a second emitter follower; a univibrator having the input thereof electrically connected through said second emitter follower to the output of said second D-C restorer; a first diode having the anode thereof electrically grounded; a second diode having the anode thereof electrically connected to the cathode of said first diode, the output stage collector of said cascaded emitter follower amplifier and the output of said univibrator; said first and second diodes being biased electrically nonconducting and conducting respectively responsive to the output of said univibrator; an operational amplifier having the input thereof electrically connected to the cathode of said second diode; a triode transistor connected between the input and the output of said operational amplifier and having the base thereof electrically grounded; and means for providing a quiescent reference current for said transistor; the output of said device being

taken between the emitter and base of said transistor to provide a voltage proportional to the logarithm of said input voltage pulse.

DONALD D. FORRER, Primary Examiner
S. T. KRAWCZEWICZ, Assistant Examiner

U.S. Cl. X.R.

References Cited

UNITED STATES PATENTS

2,451,950 10/1948 Hipple ----- 328—145
3,389,272 6/1968 Cherry ----- 307—259 XR

5 307—243, 259; 328—100, 143, 145