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Gilbreath [45] Feb. 15, 1972

[54] FUNCTION GENERATOR

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[52] **U.S. Cl.** **307/229**, 307/230, 328/145
[51] **Int. Cl.** **G06g 7/24**
[58] **Field of Search** 328/144, 145; 307/229, 230; 235/197

[56] **References Cited**

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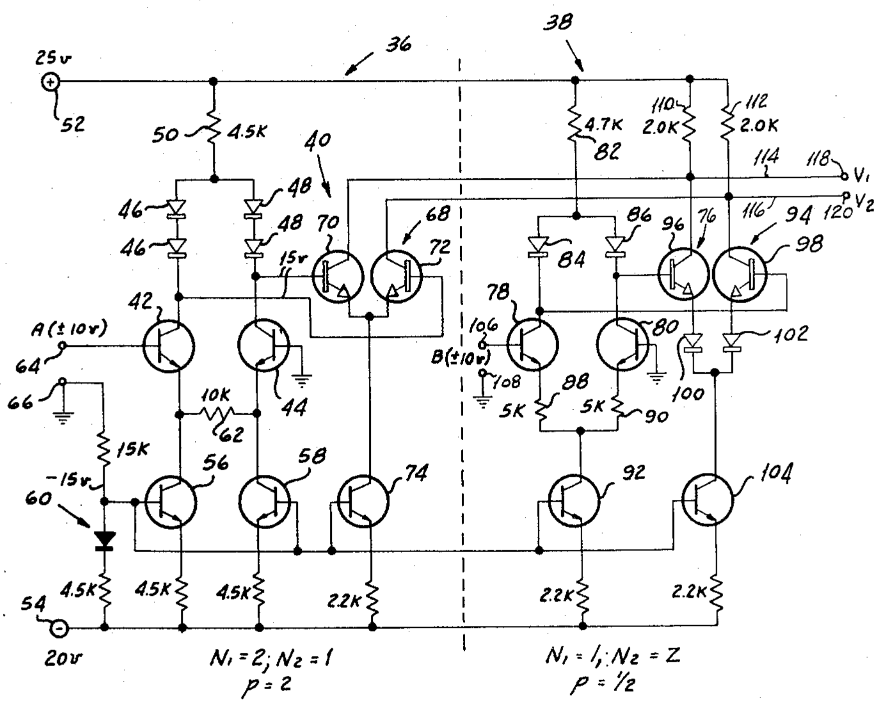
[57] **ABSTRACT**

A nonlinear generator in which each of a plurality of sections includes two differentially connected devices each of which comprises a first string of elements having the same voltage-current characteristics and through which an input current is passed to provide a voltage which is applied to a second string of a different number of similar elements to produce a current from which there is obtained an output which is proportional to the input raised to a power which is the ratio of the numbers of elements in the respective strings. In making up any function each section produces an output representing a term of the overall approximating equation of the function.

17 Claims, 3 Drawing Figures



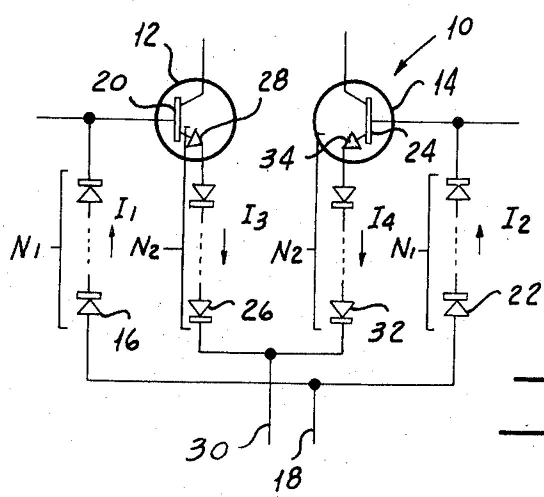


Fig 1

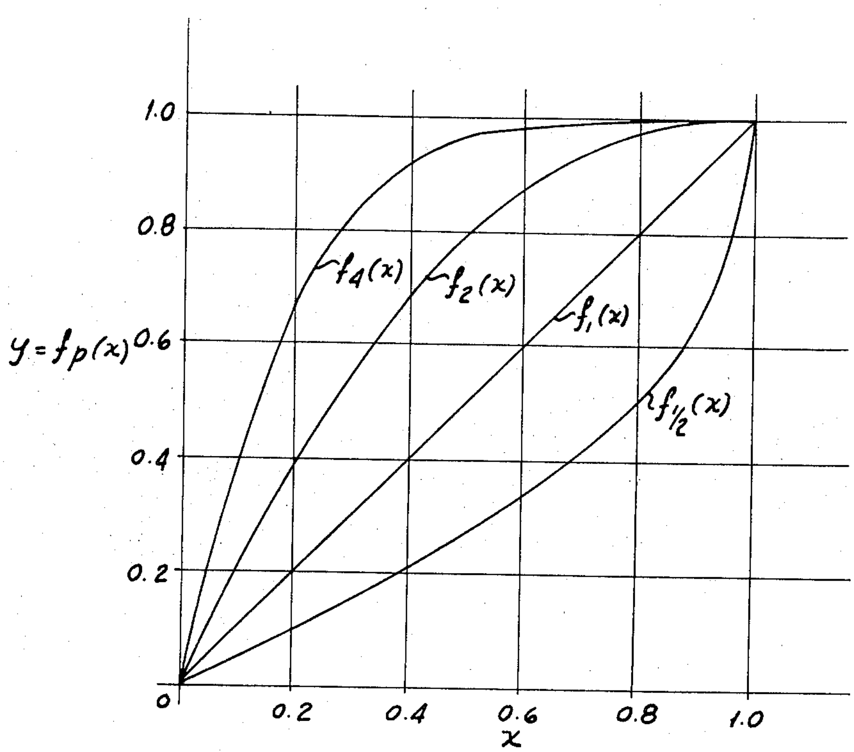


Fig 2

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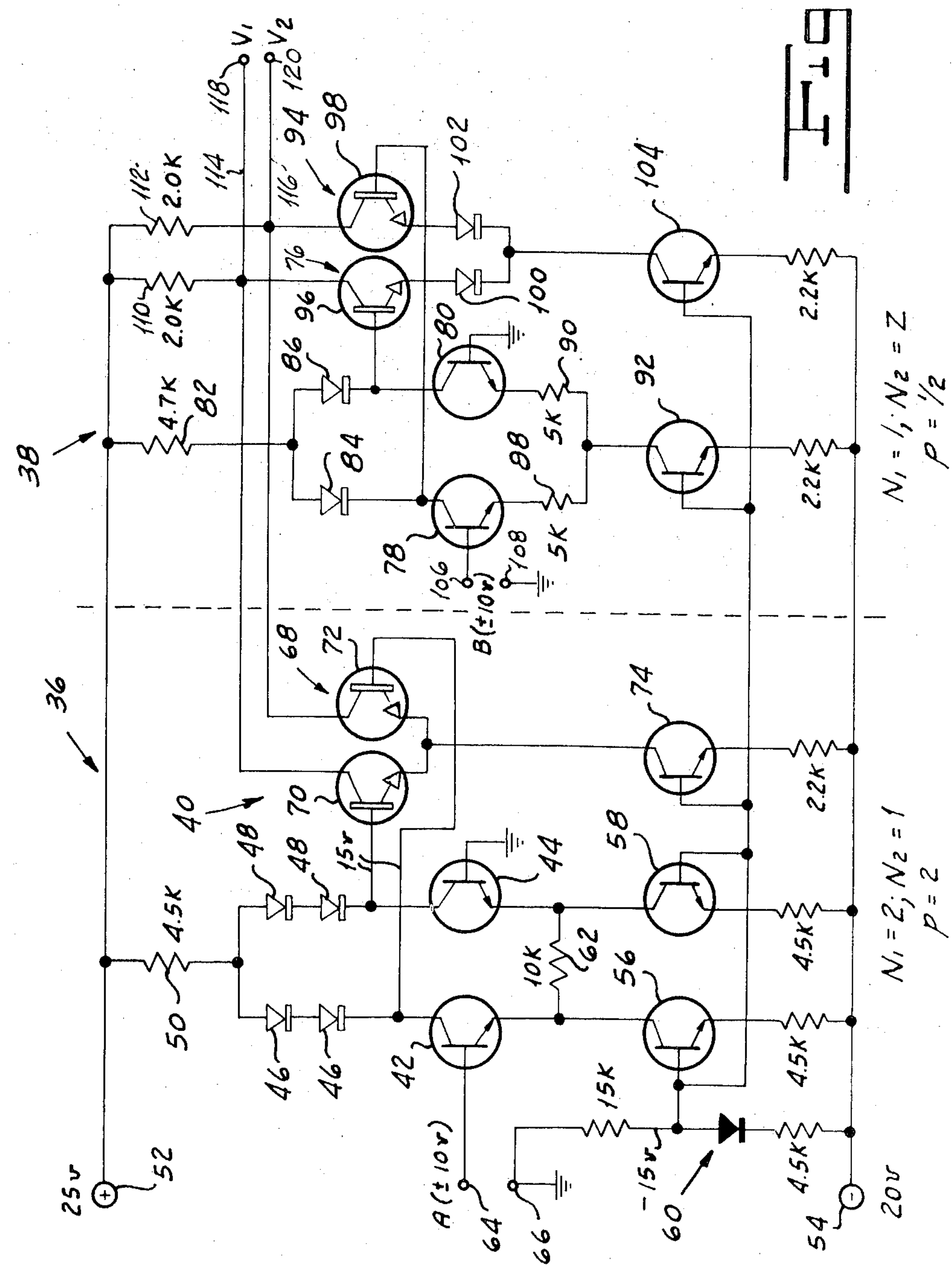
FIG. 3



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FUNCTION GENERATOR

BACKGROUND OF THE INVENTION

There are many instances in which it is necessary or desirable to produce an output which is a nonlinear function such for example as the sine, the square or the logarithm of an input. Attempts have been made in the prior art to provide such generators. Systems representing attempts of the prior art to produce such a system variously embody a number of advantages. The speed of operation of many of them is limited. Operation of many of the devices is a function of the ambient temperature. The utility of others of the devices proposed in the prior art is limited in that they will operate only in response to signals of one polarity.

I have invented a function generator for producing a desired nonlinear input-output relationship. My generator functions at a relatively high speed as contrasted with nonlinear generators of the prior art. Operation of my generator is substantially independent of the ambient temperature. My system is capable of operating on both positive and negative inputs.

SUMMARY OF THE INVENTION

One object of my invention is to provide a nonlinear generator for producing a desired nonlinear input-output relationship.

Another object of my invention is to provide a function generator which is versatile in that it is adapted to provide a wide variety of input-output relationships.

A further object of my invention is to provide a function generator which operates at a relatively high speed.

Still another object of my invention is to provide a function generator the operation of which is substantially independent of ambient temperature.

A still further object of my invention is to provide a function generator capable of operating on both positive and negative inputs.

Yet another object of my invention is to provide a function generator which is simple in construction and which is reliable in operation.

Other and further objects of my invention will appear from the following description.

In general my invention contemplates the provision of a function generator each section of which is made up of two differentially connected devices each of which incorporates input and output strings of nonlinear elements all having the same voltage-current characteristics so as to provide an input-output relationship the power of which is determined by the ratio of the numbers of elements in the respective strings. By use of my generator I can build up a system in which each section represents one term of an equation approximating the function it is desired to produce.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which form part of the instant specification and which are to be read in conjunction therewith and in which like reference numerals are used to indicate like parts in the various views:

FIG. 1 is a schematic view illustrating one section of my function generator.

FIG. 2 is a curve illustrating the various functions which can be produced by a section of my function generator.

FIG. 3 is a schematic view illustrating one embodiment of my function generator for producing a particular input-output relationship.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawings, I have illustrated an arrangement indicated generally by the reference character **10** demonstrating the manner in which my generator operates to produce a nonlinear input-output relationship. The arrangement **10** includes respective NPN-transistors **12** and **14**. I connect a first string of diodes **16** between a common line **18**

and the base **20** of transistor **12**. A second string of diodes **22** is connected between line **18** and the base **24** of transistor **14**. I connect a third string of diodes **26** between the emitter **28** of transistor **12** and a common line **30**. A fourth string of diodes **32** is connected between the emitter **34** of transistor **14** and the line **30**. In the example being considered the base-to-emitter junctions of the respective transistors **12** and **14** comprise diodes of the strings of diodes **26** and **32**. All of the diodes are selected to have the same current voltage characteristic.

As is known in the art, the current voltage relationship for any of the diodes **16**, **22**, **26** and **32** is approximately logarithmic and is given by the relationship:

(1) $V=k_1 lnI+k_2$ where k_2 is in millivolts and wherein k_1 is a function of temperature. In the example under consideration, I assume that the transistor beta is infinite although a finite but relatively large beta does not change the approach.

Considering only the transistor **12** and its associated strings of diodes **16** and of diodes **26** and assuming that the strings contain respective numbers N_1 and N_2 of diodes and that an input current I_1 is passed through the diodes **16**, and, for purposes of simplicity, that the constant K_2 is zero, the voltage across the string of diodes **16** is given by

(2) $V=N_1 k_1 lnI_1$

Since the transistor is connected as an emitter follower, the same voltage exists across the string of diodes **26** and the resultant current I_3 therethrough is given by the relationship

(3) $I_3=\text{antiln}\ V/N_2 k_1$ or

(4) $I_3=\text{antiln}\ N_1 k_1/N_2 k_1 ln\ I_1$

so that we can write:

(5) $I_3=I_1(N_1/N_2)$

It will thus be seen that the device including transistor **12** and strings of diodes **16** and **32** produces an output current which is related to the input current by an exponent which is the ratio of the numbers of the diodes in the respective strings.

Considering now the relationships over the entire circuit shown in FIG. **1**, the currents flowing in the strings of diodes **16**, **22**, **26** and **32**, are designated respectively as I_1, I_2, I_3 and I_4.

In my arrangement, I select the number N_1 of diodes **16** to be equal to the number of diodes **22** and I select the number N_2 of diodes **26** to be equal to the number of diodes **32**. Under these conditions the sum of the voltage drops around the loop including all of the diodes is given by:

(6) $-N_1(k_1 ln\ I_1+k_2)-N_2(k_1 ln\ I_3+k_2)+N_2(k_1 ln\ I_{4\ 4}+k_2)+N_1({}_1 ln\ I_2+k_2)=0$ or

(7) $-N_1 \ln I_1-N_2 \ln I_3+N_2 \ln I_4+N_1 \ln I_2=0$

which reduces to:

(8) $N_1/N_2(in\ I_2-in\ I_1)=(in\ I_3-in\ I_4)$

It is to be noted that both constants k_1 and k_2 have dropped out of the relationship so that neither affects the input-output relationship. Thus variations in ambient temperature do not result.

Taking the antilogarithm of both sides of this expression we obtain:

(9) $(I_2/I_1)^{(N_1/N_2)}(I_4/I_3)=1$

For purposes of illustration let the input variable be represented by:

(10) $x=I_2-I_1/I_2+I_1$ or

(11) $I_2/I_1=I+x/I-x$

Let the output variable y *be represented by*

(12) $y=I_3-I_4/I_3+I_4$ or

(13) $$\frac{I_4}{I_3}\frac{1-y}{1+y}$$

Substituting Equations (11) and (13) in Equation (9) we obtain:

(14) $$\left(\frac{1+x}{1-x}\right)^p\left(\frac{1-y}{1+y}\right)=1$$

where $p=N_1/N_2$ or

$$(15)\qquad yp(x)=\frac{1-\left(\frac{1-x}{1+x}\right)^{p}}{1+\left(\frac{1-x}{1+x}\right)^{p}}$$

From the foregoing it can be seen that the output variable is related to the input variable by an expression raised to a power p which is the ratio of the numbers of nonlinear elements N_1 and N_2.

Referring to FIG. 2 I have shown various relationships of the input and output variables in accordance with Equation (15). It can be seen that I am able to represent any function made up of convex or concave relationships.

Referring now to FIG. 3 I have shown a system for representing a particular input-output relationship wherein a first section indicated generally by the reference character **36** represents one term of the function depending upon the input variable A. The other section indicated generally by the reference character **38** represents a term of the function of a second variable B. Section **36** includes two differentially connected devices, the first of which is indicated generally by the reference character **40**. The device **40** includes as active elements a transistor **70** corresponding to transistor **12** of FIG. **1**, a first string of diodes **48** and a second string of diodes comprising only the base-to-emitter junction of transistor **70**. The other device **68** of the two differentially connected devices of section **36** includes transistor **68**, a first string of diodes **46** and a second string of diodes including only the base-to-emitter junction of transistor **72**.

A resistor **50** connects the common terminals of the strings of diodes **46** and **48** to the terminal **52** of a suitable source of positive potential. I connect an input transistor **42** and a balancing transistor **44** respectively between the other terminals of the strings of diodes **46** and **48** and constant current devices **56** and **58**. A weighting resistor **62** connects the emitters of transistors **42** and **44**. A biasing circuit indicated generally by the reference character **60**, connected between a ground terminal **66** and the terminal **54** of a suitable source of negative potential provides the required bias for emitter followers **56** and **58**, for an emitter follower **74** connected between the common emitter terminals of transistors **70** and **72** and terminal **54** and for other constant current devices, to be described hereinafter, of the section **38**. I apply the input A to a terminal **64** connected to the base of transistor **42**.

In the section **36** I provide the same number of diodes **46** as diodes **48** which number is N_1 in the expressions outlined hereinabove. Moreover in the section **36** the base-to-emitter junctions of the transistors **70** and **72** make up the nonlinear elements of the differentially connected devices **40** and **68**. In the arrangement shown since only one of these devices is in the path of each of the currents I_3 and I_4, $N_2=1$. As a result for the section **36** $p=2$.

In the other section **38** the first one, indicated generally by the reference character **76**, of the two differentially connected devices includes the transistor **96**, a first diode string including a single diode **86** and a second diode string including the base-to-emitter junction of transistor **96** and a diode **100**. The other device, indicated generally by the reference character **94**, of the section **38**, includes a transistor **98**, a first diode string including a single diode **84** and a second diode string including the base-to-emitter junction of transistor **98** and a diode **102**.

A resistor **82** connects the common terminal of diodes **84** and **86** to terminal **52**. Respective weighting resistors **88** and **90** connect the emitter terminal of input and balancing transistors **78** and **80**, connected respectively to diodes **84** and **86**, to a constant current emitter follower **92**. Another constant current emitter follower **104** connects the common terminal of diodes **100** and **102** to terminal **54**. Circuit **60** provides the bias for emitter followers **92** and **104**.

I apply the second input variable B between a terminal **106** connected to the base of input transistor **78** and a ground terminal **108**. Respective resistors **110** and **112** connect output lines **114** and **116** to terminal **52**. Line **114** is common to the collectors of transistors **70** and **96**. It leads to an output terminal **118**. Line **116** is common to the collectors of transistors **72** and **98**. It leads to an output terminal **120**.

From the foregoing it will be seen that the number N_1 of diodes **84** and of diodes **86** is one while the number N_2 of diodes in each of the emitter circuits of transistors **86** and **98** is two. Thus, for section **38** the output power p is one-half.

For purposes of clarity in FIG. **3** I have illustrated the active nonlinear elements of the various differential devices by open symbols while the other elements of the system are indicated as being solid. It will readily be appreciated that any nonlinearity in those other elements is masked by the resistors associated therewith such as the various resistors indicated in the FIG. as being associated with the emitter circuits of the other transistors.

In FIG. 3 I have indicated nominal values for the various potentials and resistors which will produce the desired relationships. Further, form EQuation (12) above it will be apparent that for any section of my system the output current derived will be:

$$(16)\qquad I_3-I_4=Y(I_3+I_4)$$

In terms of voltage the output voltage V is given by:

$$(17)\qquad V=Y(I_3+I_4)R$$

where R is an output resistor.

For the particular system illustrated in FIG. **3** the voltage between terminals V_1 and V_2 is:

$$(18)\qquad V_2-V_1=K(y_1+y_2)$$

where K is the product of I_3 and I_4 for each section and of the output resistance. In the particular instance illustrated $K=2x\ 10^{-3}$ amps times 2×10^3 ohms or 4 volts.

Substituting for y_1 and for y_2 in Equation (18) we obtain:

$$(19)\qquad V_2-V_1=K\left[\frac{1-\left(\frac{1-x_1}{1+x_1}\right)^{p_1}}{1+\left(\frac{1-x_1}{1+x_1}\right)^{p_1}}+\frac{1-\left(\frac{1-x_2}{1+x_2}\right)^{p_2}}{1+\left(\frac{1-x_2}{1+x_2}\right)^{p_2}}\right]$$

In section **36**, owing to the presence of resistor **62**, $x_1=A/10$, and $p_1=2$. In section **38**, owing to the presence of resistors **88** and **90**, $x_2=b/10$, and $p_2=1/2$. Substituting these values in Equation (19) the output across terminals V_1 and V_2 is given by:

$$(20)\qquad V_2-V_1=4\left[\frac{1-\left(\frac{1-A/10}{1+A/10}\right)^{2}}{1+\left(\frac{1-A/10}{1+A/10}\right)^{2}}+\frac{1-\left(\frac{1-B/10}{1+B/10}\right)^{1/2}}{1+\left(\frac{1-B/10}{1+B/10}\right)^{1/2}}\right]$$

It will thus be seen that the output in terms of the inputs for the system of FIG. **3** includes two terms one of which may be termed a convex or square power term of a first variable provided by section **36** and the other of which is a square root term of a second variable provided by section **38**.

The operation of my system will readily be apparent from the description thereof given hereinabove. Considering any section thereof it produces an output which is related to the input by an exponent or power which is the ratio of the numbers N_1 and N_2 of nonlinear devices in the section. The section provides one term of an equation approximating the desired function to be generated. By adding sections to the system the number of terms in the approximation may be increased.

It will be seen that I have accomplished the objects of my invention. I have provided a function generator which overcomes the defects of generators of the prior art. It closely approximates any desired function. Its operation is substantially independent of ambient temperature. It will operate on either positive or negative potentials. Its operation is more rapid than is that of generators of the prior art.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of my claims. It is further obvious that various changes may be made in details within the scope of my claims without departing from the spirit of my invention. It is, therefore, to be understood that my invention is not to be limited to the specific details shown and described.

Having thus described my invention, what I claim is:

1. A function generator for producing a desired input-output relationship including in combination, a first number of serially connected elements each having a particular nonlinear voltage-current characteristic, a second number of serially connected elements each having a certain nonlinear voltage-current characteristic, said first and second numbers being unequal, means for passing an input current through the first elements to produce a first voltage thereacross, means for applying said first voltage across the second elements to produce a first current therethrough, and means responsive to said first current for producing an output current related to said input current by an exponent equal to the ratio of the first number to said second number.

2. A function generator as in claim 1 in which said first ans second elements are diodes each having the same nonlinear characteristic.

3. A function generator as in claim 1 in which said voltage-current relationship is logarithmic.

4. A function generator as in claim 1 in which said first number is greater than said second number.

5. A function generator as in claim 1 in which said second number is greater than said first number.

6. A function generator as in claim 1 in which said means for applying said first voltage includes a transistor having a base-to-emitter junction comprising one of the second elements.

7. A function generator as in claim 1 in which said elements are diodes having a logarithmic voltage-current characteristic, and in which said means for applying said first voltage comprises a transistor having a base-to-emitter junction comprising one of the second elements.

8. A function generator as in claim 1 in which one of said numbers is unity.

9. A function generator for producing a desired input-output relationship including in combination, a first number of serially connected elements each having a particular nonlinear voltage-current characteristic, a second number of serially connected elements each having a certain nonlinear voltage-current characteristic, said first and second numbers being equal, means for differentially applying an input current to said first and second numbers of elements of produce first voltages thereacross, a third number of serially connected elements having a certain nonlinear voltage-current characteristic, a fourth number of serially connected elements each having a certain nonlinear voltage-current characteristic, said third number being equal to said fourth number, means for differentially applying said first voltages to said third and fourth numbers of elements to produce first currents therethrough, and means differentially responsive to said first currents for producing an output voltage.

10. A function generator as in claim 9 in which said input current applying means comprises means for maintaining of the currents through said first and second numbers of elements constant.

11. A function generator as in claim 9 in which said first voltage applying means comprises means for maintaining the sum of the currents through said third and fourth numbers of elements constant.

12. A function generator as in claim 9 in which said input current applying means comprises first means for maintaining the sum of the currents through said first and second numbers of elements constant and in which said first voltage applying means comprises means for maintaining the sum of the currents through said third and fourth numbers of elements constant.

13. A function generator as in claim 9 in which said input current applying means comprises a weighting resistance between said first and second strings.

14. A function generator as in claim 9 in which said voltage applying means comprises transistors each having a base-to-emitter junction, each of said junctions forming an element of one of the third and fourth numbers of elements.

15. A function generator as in claim 9 in which said input current applying means comprises a transistor connected to said first number of elements and means for applying an input signal to said transistor.

16. A function generator as in claim 9 in which said input current applying means comprises means for maintaining the sum of the currents through said first and second numbers of elements constant, and a weighting resistance between said first and second numbers of elements, and in which said voltage applying means comprises transistors each having a base-to-emitter junction and in which each of said junctions forms an element of one of the third and fourth numbers of elements and means for maintaining the sum of the currents through said third and fourth numbers of elements constant.

17. A function generator for producing a desired function of one or more input variables including in combination, a first section, a second section, each of said sections including a first device comprising a first string of elements having a particular nonlinear voltage- current characteristic, a second string of a second different number of said elements, and means for applying a voltage produced by a current flow through said first string across said second string, and a second device comprising a third string of said first number of said elements, a fourth string of said second number of elements, and means for applying a voltage produced by a current flow through said first string across said second string, means for applying inputs to said sections to cause currents to flow in said first strings, the second string voltages resulting from said first string currents producing currents in said second strings, and means for producing an output from the combined second string currents.

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Disclaimer

3,643,107.—*Dennis R. Gilbreath*, New Haven, Conn. FUNCTION GENERATOR. Patent dated Feb. 15, 1972. Disclaimer filed Nov. 23, 1973, by the assignee, *United Aircraft Corporation.*

Hereby enters this disclaimer to claims 1–8, inclusive, of said patent.

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