Dec. 11, 1945. H. G. BRINTON 2,390,773

AMPLIFIER CIRCUITS

Filed July 3, 1943

Fig. 1.

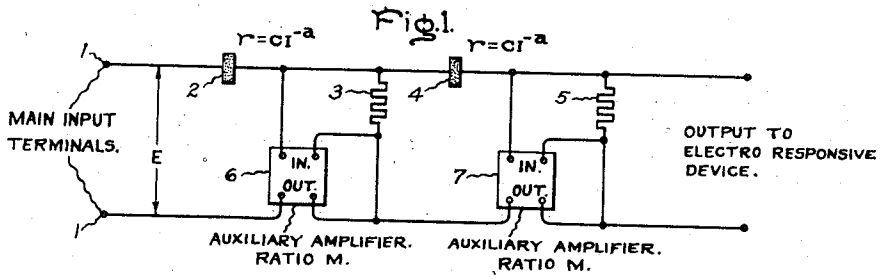


Fig. 2.

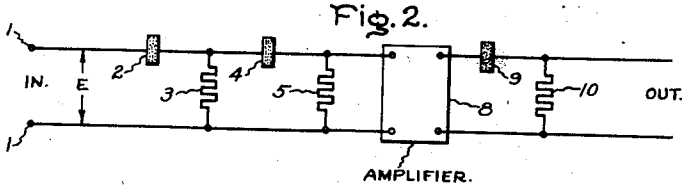


Fig. 3.

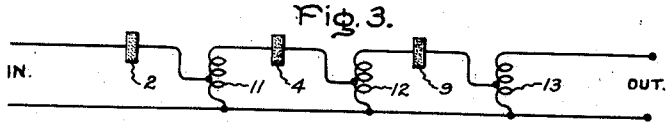


Fig. 4.

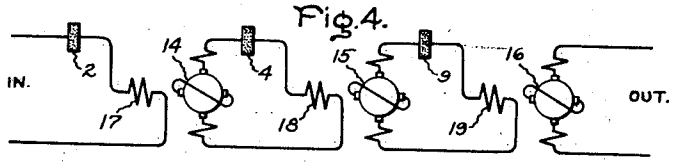


Fig. 5.

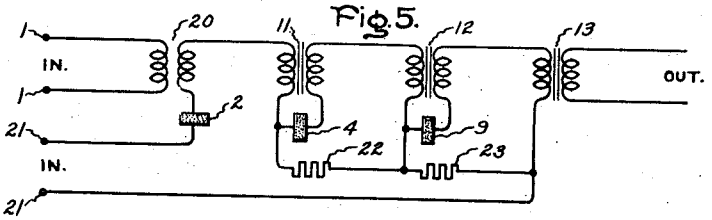


Fig. 6.

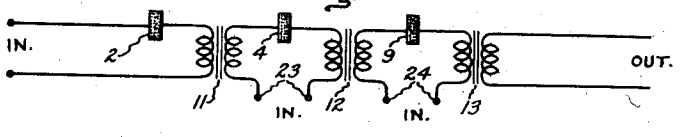
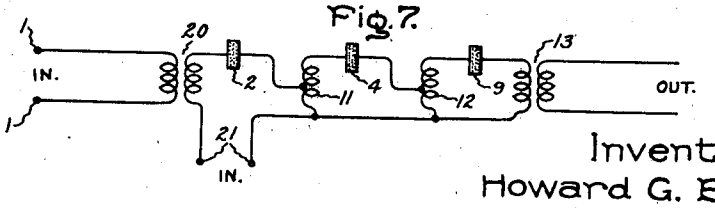


Fig. 7.



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2,390,773

AMPLIFIER CIRCUITS

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Application July 3, 1943, Serial No. 493,335

11 Claims. (Cl. 179—171)

This invention relates to amplifier circuits and more particularly to improvements in percentage change type amplifiers.

By a "percentage change amplifier" is meant an amplifier in which if the input quantity, such as voltage, changes by a given percentage, the output will change by a greater percentage although the absolute values of the output may be very much less than the absolute values of input. In other words, it is a non-linear amplifier, as contrasted with a linear amplifier in which the ratio of the input to the output is constant.

The invention utilizes as its principal element a varistor which is a resistor having such a pronounced non-linear volt-ampere characteristic that practical use may be made of it. In particular it uses a ceramic varistor made in accordance with Patent 1,822,742, granted September 8, 1931 on an application of K. B. McEachron and assigned to the assignee of the present application. This material is manufactured by applicant's assignee under the name of Thyrite. The characteristic of this material is usually defined by the fundamental equation $I^{\alpha}r=C$. In this equation I is the instantaneous value of current through the resistor in amperes, r is its instantaneous resistance in ohms, C is its resistance in ohms when the current through it is one ampere and this is determined principally by the dimensions of the resistor, and α is an exponent whose value is determined by the controls used in the manufacture of the material. It is always less than 1 and is usually somewhere between .6 and .85.

In accordance with the present invention there is provided an amplifier system in which in effect the exponent α is increased so as to approach the limiting value of unity, at which value the amplifier would have an infinite percentage change amplification. As varistors are rugged, static and stable devices and as Thyrite is substantially instantaneous in action, a percentage change amplifier utilizing the properties of such material will also be a rugged, fast, static and stable device.

An object of the invention is to provide a new and improved amplifier system.

Another object of the invention is to provide a high percentage change amplifier system which is rugged, fast, static and stable.

The invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing Fig. 1 illustrates diagrammatically a multi-stage embodiment of the invention utilizing feed back and an auxiliary amplifier to produce increased percentage change amplification, Fig. 2 is similar to Fig. 1 but does not have feed back, Fig. 3 is a modification utilizing transformers between stages which is particularly suitable for alternating-current applications, Fig. 4 is another modification suitable for direct current in which the stages of the amplifier are coupled through high-speed dynamo-electric amplifiers, Fig. 5 is a modification in which separate terminals are provided for input power and the input signal, Fig. 6 is a modification of Fig. 5, and Fig. 7 is another modification of Fig. 5.

Referring now to the drawing and more particularly to Fig. 1, the amplifier system is provided with a pair of main input terminals 1 across which the input voltage E is impressed. Serially connected in a circuit across these input terminals 1 is a non-linear resistor 2 and a second resistor 3. The voltage across a part or all of the resistor 3 is the output voltage of the first stage of the amplifier and consequently the second stage input terminals will correspond to the first stage output terminals. The second stage is similar to the first and consists of another non-linear resistor 4 and a resistor 5 serially connected in a circuit across the resistor 3. Although only two stages have been shown, it will be obvious that as many similar stages as desired may be employed. The main output terminals are connected across the resistor 5 of the last stage.

In order to improve the operation of the resistor by either increasing its percentage change amplification or by increasing the output voltage an auxiliary amplifier 6 of any suitable and well-known type may have its output terminals connected in circuit with resistors 2 and 3 and have its input terminals connected to respond to the voltage drop in resistor 3, and a similar amplifier 7 may have its output terminals connected in circuit with the resistors 4 and 5 and have its input terminals respond to the voltage drop across resistor 5.

Resistors 2 and 4 are preferably of the type whose resistance current characteristic is defined by the previously-mentioned equation $I^{\alpha}r=C$. In some cases it is more convenient to convert this equation into one which defines r in terms of I, α and C, this latter equation being $r=CI^{-\alpha}$.

The operation of Fig. 1 is as follows: Neglecting for the time being the auxiliary feed back

controlled amplifiers 6 and 7 and assuming that the ohmic values of resistors 3 and 5 are very small in comparison with the ohmic values of resistors 2 and 4, then the current I in resistor 3 (which, of course, is also the current in resistor 2) will be approximately equal to

$$\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

Thus, if a has a value of .715, the voltage across the resistor 3, assuming it to be a linear resistor, will vary as approximately the 3.5 power of the input voltage E. As this voltage across the resistor 3 is the input voltage of the next stage, it follows that the output voltage of any number of stages n will be proportional to

$$E^{\left(\frac{1}{1-a}\right)^n}$$

so that for the same value of a of .715 the output voltage of the second stage will be proportional to the 12.25 power of the input voltage E, the output voltage of the third stage will be proportional to the 44th power of E and the output voltage of the fourth stage will be proportional to the 153rd power of E. With a given input voltage the final output voltage decreases with the number of stages n and may be quite small; but nevertheless the small output voltage is proportional to

$$E^{\left(\frac{1}{1-a}\right)^n}$$

so that a small increase of E produces a large percent change in output voltage. For example with a=.3 the output voltage is proportional to $E^{(5)^3}$ or E^{125} with three stages. Then with a 1% increase in E the output voltage would be increased by a factor 1.01^{125} when 1.01 is the per unit value of input voltage corresponding to a 1% increase.

This amplifying effect can be further increased by making resistor 3 or resistor 5 or both of such material that its resistance increases as its current increases. For example, they can be tungsten lamp filaments or they can be iron hydrogen ballast resistors.

Considering now the action of the feed back controlled auxiliary amplifiers 6 and 7, assume that they have an amplification ratio of M. Assume further that Z is the total impedance of the first stage between the main input terminals exclusive of the resistance r of the resistor 2. Then the voltage drop in the resistor 2 which is equal to $CI^{(1-a)}$ plus the voltage drop in the impedance of the rest of the circuit (ZI) will be equal to E plus the output voltage of the auxiliary amplifier 6 which will be equal to its input voltage or RI, in which R is the resistance of resistor 3, times its ratio M or MRI. By collecting the terms in I this equation may be written in simplified form as

$$I^{(1-a)}-KI=\frac{E}{C}$$

in which K is

$$\left(\frac{MR-Z}{C}\right)$$

I have found that this circuit will produce the maximum possible percentage change amplification if K is equal to

$$\left(\frac{1-a}{I^a}\right)$$

It therefore follows that comparatively small values of Z and R are not necessary in order to have the optimum value of K. Another feature of the circuit is that the efficiency of percentage amplification is not dependent upon taking a small part of the current away from resistor 3 for the output or for a second stage.

Although two stages have been shown in Fig. 1 either one stage alone may be used or as many additional stages as desired may be added.

In Fig. 2 the feed back control amplifications 6 and 7 have been omitted from stages 1 and 2 so that there is straight resistance coupling between the stages 1 and 2 and also between stages 2 and 3. In addition an amplifier of any suitable type, such as a vacuum tube amplifier 8, has been inserted in the third stage so as to make up for the drop in voltage through the circuit. The output of the amplifier 8 is connected to another non-linear resistor amplifier stage consisting of non-linear resistor 9 and resistor 10, resistor 9 being similar to resistors 2 and 4.

The operation of Fig. 2 will be obvious from the previous description of Fig. 1.

In Fig. 3 the amplifier stages are coupled by voltage step-up autotransformers 11, 12 and 13 which take the place of the resistors 3, 5 and 10 of Fig. 2. Consequently, this circuit is only suitable for alternating current, whereas the circuits of Fig. 1 may be used with either alternating or direct current. By means of these step-up voltage transformers 11, 12 and 13 the output voltage of the system may have any desired absolute value.

In Fig. 4 the stages are coupled by high-speed high-gain dynamo-electric amplifiers 14, 15 and 16 of the type described and claimed in Edwards and Alexanderson Patent 2,237,992, granted January 7, 1941 and assigned to the assignee of the present application. These machines are known in the art as amplidynes and they are characterized by having their main excitation produced by cross armature reaction. They each have a control field winding 17, 18 and 19 whose axis is in line with the load brush axis of the armature combined with a pair of quadrature-related short-circuited brushes for permitting a heavy short-circuit current to flow in the armature and the armature reaction produced by this heavy quadrature circulating current provides the main excitation for the machines.

In the operation of this circuit the non-linear resistors 2, 4 and 9 cause the voltage across the control field windings 17, 18 and 19 to increase at a greater rate than the input voltage to their respective stages and the output voltages of the armatures of the machines 14, 15 and 16 being very much larger than the voltages across their control field windings will produce a further amplifying effect.

Obviously, it is not necessary to have as many amplidynes as there are stages and some of the stages may be straight resistance coupled or they may have feed back amplifiers as in Fig. 1.

In Fig. 5 an insulating transformer 20 is connected between the main input terminals and the first stage and another pair of input terminals 21 is connected to supply energy to the first stage through the non-linear resistor 2 and the primary winding of the voltage step-up transformer 11. This circuit is completed through resistors 22 and 23 which are in the circuits of the second and third stages respectively so that variations in voltage between the input terminals

21 will also be communicated to the second and third stages so as further to increase the amplification. Input terminals 1 may be considered those which receive a low power input control signal and input terminals 21 may be connected to a source of relatively large power or these terminals may be interchanged so that 21 receives the control signal and terminals 1 are energized by the source of control power or both may receive variable control signals.

In Fig. 6 three different control signals may be mixed by applying one of them to terminals 1 and the remaining two to terminals 23 and 24 respectively, which latter two terminals are in the second and third stages.

Fig. 7 is similar to Fig. 5 except that the resistors 22 and 23 have been omitted so that variations in voltage between input terminals 21 are only applied directly in the circuit of the first stage which includes the non-linear resistor 2.

While there have been shown and described particular embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications can 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 I claim as new and desire to secure by Letters Patent of the United States is:

1. In an amplifier system of the type having a source of variable voltage, a pair of output terminals, and means for impressing a voltage across said output terminals which varies when the voltage of said source varies but by a much greater percentage, the combination of an impedance connected in circuit with said source of variable voltage, said impedance having a non-linear volt-ampere characteristic expressed by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohmic impedance when carrying one ampere and a is less than 1, a linear impedance connected in series with said non-linear impedance, the value of said linear impedance being so much smaller than the value of said non-linear impedance that substantially all of the voltage of said source of variable voltage is across said non-linear impedance throughout the entire range of variation of said voltage, a second non-linear impedance similar to the first one, means for connecting said second non-linear impedance in a circuit whose voltage is proportional to the current in the said linear impedance, a second linear impedance connected in series with said second non-linear impedance, the value of said second linear impedance being so much smaller than the value of said second non-linear impedance that substantially all of the voltage of the first linear impedance is across said second non-linear impedance throughout the entire range of variation of said voltage, means for obtaining a voltage which is responsive to the current in said second linear impedance, and means for impressing said last-mentioned voltage across said output terminals.

2. A simple, rugged, fast, static, stable high percentage change amplifier comprising, in combination, a pair of input terminals, a pair of output terminals, a plurality of varistors whose volt-ampere characteristics are defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through them, E is the voltage across them, C their ohms with one ampere through them and a is between 0 and 1, means for connecting one of said varistors in a circuit across said input terminals, means including separate impedors in series with said varistors for developing separate voltages proportional to the current in each of said varistors respectively, said impedors having ohmic values which are very much smaller than the ohmic values of said varistors throughout the entire resistance variation range of the latter, and means for connecting said output terminals across the voltage developing means which is responsive to the current in another of said varistors, and means for connecting said other varistor in a circuit which is responsive to the voltage developing means which is associated with the varistor which is connected in circuit with said input terminals.

3. A multi-stage percentage change amplifier comprising, in combination, a pair of input terminals, a pair of resistors connected in series between said terminals, one of said resistors having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohms with one ampere through it, and a is more than 0 and less than 1, a second pair of resistors connected in series across the other resistor of the first pair, one of the resistors of the second pair also having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

and a pair of output terminals connected to be responsive to the voltage across the other of the resistors of the second pair, said other resistors being linear and having ohmic values which are very much less than the ohmic values of said non-linear resistors throughout the entire resistance variation range of the latter.

4. A multi-stage percentage change amplifier comprising, in combination, a pair of input terminals, a pair of resistors connected in series between said terminals, one of said resistors having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohms with one ampere through it, and a is more than 0 and less than 1, a second pair of resistors connected in series across the other resistor of the first pair, one of the resistors of the second pair also having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

and a pair of output terminals connected to be

responsive to the voltage across the other of the resistors of the second pair, said other resistors having ohmic values which are very much less than the ohmic values of said non-linear resistors throughout the entire resistance variation range of the latter, at least one of said other resistors having a positive resistance current characteristic.

5. A multi-stage percentage change amplifier comprising, in combination, a pair of input terminals, a pair of resistors connected in series between said terminals, one of said resistors having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohms with one ampere through it, and a is more than 0 and less than 1, the value of the other of said resistors being so much smaller than the value of said non-linear resistor that substantially all of the voltage between said input terminals is across said non-linear resistor throughout the entire range of variation of said voltage, a second pair of resistors connected in series across the other resistor of the first pair, one of the resistors of the second pair also having a non-linear volt-ampere characteristic which is defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

the value of the other resistor of the second pair of resistors being so much smaller than the value of the non-linear resistor of the second pair that substantially all of the voltage across the other resistor of the first pair is across the non-linear resistor of the second pair, a pair of output terminals connected to be responsive to the voltage across the other of the resistors of the second pair, and means for boosting the voltage across said output terminals.

6. A multi-stage non-linear amplifier comprising, in combination, a plurality of voltage step-up transformers in which the primary winding of each one except the first is connected in circuit with the secondary winding of a different one, an equal number of resistors each having a volt-ampere characteristic defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohms at one ampere and a is more than 0 and less than 1, said resistors being connected respectively in series circuit relation with the secondary windings of all but the last of said transformers, and a pair of output terminals connected to the secondary winding of the last transformer.

7. A percentage change amplifying system comprising, in combination, a pair of main amplifier input terminals, a pair of resistors, an auxiliary linear amplifier having an amplification ratio M, said resistors and the output of said auxiliary amplifier being connected in series between said main input terminals, one of said resistors having a current dependent ohmic value equal to CI^{-a} where C is its ohms at one ampere through it, I is the amperes through it and a is greater than 0 and less than 1, the other of said resistors having a substantially constant ohmic value R, and a pair of main amplifier output terminals, said main amplifier output terminals and the input of said auxiliary amplifier being connected to respond to the voltage drop across said other resistor, the total impedance between said main amplifier input terminals exclusive of said current dependent resistance being Z,

$$\frac{MR-Z}{C}$$

being substantially equal to

$$\frac{1-a}{I^a}$$

8. In combination, a pair of input terminals, a pair of output terminals, a plurality of non-linear resistors which have a volt-ampere characteristic defined by the equation

$$I=\left(\frac{E}{C}\right)^{\frac{1}{1-a}}$$

where I is the amperes through it, E is the volts across it, C is its ohms with one ampere through it and a is more than 0 and less than 1, and means including a plurality of linear resistors whose ohmic values are very much smaller than the ohmic values of said non-linear resistors throughout the entire resistance variation range of the latter for connecting said non-linear resistors between said pairs of terminals in cascade circuit relationship so that the voltage across the pair of output terminals will vary as the

$$\left(\frac{1}{1-a}\right)^n$$

power of the per unit value of the voltage across the pair of input terminals where n is the number of cascaded steps.

9. An amplifier having a stage comprising, an input circuit and an output circuit, an amplidyne generator having an armature connected in said output circuit, a non-linear resistor having an ohmic value equal to CI^{-a} where C is its ohms at one ampere through it, I is the amperes through it and a is greater than zero and less than 1, and a control field winding for said amplidyne generator, said resistor and control field winding being connected in series circuit relation in said input circuit, the resistance of said control field winding being so much smaller than the resistance of said non-linear resistor that substantially all the voltage of the input circuit is across said non-linear resistor.

10. An amplifier having a stage comprising, an input circuit and an output circuit, an amplidyne generator having an armature connected in said output circuit and a control field winding connected in said input circuit, and a non-linear resistor whose ohmic value decreases with increases in current through it connected in said input circuit, the resistance of said non-linear resistor throughout its range of variation being such that substantially all of the input circuit voltage is across it.

11. An electric translating system comprising, an input circuit and an output circuit, an amplidyne generator having an armature connected in said output circuit and a control field winding connected in said input circuit, a non-linear resistor connected in said input circuit, the minimum operating resistance of said non-linear resistor throughout the range of operation of said translating system being such that substantially all of the input circuit voltage is across it.

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