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ELECTRIC SIMULATORS OF ARBITRARY FUNCTIONS

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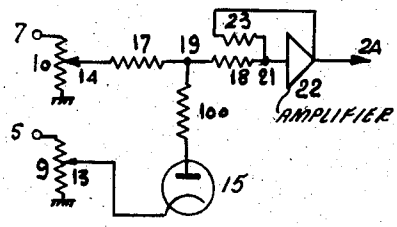



FIG.1

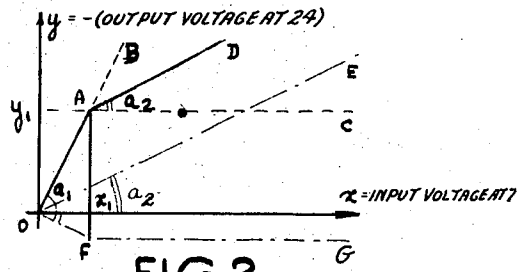



FIG.2

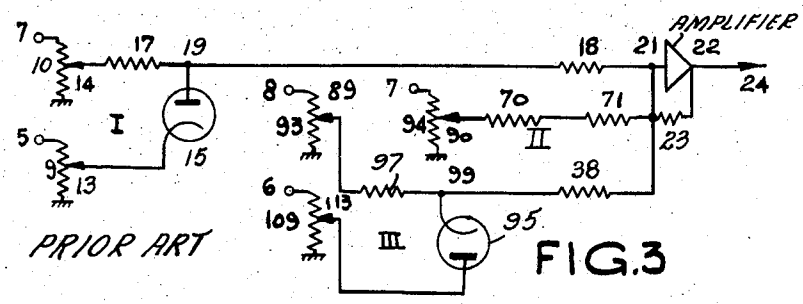



FIG.3

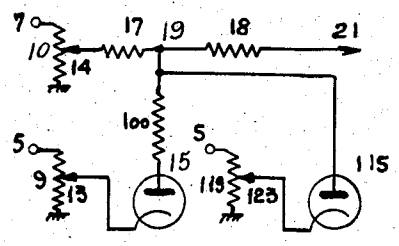



FIG.4

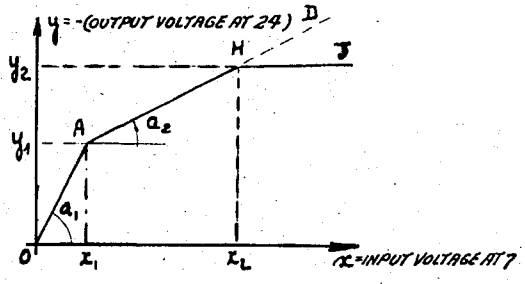



FIG.5

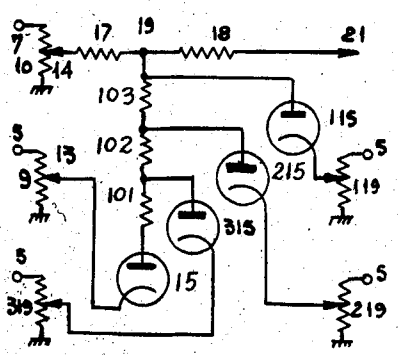



FIG.6

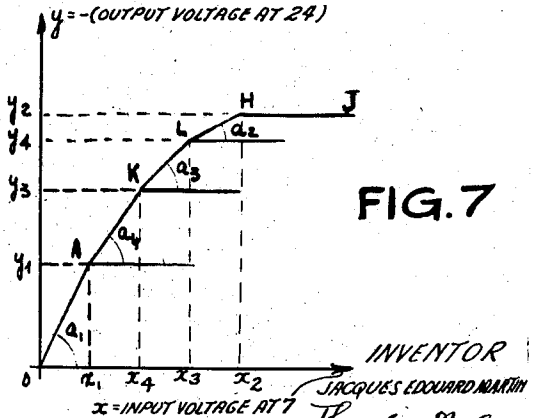



FIG.7

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# ELECTRIC SIMULATORS OF ARBITRARY FUNCTIONS

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2 Claims. (Cl. 250—27)

The present invention relates to electric simulators of arbitrary functions, i.e. electric devices which may be given any desired transfer characteristic corresponding to an arbitrary though adjustable law of variation of a geometrical curve which has been previously reduced, by graphical analysis, to a combination of elementary functions each of which represents a portion of a straight line having a predetermined slope. By transfer characteristic is meant the curve obtained by plotting the values of an output voltage as ordinates, against the values of at least one input voltage, as abscissa.

Copending application Serial Number 290,588, now Patent No. 2,831,107, filed May 22, 1952, filed by François Henri Raymond, Pierre Louis Chapouille and Jacques Edouard Martin and assigned to the same assignee as the present application, provided an electric simulator of an arbitrary function of at least one variable, composed of elementary functions each of which represents a portion of a straight line of determined slope. In this simulator at least one variable representative voltage is supplied to at least an array of transfer stages having input means connected to such voltage supply and each including means for adjusting the attenuation of such voltage to a predetermined ratio depending upon coefficients of the elementary functions. At least some of these transfer networks include means for limiting their output voltages to a predetermined value depending upon coefficients of the elementary functions, such transfer stages having outputs connected to the input of at least one summation amplifier.

Such an arrangement apparently requires one separate transfer network for the electric representation of each portion of a straight line of determined slope. Each transfer network includes a calibrated series resistor connected to a further calibrated series resistor forming part of an input coltage mixer for a summation amplifier. Further, each transfer network in addition to being provided with means for limiting its output voltage to a predetermined value, has a shunt branch including at least one unidirectionally conducting element, preferably a vacuum diode tube one electrode of which is connected to the end of the first of these series resistors and the other is connected to a predetermined voltage supply.

The present invention, which constitutes a continuation in part of the above mentioned copending application, has for its object to provide a more simple and economical arrangement for an electric simulator of an arbitrary function of the kind specified above.

Another object of the invention is to provide an improved arrangement of transfer networks for an electric simulator of an arbitrary function of the kind specified whereby a substantial reduction in the number of transfer networks is achieved while a determined overall efficiency and simulator accuracy are maintained. Alternatively, in accordance with the invention a greater efficiency and a greater accuracy are achieved with a determined number of component transfer networks.

A further object of the invention is to provide an



improved transfer network for an electric simulator of an arbitrary function of the kind specified, the transfer characteristic of which represents at least two and possibly more than two portions of straight lines of different predetermined slopes, each portion of a straight line abutting the nex preceding one in the elementary transfer characteristic of this transfer network.

According to the invention, in an electric simulator of an arbitrary function of the kind specified, at least some of the component transfer networks include each a series resistor in its limiting shunt branch, between the connection point of that shunt branch and the corresponding electrode of its unidirectionally conducting element. In this way, the transfer characteristic of this network is made to consist of a first portion of a straight line starting from the origin with a first predetermined slope, and a following portion of a straight line starting from the end point of the first slope and having a second predetermined slope; the end point corresponds to the voltage value for which the unidirectionally conducting element is activated.

According to another object of the invention, further, the series resistor is tapped at intermediary points and each tap is connected over a separate unidirectionally conducting element to a separate voltage supply. In this way the transfer characteristic of the transfer network is made to consist of as many portions of straight lines of different predetermined slopes as there are provided unidirectionally conducting elements, and of an additional portion of a straight line having a predetermined different slope defined by the value of the portion of the resistor inserted between the connection point and the first tap of the series resistor.

These and other objects of the invention will now be described more fully and by way of examples with reference to the accompanying drawings, wherein:

Fig. 1 shows a relatively simple arrangement of a transfer network for an electric simulator of an arbitrary function of the kind specified, according to the present invention;

Fig. 2 shows the transfer characteristic of the network of Fig. 1;

Fig. 3 represents a combination of transfer networks having the same transfer characteristic in an electric simulator such as disclosed in the above mentioned copending application;

Fig. 4 shows an extension of the embodiment of Fig. 1, according to the invention;

Fig. 5 shows the transfer characteristic of the network of Fig. 4;

Fig. 6 shows another extension of the embodiment of Fig. 1 according to the invention; and,

Fig. 7 shows the transfer characteristic of the embodiment of Fig. 6.

From these illustrations of the invention many other lay-outs of transfer networks for an electric simulator of an arbitrary function of the kind specified and such as disclosed in the above mentioned copending application can be developed without departing from the scope of the invention.

In Fig. 1, a transfer network is shown to consist of series resistor **17** connected at point **19** to a further series resistor **18** forming part of the input voltage mixer of a summation amplifier. Such summation amplifier is illustrated by amplifier **22** and feedback resistor **23**. The values of the three resistors **17**, **18** and **23** may be considered equal. The input of summation amplifier **22** is indicated at **21** and its output at **24**. The variable voltage is applied at terminal **7** of a potentiometer **10**; the slider **14** of potentiometer **10** is connected to one end of series resistor **17**. If $x$ denotes the variable voltage at point **7** and $a_1$ the predetermined slope which would be the slope

of the transfer characteristic of the network if it would only contain the above elements, the slider **14** is so adjusted that the voltage applied to resistor **17** is $x.\tan a_1$. This slope $a_1$ is that of the line OB in Fig. 2.

A calibrated reference voltage is applied to terminal **5** and fed through an adjustment potentiometer **9** for instance, over slider **13** to the cathode of a vacuum tube diode **15**. The anode of tube **15** is connected to point **19** through a series resistor **100**. The voltage value on slider **13** is adjusted to be proportional to $y_1=x_1.\tan a_1$, viz. the ordinate value limiting, as shown in Fig. 2, the portion of a straight line starting from origin O and ending at point A for an abscissa value $x_1$.

If resistor **100** were omitted, as for example in transfer networks such as disclosed in the above mentioned co-pending application, for any value of $x$ greater than $x_1$, the output voltage would be on the portion of a straight line AC which is parallel to the abscissa axis of the characteristic. Diode **15** would then be conducting and, at **19**, the voltage value $x_1.\tan a_1$, substituted for the voltage value $x.\tan a_1$. If however, as in the present case, the resistor **100** is provided the characteristic does not present a zero slope in that part of the plane. Once diode **15** becomes conducting, the transfer characteristic presents a slope $a_2$, namely, a straight line portion AD in Fig. 2.

If $R_{100}$ denotes the value of resistor **100** and $R_{17}$ the value of resistor **17**, which is also the value of the resistor **18**, and if K denotes the value of the ratio between the slopes after and before diode **15** is activated, viz.

(i) $$k=\tan a_2/\tan a_1$$

the following relation exists between $R_{100}$ and $R_{17}$—

(ii) $$R_{100}=R_{17}\cdot\frac{k}{2(1-k)}$$

The significance of Relation ii is apparent: For any definite value of resistor **100** there is obtained a definite slope $a_2$ of the portion of a straight line AD. Conversely, to adjust the slope of AD to a predetermined value, it will be sufficient to provide a value $R_{100}$ for resistor **100** derived from Relation ii for a ratio $k$ such as derived from Relation i.

In order to visualize the simplification in structure of an electric simulator of the kind specified and brought about by putting the present invention into practice, Fig. 3 shows the lay-out of part of such a simulator which is required to obtain the same characteristic as that illustrated in Fig. 2 without realising the invention. It is apparent that three transfer networks are required in such a case.

A first network I is of the same structure as that disclosed in Fig. 1 except that resistor **100** is omitted. This network has the transfer characteristic OAC of Fig. 2. A second network II mainly comprises resistors **70** and **71**; resistor **71** forms part of the input mixer of the summation amplifier. The variable voltage is applied to this second network from slider **90** of potentiometer **94** fed from the same terminal **7** as the first network. Slider **90** is so adjusted as to impart to the variable voltage an attenuation proportional to $\tan a_2$. The third network III is of a structure similar to that of Fig. 1 but the direction of conductibility of its own diode tube **95** is reversed; the cathode is connected to point **99** of interconnection between resistors **97** and **98** (the latter forming part of the input mixer of the summation amplifier). Resistor **97** receives its supply voltage from slider **89** of a potentiometer **93** which receives at terminal **8** the variable voltage with a polarity opposite to that of the variable voltage applied at **7**. The anode of diode **95** is connected to slider **113** of a potentiometer **109** which receives the reference voltage at terminal **6** with a polarity opposite to that of the reference voltage at **5**. Sliders **90** and **113** are adjusted to positions corresponding to those of sliders **14** and **13** in network I.

The transfer characteristic of the network II is developed as a portion of a straight line OE, Fig. 2, and the transfer characteristic of network III is represented by OFG, Fig. 2. The overall characteristic of the arrangement of Fig. 3 is that resulting from the addition of the three characteristics OB, OE and OFG, viz. OAD. Such a characteristic OAD is derived from a single network if this network is designed in accordance with the present invention.

If now, Fig. 4, a second diode **115** is connected to point **19**, and the cathode of diode **115** receives from slider **123** of a further potentiometer **119** fed by reference voltage at **5**, a voltage of a value $y_2$ higher than $y_1$, the transfer characteristic will be as shown in Fig. 5. As soon as the variable voltage at **7** becomes greater than $y_2$, the point of line AD for which $y=y_2$, the output voltage of the transfer network is limited to this value $y_2$. The overall characteristic of the network contains the portions OA and AH and HJ parallel to the abscissa axis.

If for illustration sake, resistor **100** is replaced by or formed of three series resistors **101**, **102** and **103**, Fig. 6, two further diodes **215** and **315** may be connected to the connection points between these resistors, in addition to diode tubes **15** and **115**. The cathodes of diodes **215** and **315** receive reference voltages of values $y_3$ and $y_4$ intermediate between the values $y_1$ and $y_2$, through potentiometers **219** and **319** receiving the reference voltage at **5**. The overall or resulting transfer characteristic therefore will be as shown in Fig. 7, containing the portions of straight lines OA, of slope $\tan a_1$, AK, of slope $\tan a_4$, KL, of slope $\tan a_3$, LH, of slope $\tan a_2$, and HJ, of zero slope.

Any other subdivision of resistor **100** can be provided to obtain a transfer characteristic of any other number of portions of straight lines. The sole restriction lies in the condition that the value of any of the resistors such as **101**, **102**, . . ., must not be of the same order as the internal resistance of the diodes. This condition may also be stated as follows: The ratios between consecutive slopes of the transfer characteristic must not be too high.

Considering for instance the circuit of Fig. 6 and the characteristic of Fig. 7, the following relations may be established between the slopes of straight line portions OA, AK, KL and LH:

(iii) $$\tan a_2=(\tfrac{1}{4}).\tan a_1$$
$$\tan a_3=(\tfrac{1}{2}).\tan a_1$$
$$\tan a_4=(\tfrac{3}{4}).\tan a_1$$

Then the value of resistor **103**, defining a slope equal to a quarter of the initial slope, must be made equal to one-sixth of the value of resistor $R_{17}$, according to Relation ii. This relation gives:

(iv) $$R_{103}=R_{17}\cdot\frac{\frac{1}{4}}{2(1\frac{1}{4})}=R_{17}/6$$

The resistance value which determines a slope of half the value of the initial slope is the sum of resistances **103** and **102**. From Relation ii, the following value of resistor **102** is obtained:

(v) $$R_{102}=R_{17}\cdot\frac{\frac{1}{2}}{2(1\frac{1}{2})}-R_{103}=R_{17}/3$$

The resistance value which determines a slope which is three-quarters of the value of the initial slope, is the sum of resistances **101**, **102** and **103**. From Relation ii, the following value of the resistor **101** is obtained:

(vi) $$R_{101}=R_{17}\cdot\frac{\frac{3}{4}}{2(1\frac{3}{4})}-R_{103}-R_{102}=R_{17}$$

The value of $R_{17}$ will of course be high with respect to the internal resistance of a diode vacuum tube, for instance of the order of a megohm. The smallest resistance in the shunt branch of the transfer network, in the case concerned will be equal to one-sixth of a megohm,

which is comparatively high with respect to any internal resistance of a vacuum tube diode available in present technique.

I claim:

1. In a transfer arrangement for an electric simulator of an arbitrary function of at least one variable, composed of elementary functions each of which represents a portion of a straight line of predetermined slope, at least one transfer network including a series attenuator comprising two series connected resistances, at least another transfer network including unidirectionally conducting means, variable direct current voltage supply means and reference direct current voltage supply means coupled, respectively, to said transfer networks, at least one voltage limiting branch extending from the junction point of said resistances through said unidirectionally conducting means to said reference voltage supply means, a further resistance connecting said unidirectional means to said junction point, further voltage limiting branches derived from said junction point and including further unidirectional means connected respectively at one side to different points along said further resistance, a further voltage supply means connected respectively to the other side of said unidirectionally conducting means and means



including a summing amplifier for linearly adding the voltage outputs derived from said series attenuator and said voltage limiting branch, respectively.

2. Arrangement according to claim 1 wherein said further unidirectionally conducting means are connected substantially with the same direction of conductibility, and wherein said further voltage supply means include voltage adjusting means so adjusted that the voltage values thus applied are stepped up according to values increasing towards said junction point.

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