Jan. 5, 1943. E. M. SORENSEN 2,307,308

DEGENERATIVE EXPANDER-COMPRESSOR CIRCUIT

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FIG. 1

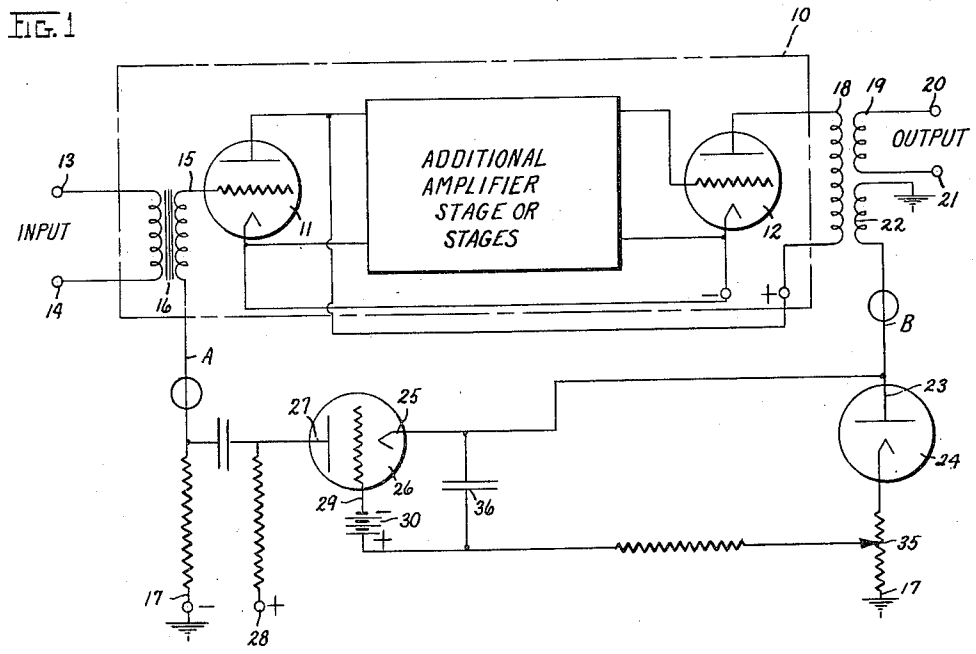
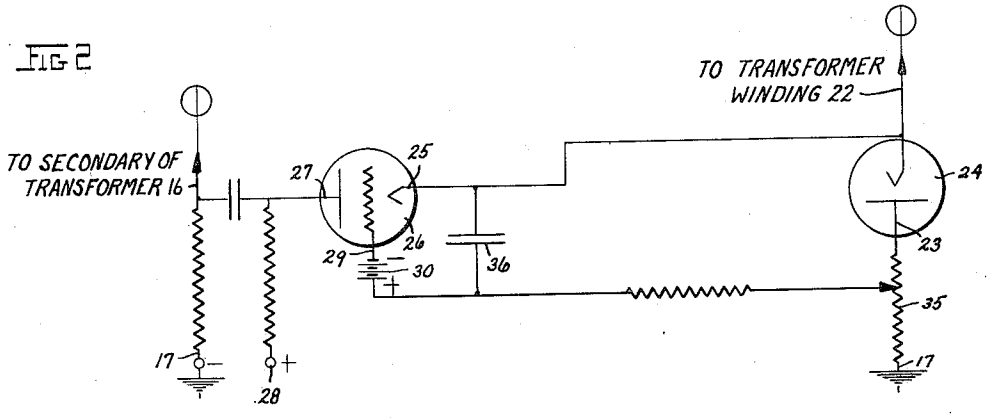


FIG 2



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FIG. 3

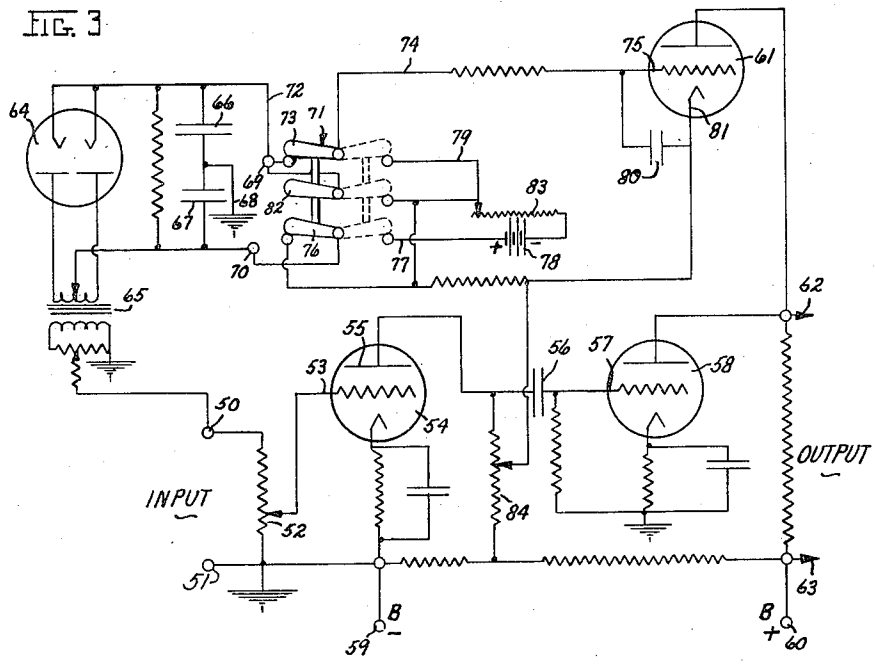


FIG. 4

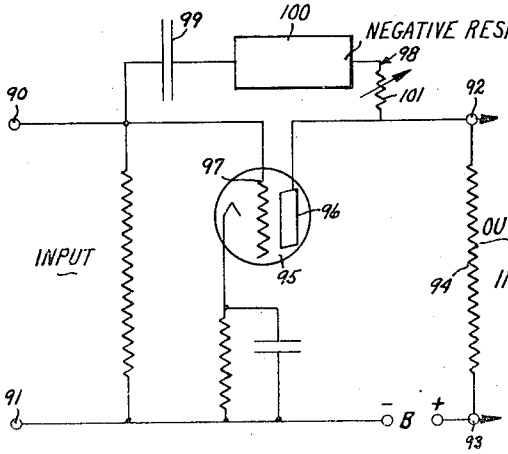
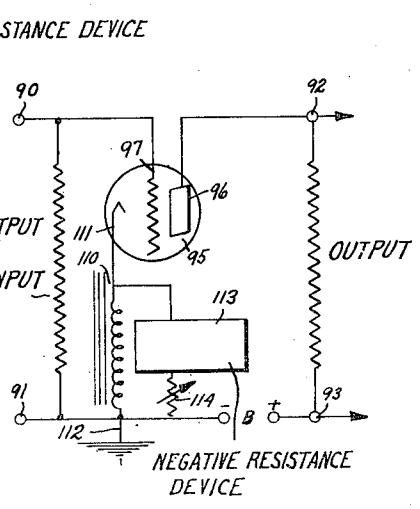


FIG. 5



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DEGENERATIVE EXPANDER-COMPRESSOR CIRCUIT

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Application August 2, 1940, Serial No. 349,863

6 Claims. (Cl. 179—171)

This invention relates broadly to degenerative circuits, and in particular to circuits for providing expansion or compression of an alternating current voltage in a non-linear manner. Compression circuits are quite frequently used in connection with radio broadcasting and phonograph recording, and expansion circuits are useful in connection with amplifiers or phonograph reproducers for restoring the audio tone to its original quality before it is compressed in the broadcasting station apparatus, or in the phonograph recording apparatus.

Another application of the compression circuit which finds a great number of uses is for limiting the audio tone to a sharp cut-off at a given decibel quantity. An illustration of this use is as a volume-limiting control for a radio loud speaker.

Circuits heretofore used for compression and expansion have been subject, among other disadvantages, to an undue amount of distortion, and also have not been capable of controlling the expansion or compression over a wide range of input signal voltage and/or frequency variation. It is therefore an object of my invention to provide a novel degenerative circuit which will provide compression over a wide range of input signal variation, and a wide range of expansion, while limiting distortion to an exceedingly small amount. With my novel circuit, expansion and compression can be provided to an extent which is limited only by the gain of the amplifier without distortion within itself.

It is another object of my invention to provide degeneration control through the use of an element whose resistance progressively decreases with an increase in applied voltage. Such resistance may be termed a "negative" resistance and can be obtained in several ways, as for instance, by the use of a vacuum tube with its grid and plate circuit connected to a common voltage source; by the use of a material which rectifies, such as galena, pyrite, carborundum or copper oxide. One material of exceptional importance in this connection is "thyrite," disclosed in Patent No. 1,822,742 issued to Karl B. McEachron on September 8, 1931. The resistance of this material changes as a hyperbolic function with respect to the amount of voltage applied.

Many other objects, advantages and applications of my invention will be apparent from the following description and the accompanying drawings.

In the drawings:

Figure 1 shows a basic circuit, illustrating my invention as used for compression.

Figure 2 is a part of the circuit shown in Figure 1, as rearranged to provide expansion.

Figure 3 is a combined expansion and compression circuit with a double-throw switch shown in position for providing compression, and in dotted position for providing expansion, and further differing from Figure 1 in the circuit connections to the amplifier.

Figure 4 is a basic circuit illustrating the use of a negative resistance material, such as "thyrite," for compression.

Figure 5 is a circuit similar to Figure 4, but arranged for expansion.

It will be seen from the drawings that the invention, in principle, contemplates the connection of a circuit between two points in an amplifying circuit, which points have a phase difference of approximately 180 degrees, and providing in said circuit a resistance which decreases at a greater rate than the voltage increases. Such resistance is provided in one variation by means of a vacuum tube having a grid controlled by some of the rectified audio voltage. In this way the resistance of the vacuum tube is varied by changing the bias on the grid, and the bias on the grid is proportioned to the increase or decrease in the audio signal. By changing the polarity of the rectifier, the bias on the grid can be made more positive as the audio signal increases, thereby enabling a greater amount of degeneration to provide compression, or the bias on the grid can be made more negative as the audio signal increases, decreasing the amount of degeneration to thereby provide expansion of the audio signal. In lieu of the vacuum tube circuit, one of the negative resistance materials discussed above may be used.

It will be understood that the connection of the circuit to the amplifier at points of opposite voltage phase may be made by connecting across the plate and grid of a vacuum tube, or across any odd number of amplification stages. Also, that a transformer reverses the voltage phase and must be counted as a stage of amplification for this purpose.

Referring to the drawings, Figure 1 shows an elementary form of an application of the invention. In the drawings there is shown schematically an audio amplifier 10 which may comprise one or more stages of amplification, and as illustrated, shows a two-stage amplification by means of the tubes 11 and 12. The alternating voltage input between the points 13 and 14 is coupled

to the grid 15 by means of the transformer 16. The voltage between the points 15 and 17 is 180 degrees out of phase with the input signal, due to the well known action of the transformer. The audio signal is successively passed through the amplifier until it is present in the primary winding 18 at the output of the amplifier. The secondary winding 19 is coupled to the primary winding, and provides the output signal at points 20 and 21 for operating the loud speaker or other apparatus. A secondary winding 22 is also coupled to the primary 18 and connects to the plate 23 of the diode rectifier 24. The voltage of the alternating current, in passing through the audio amplifier to the secondary winding 22, has been successively reversed until the voltage between the winding 22 and ground 17 is 180 degrees out of phase with the voltage between the grid 15 and ground 17. The signal on the secondary 22 is also supplied to the cathode 25 of tube 26. Tube 26 functions as a variable resistance and not as an amplifying tube. There is no phase reversal of the voltage in passing through this tube. The plate 27 is supplied with current from potential source 28. It will thus be seen that there is a direct current circuit from potential 28, through tube 26, tube 24 to ground 17. There is also a pulsating direct current from the secondary 22, through tube 26 to the secondary of the transformer 16, but this current is 180 degrees out of phase with the voltage on the secondary of transformer 16.

Grid 29 of tube 26 is provided with a steady negative bias by battery 30, the biasing current flowing through the winding 22 to ground. There is further impressed on the grid a rectified pulsating voltage from rectifier 24. It will therefore be seen that on the plus cycles of the alternating current in the circuit from winding 22 to the secondary of the transformer 16, that the bias on grid 29 will be made less negative and the flow of current through the tube will be facilitated, and also that as the voltage present on secondary 22 increases, an increased voltage of opposite phase relation will be impressed upon the secondary of transformer 16, thereby cancelling out a quantity of the signal voltage being applied across points 13 and 14. In this way the circuit serves to maintain approximately constant the output of the amplifier, regardless of variation in the input signal voltage. Variable resistor 35, connected in the cathode circuit of diode tube 24, is used to provide adjustment for the amount of compression which is desired to be obtained, which follows as the amount of voltage being applied to grid 29 is controlled thereby. Condenser 36 serves as a filter condenser to filter out any alternating current component from the voltage being applied to the grid 29.

The foregoing circuit provides a control for single-sided amplifiers. The circuit can be adapted to function on push-pull arrangements by the addition of duplicate equipment.

The same circuit, with a few modifications, is used to expand the audio signal being applied to points 13 and 14. Such a modified circuit is shown in Figure 2. A and B designate the points in Figure 1 where the circuit of Figure 2 is connected in Figure 1. It will be seen that the only difference is that the cathode and anode connections of diode rectifier tube 24 are reversed. Since the diode tube is now reversed, it provides a negative polarity connection to grid 29 and functions to increase the negative bias applied to the grid 29 as the voltage on secondary winding 22 increases. In this manner, the amount of voltage which is normally being fed back to the secondary winding of transformer 16 out of phase with the voltage present thereon from the transformer is reduced as the signal voltage increases, thereby enabling expansion of the received signal.

The circuit shown in Figure 3 is a combination arrangement of circuits for providing either expansion or compression. The circuit further differs from the circuit described in Figure 1, among other things, in that a part of the input signal voltage is rectified and employed to control the grid of the tube in the circuit connecting the output voltage back to the input side of the second stage of the amplifier, in order to control the expansion or compression.

Referring to the drawings, the input terminals 50 and 51 are connected through variable resistor 52, which serves as the volume control to the grid 53 of vacuum tube 54 constituting the first stage of the amplifier. The plate 55 of tube 54 is connected through condenser 56 to the grid 57 of the tube 58, constituting the second stage of the amplifier. Battery terminals 59 and 60 provide the plate current for tubes 54 and 58 and tube 61, which corresponds in this circuit to tube 26 in Figure 1. The output voltage is taken off at terminals 62 and 63. Rectifying tube 64 is connected to input terminal 50 through transformer 65, the latter serving to isolate the voltage in the circuit of tube 64 above ground. Then, by means of the condensers 66 and 67 connected across the plate and cathode circuits of tube 64 with a ground connection 68 intermediate the condensers 66 and 67, voltage at terminal 69 connected to the cathode of vacuum tube 64 is made positive with respect to ground, and voltage at terminal 70 connected to the plate circuit of vacuum tube 64 is negative with respect to ground. By means of a three-pole, double-throw switch 71 the positive terminal 69 is connected through conductor 72, arm 73 and conductor 74 to the grid 75 of tube 61, in the full-line position shown. In the dotted-line position the negative terminal 70 is connected to the grid 75 of tube 61 through arm 76, conductor 77, battery 78, conductor 79, arm 73 and conductor 74. In the full-line position of switch 71, negative terminal 70 is connected to the cathode 81, through arm 76 and suitable conductors; and in the dotted-line position, plus terminal 69 is connected to the cathode 81, through arm 82 and a suitable conductor network. Condenser 80, connected across the grid 75 and cathode 81 of tube 61, serves as a filter condenser in the same manner as condenser 36 in Figure 1. Variable resistor 83 across battery 78 enables adjustment of the fixed negative bias.

It will thus be seen that in operation there is a direct current flowing from battery terminal 60, through tube 61, variable resistor 84 connected to the cathode of tube 61, and back to the negative battery terminal 59. There is also the alternating current of the amplified signal voltage flowing through the tube 61 from output terminal 62, through a portion of the variable resistor 84 to the circuit of grid 57 of the second amplifying tube. In this connection, it should be noted that the signal voltage on grid 57 is 180 degrees out of phase with the input signal voltage being applied to grid 53, and that again the output voltage in the plate circuit of tube 58, which is commonly connected to the plate circuit of tube 61, is 180 degrees out of phase with the

signal voltage being applied to grid 57. There is no change in tube 61. It will therefore be seen that the alternating current voltage passing through tube 61 to grid 57 is 180 degrees out of phase with the signal voltage coming from plate 55 of tube 54, and that on the positive cycles the flow of the alternating current voltage through tube 61 will be facilitated by the action of grid 75, and that as the output of tube 58 tends to increase the amount of voltage passed by tube 61 of opposite phase to that being impressed on grid 57 by tube 54 increases, thereby nullifying the increase in output of tube 58 which would otherwise take place, and providing the compression desired. On the other hand, when the three-pole switch 71 is thrown to the dotted position, putting bias battery 78 and the negative terminal of tube 64 in the grid circuit of tube 61, the grid 75 is made more negative, thereby reducing the amount of alternating current flowing through tube 61, and as the output voltage of tube 58 tends to increase the amount of voltage being fed to the grid 57 of tube 58 from tube 61, and out of phase with the voltage on grid 57 from tube 54, is decreased, thereby providing the desired expansion.

Variable resistor 83 across battery 78 serves to set the threshold level for expansion. By the term "threshold level" is meant that initial point at which the expansion is made operative. Variable resistor 84 corresponds to variable resistor 35 in Figure 1, and may be adjusted to control the amount of degeneration being applied to grid 57 of tube 58. For expansion a greater amount of degeneration will be initially applied to the grid, so that it may be reduced as the audio signal increases, and for compression a less amount of degeneration will be applied initially, so that the tube 61 may supply more as the signal increases.

In Figure 4 is shown a basic amplifying circuit having input terminals 90 and 91, output terminals 92 and 93 having a resistor 94 between them, and a vacuum tube 95 arranged as an amplifier. Connected across plate 96 and grid 97 of the vacuum tube is a circuit 98 having a condenser 99 in series with a piece of "thyrite" 100 as a non-linear or negative resistance. Because of the special property of "thyrite" to conduct a current which increases in value out of proportion to an increase in voltage applied, it will be seen that as the current in plate 96 increases, a current increases in circuit 98 out of proportion to the plate circuit current. Since the current in plate circuit 96 is 180 degrees out of phase with that of the input signal on grid 97, the current conducted by circuit 98 opposes the incoming signal in a manner corresponding to the amplification factor of tube 95, thereby causing the voltage between the output terminals 92 and 93 to remain approximately constant, regardless of variation in input signal over a wide range and above a threshold or predetermined value. By way of example, this may be explained as follows: Assume that the amplifier tube 95 has a gain of 10. The voltage between input terminals 90 and 91 may vary from one-tenth to one volt, but the voltage across resistor 94 will remain approximately constant at one volt. The threshold level at which this circuit operates may be controlled by variable resistor 101 in series with the "thyrite" and condenser. It should be pointed out that the condenser 99 is not necessary in more than one stage of amplification, as the "thyrite" may be connected directly between the plate circuit of one stage and the plate circuit of the preceding stage. It may also be connected in a push-pull amplifier circuit in the same manner.

In Figure 5 is shown an amplifying circuit similar to that of Figure 4, but with the "thyrite" arranged to provide expansion. In this figure there is provided an inductor 110 in series with cathode 111 of vacuum tube 95, and connected to ground at 112. Connected in shunt across the inductor is a piece of "thyrite" 113. The inductor builds up a voltage 180 degrees out of phase with the signal voltage being applied to grid 97, thereby opposing the input signal voltage. The inductor introduces degeneration to this extent, and lowers the normal gain of the tube 95. The "thyrite" being in shunt connection with the inductor serves to limit the amount of voltage that can be present across inductor 110. By way of illustration, assume that this value is set at 5 volts. If the "thyrite" were not across the inductor and the input voltage across terminals 90 and 91 were increased, the voltage across inductor 110 would increase in the same ratio, causing degeneration in the same ratio, merely resulting in linear amplification. With the presence of "thyrite" across inductor 110, as the voltage across terminals 90 and 91 is increased, the potential across inductor 110 is not increased, since the "thyrite" shunts this voltage, due to its property noted above. In this way, the degenerative effect of inductor 110 is held to a given value or reduced, and non-linear amplification of an expanding quality is obtained. The "thyrite" also serves to aid this result, not only by limiting the degenerative effect of the inductor 110 but also by decreasing the bias in the cathode-grid circuit. The threshold level at which expansion takes place may be controlled by variable resistor 114 in series with the "thyrite."

It will be understood that in lieu of "thyrite" any of the negative resistance materials discussed, or any other circuit providing a resistance of such quality, may be used, "thyrite" being illustrative of a preferred modification because of the variations in its qualities which can be obtained by different compositions and processes of manufacture.

It is to be further understood that the terms used and circuits illustrated are descriptive only, and that my invention includes such variations and equivalents as may be included within the scope of the appended claims.

Having thus fully described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said circuit including a rectifier and a resistance means controlled thereby whose resistance progressively varies with a change in the voltage applied to it, said rectifier receiving energy directly from said amplifying circuit, said resistance means and rectifier being arranged in said circuit so as to vary the amount of voltage being applied by said circuit to said point in response to a varying input signal, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the resistance for controlling purposes.

2. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said cir-

cuit including a grid controlled vacuum tube serving as a variable resistance, a second circuit including a rectifier receiving energy directly from said amplifying circuit and feeding rectified energy directly to the grid of said vacuum tube so as to vary the negative bias of said grid as the signal applied to said amplifier varies, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the vacuum tube for controlling purposes.

3. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said circuit including a rectifier and a resistance means controlled thereby, whose resistance progressively increases with an increase in the voltage applied to it, said rectifier receiving energy directly from said amplifying circuit, said resistance means and rectifier being arranged in said circuit so as to increase the amount of voltage being applied by said circuit to said point in response to an increase of the input signal, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the resistance for controlling purposes.

4. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said circuit including a rectifier and a resistance means controlled thereby whose resistance progressively decreases with a decrease in the voltage applied to it, said rectifier receiving energy directly from said amplifying circuit, said resistance means and rectifier being arranged in said circuit so as to decrease the amount of voltage being applied by said circuit to said point in response to an increase of the input signal, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the resistance for controlling purposes.

5. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said circuit including a grid controlled vacuum tube serving as a variable resistance, a second circuit including a rectifier receiving energy directly from said amplifying circuit and feeding rectified energy directly to the grid of said vacuum tube so as to decrease the negative bias of said grid as the signal applied to said amplifier decreases, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the vacuum tube for controlling purposes.

6. In an amplifying circuit, a circuit having one end connected at a point of amplified voltage and the other end to a point of opposite voltage phase in the amplifying circuit, said circuit including a grid controlled vacuum tube serving as a variable resistance, a second circuit including a rectifier receiving energy directly from said amplifying circuit and feeding rectified energy directly to the grid of said vacuum tube so as to increase the negative bias of said grid as the signal applied to said amplifier increases, whereby a portion of the energy derived from the amplifier output circuit is rectified and fed to the vacuum tube for controlling purposes.

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