Oct. 17, 1944. J. A. RANKIN 2,360,794

REGENERATION STABILIZATION CIRCUIT

Filed March 12, 1942

Fig. 1.

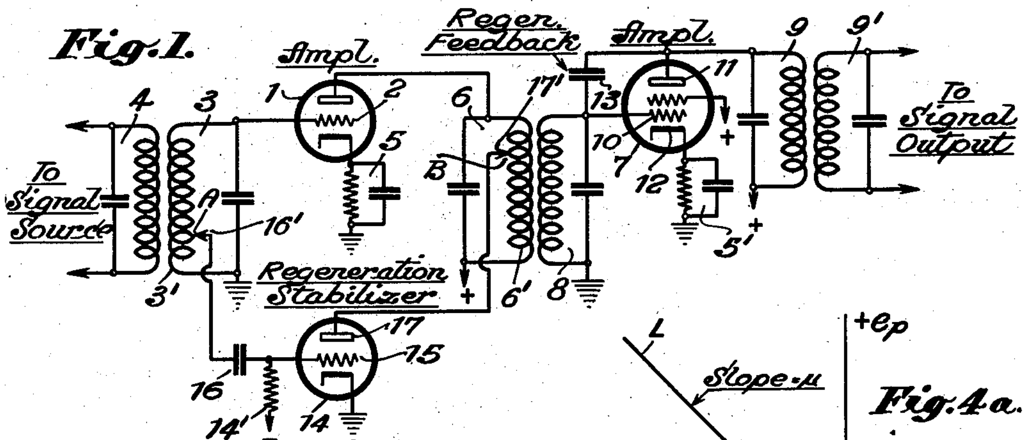


Fig. 4a.

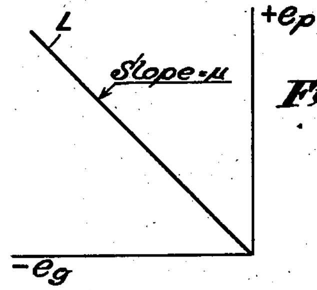


Fig. 2.

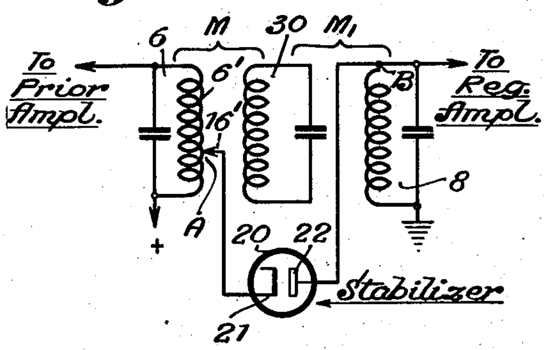


Fig. 4b.

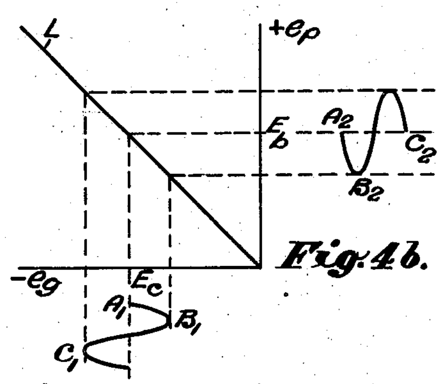


Fig. 3.

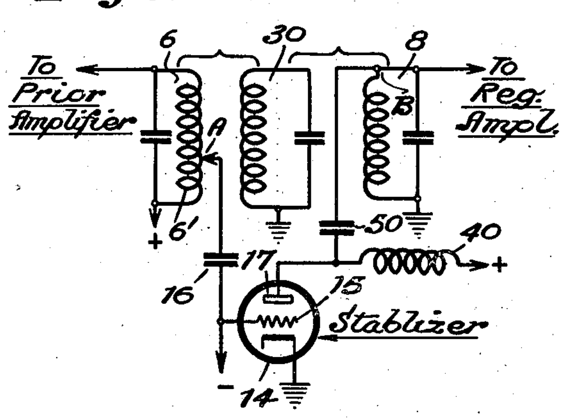
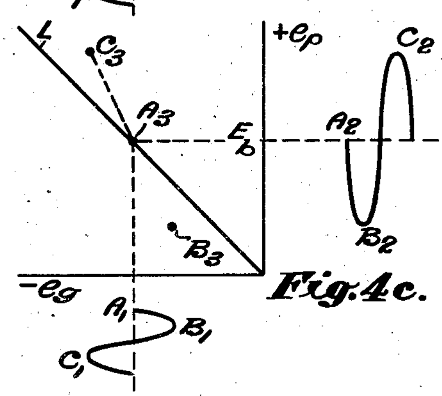


Fig. 4c.



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REGENERATION STABILIZATION CIRCUIT

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14 Claims. (Cl. 179—171)

My present invention relates to regenerative signal transmission circuits, and more particularly to a novel and improved method and means for stabilizing regeneration.

One of the main objects of my present invention is to provide in a signal transmission system employing a regenerative circuit, a regeneration stabilizer network which automatically functions to increase the damping of the regenerative circuit upon increase of regeneration above a predetermined and desired magnitude.

Another important object of my invention is to provide in conjunction with a plurality of cascaded resonant circuits, all tuned to a common signal frequency, a means for regenerating the last of the circuits, and additional means which is responsive to an undesired increase of regeneration for automatically damping the regenerated resonant circuit.

Still another important object of my invention is to provide in combination with a regenerative signal amplifier, a regeneration stabilizer circuit which includes an electron discharge device whose input and output electrodes are connected between a prior point of the amplifier system and the regenerative circuit respectively, the stabilizer device normally being non-conductive, and the stabilizer device providing a flow of damping current for the regenerative input circuit upon an undesired increase of regeneration.

Still other objects of my invention are to improve generally the simplicity and efficiency of regenerative high frequency circuits, and more particularly to provide a stabilizer network for regenerative amplifier circuits which is not only reliable and efficient in operation, but is economically manufactured and assembled.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows an embodiment of the invention,

Figs. 2 and 3 illustrate alternative modifications,

Figs. 4a, 4b and 4c graphically illustrate the operation of the invention.

Referring, now, to the accompanying drawing, wherein like reference characters in the different figures designate similar circuit elements, there is shown in Fig. 1 a pair of cascaded high frequency amplifier tubes. Amplifier tube 1 has its control grid 2 connected to the high potential side of a tuned input circuit 3. The latter may be coupled to the tuned circuit 4. Assuming that the amplifier 1 is in the intermediate frequency (I. F.) network of a superheterodyne receiver, then the circuits 4—3 would each be tuned to the operating I. F. value. The latter may be chosen to be 455 kilocycles (kc.) if the receiver is adapted to operate in the broadcast range of 550 to 1700 kc. The usual signal wave collector, converter and subsequent I. F. stages may precede the circuit 4. Of course, the invention is equally applicable to other frequency ranges, either below 550 kc. or above 1700 kc. Furthermore, the amplifiers may be in a wave transmission system other than a receiver. Indeed, the invention is applicable to any system wherein regeneration of high frequency currents is desired to be stabilized.

The cathode of tube 1 may be connected to ground through the usual self-biasing network 5. The tuned circuit 6 is arranged in the plate circuit of tube 1, and is resonated to the frequency of input circuit 3. The following amplifier tube 7 is the regenerative amplifier. Its input circuit 8 is coupled to circuit 6, and the two are tuned to the common operating frequency of all the resonant circuits. The self-biasing network 5′ connects the cathode 12 of amplifier tube 7 to ground. The input circuit 8 is connected between the grid 10 and ground. The plate 11 has the tuned output circuit 9 connected thereto. The tuned circuit 9′ may feed the amplified high frequency energy to any desired type of utilization network.

The circuits 4—3—6—8—9—9′ are each tuned to the operating input frequency; in the assumed example this would be the I. F. value. Regeneration in amplifier 7 is provided by capacity 13 between the plate 11 and grid 10. The capacity 13 may be an actual physical condenser outside the tube, or it may even be provided by the inherent capacity within the tube between grid 10 and plate 11.

An example of a stabilizing means, in accordance with my present invention, is shown in Fig. 1. The tube 14 has its grid 15 coupled by condenser 16 to a point on the coil 3′ of the input circuit 3 of tube 1. The tap 16′ may be provided so as to adjust the point on coil 3′ to which the grid 15 is to be connected. The cathode of tube

14 is grounded; while the plate 17 is connected by an adjustable tap to coil 6' of output circuit 6 of tube 2. The grid 15 of stabilizer tube 14 may be biased negatively through resistor 14' from any negative voltage source. It will be seen that the plates of tubes 14 and 1 are provided with positive potential through the common coil 6'.

To explain the operation of the invention, there will first be considered the regenerative action taking place in the stage including tube 7. In that stage, as condenser 13 is increased in value of capacity from zero there occurs an increased reflection of negative resistance between grid 10 and cathode 12. This raises the "Q" of the input circuit 8. Even though the circuit 8 be made to oscillate by virtue of the increased value of capacity 13, there will be no relative change in the voltage applied to the grid-cathode circuit when this voltage is compared to the plate-cathode voltage. In other words, the gain of tube 7 is constant, unless, of course, the operating conditions, such as grid bias, screen voltage etc., are changed due to oscillation. However, the regenerative process does increase the gain of the overall amplifier, as is well known. Considering the overall amplifier circuit of Fig. 1, as the value of C_{13} is increased the gain between grid 2 and circuit 9 will increase. That is, the ratio of the output voltage across circuit 9 to the voltage across circuit 3 will increase as C_{13} increases. This means that the negative resistance, due to regeneration, between grid 10 and cathode 12 has increased the Q of input circuit 8, and that the gain of the coupled tuned circuits 6—8 is increased. Likewise, the gain from grid 2 to either of circuits 6 or 8 will be increased.

The tube 14 and its associated circuits is provided to maintain the gain between any two points of the amplifier system constant. This is done by introducing damping when the gain between the said two points increases above a predetermined value. The two points in Fig. 1 are the points where the taps 16' and 17' are set. The points are designated as A and B respectively. The manner in which the stabilizing circuit acts to stabilize the regenerative process will now be explained, special reference being made to Figs. 4*a*, 4*b* and 4*c*.

Assume that the regenerative tube 7 has been adjusted to provide regeneration of a predetermined magnitude by virtue of the proper adjustment of condenser 13. The grid 15 of the stabilizing tube 14 is connected to a suitable point A on coil 3'. The grid 15 is biased negatively to an extent such as to be sufficient to produce plate current cut-off of tube 14. The tube 14 may be a triode of a given mu. The points A and B are so chosen that the gain between these two points is mu. The $E_g—E_p$ characteristic of the stabilizer tube 14 is shown in Fig. 4*a*. The line L is drawn with a slope of mu.

Considering, now, Fig. 4*b*, a value of $e_p—E_b$ is selected. This is the exact value of the plate operating voltage of tubes 1 and 14. The bias for the control grid 2 is then fixed by this value of E_b and will be equal to a value of E_c. This value of E_c is sufficient to exactly produce plate current cut-off and is equal to E_b/mu. As signal energy is applied to the input circuit 3 the grid 15 of tube 14 will have applied to it from input circuit 3 a given amount of input signal. Similarly a signal will be applied to the plate 17 from the output circuit 6 of tube 1. The grid voltage at grid 15 is represented by the wave $A_1—B_1—C_1$, and the plate wave is represented as $A_2—B_2—C_2$. These two wave amplitudes are in the ratio of mu, and due to the phase reversal in tube 1 are out of phase as shown. As long as the high frequency voltage applied to the grid 15 and plate 17 of tube 14 remain in the ratio of mu, then no plate current will flow in tube 14. This will be understood by following the two waves from A to B to C, and noting that the projection of each wave at each point intersects the line L.

Referring, now, to Fig. 4*c*, the condition is represented in which the gain between selected points A and B has increased above that for stability, and this increase is due to an increase in regeneration or some factor that affects the regenerator tube. In this diagram the plate voltage is greater by mu times the grid voltage applied to tube 14. If we now follow the wave through its various points, it will be seen that at point A_1 no plate current flows due to the fact that the projections of the grid voltage wave and the projections of the plate wave intersect on line L which has a slope equal to mu. At point B_1 the projections intersect at point B_3 which is below the line L. In this region the tube 14 is beyond plate current cut-off, and, hence, plate current cannot flow. However, the projection of point C_1 of the grid voltage wave and point C_2 of the plate voltage wave intersect at point C_3 which is above the line L. Hence, plate current will flow in tube 14. The plate current will flow over the half cycle in which the plate voltage is positive. The fact that plate current flows will damp the circuit across which the plate is connected, and tend to lower its impedance and hence counteract the increased regeneration.

In the circuit shown in Fig. 1, the circuit 6 will also be damped if the gain between the grid and plate of tube 14 should fall below the mu of the tube. Hence, for satisfactory operation, the grid 15 should be connected to a point such that the gain between the grid and plate of tube 14 is slightly higher than mu. The tube 14 adds a capacity between the grid and plate of tube 1 that would have to be neutralized for satisfactory operation. Tube 1 is normally biased, and the bias is fixed. It is only tube 14 which is biased to cut-off as long as regeneration of tube 7 is below the predetermined magnitude. The stabilizer tube 14 has its grid and plate alternating voltages so chosen as to be in balance thereby to prevent plate current flow. When the plate current of tube 14 flows, the damping of circuit 6 will in turn affect the damping of circuit 8.

In Fig. 2 there is shown a simplified form of the invention possessing certain advantages. In place of the triode stabilizer tube 14 there is utilized a diode 20. The cathode 21 of the latter is connected by the tap 16' to a point on the coil 6' of the output circuit 6 of the amplifier tube 1. The anode 22 of the diode 20 is connected to the high potential side of the input circuit 8 of the regenerative amplifier 7. A link coupling circuit 30, which is tuned to the operating signal frequency, is positioned between circuits 6 and 8. In other words, the three circuits 6, 30 and 8 are each tuned to the same transmitted frequency; circuits 6 and 30 are magnetically coupled at M, and circuits 30 and 8 are magnetically coupled as at M_1. It will, therefore, be seen that points A and B in Fig. 2 are located respectively at the output circuit of amplifier 1 and the input circuit of the regenerative amplifier. Hence, it will be seen that the invention is not limited to providing the stabilizing circuit between the input and output circuits of the amplifier preceding the regenerative amplifier, but that the stabilizing circuit may be provided between the coupled tuned circuits between amplifier tubes 1 and 7.

The diode 20 is connected across the input and output circuits of a transformer network 6—30—8. The transformer is so arranged that points A and B are in phase, and the gain between points A and B is equal to, or slightly greater than, unity with the desired amount of regeneration effective in tube 7. If the regeneration at tube 7 increases for any cause, the gain between points A and B will likewise increase, but the diode will then draw current and damp the input circuit 8 of the regenerative amplifier thereby to prevent the gain from rising. This results in stabilization of the regenerative amplifier.

The diode 20 may be replaced by a low mu triode of the type shown at 14 of Fig. 1. In this case the circuit would have to be arranged so that points A and B are out of phase and separated by a gain of mu, or slightly more than mu. The circuit shown in Fig. 3 is similar to that shown in Fig. 2 with the exception that the tube 14 of Fig. 1 replaces the diode 20. This circuit is preferred and has the advantage over that shown in Fig. 1 in that only passive circuit elements appear between the two points A and B at which the stabilizing tube is connected. As shown in Fig. 3 the condenser 16 couples the grid 15 to point A. The cut-off bias is applied to grid 15, and the plate 17 is connected to a source of positive potential through the radio frequency choke coil 40. The point B of circuit 8 is connected to the plate 17 by the direct current blocking condenser 50. The points A and B in Fig. 3 are arranged to be 180 degrees out of phase. These points have a voltage difference of mu times, or slightly greater than mu. In this case the tube 14 will damp circuit 8 if the gain between points A and B increases due to any increase in regeneration.

It will now be seen that I have provided various regeneration stabilizing circuits which have in common certain generic structures and functions. From a generic viewpoint, an amplifier system embodying a regenerative amplifier has arranged between the regenerative input circuit and a point of the amplifier system spaced therefrom, an electron discharge device which has input and output electrodes connected to the respective points. The electron discharge device normally is non-conductive as long as the regenerative amplifier produces a predetermined amount of regeneration. However, upon an increase in regeneration the aforesaid electron discharge tube becomes conductive, and permits current to flow through the regenerative amplifier input circuit thereby increasing its damping to an extent sufficient to counteract the undesired increase in regeneration. The electron discharge device may be of any desired type, and the input and output electrodes thereof have high frequency voltage applied thereto from the aforementioned spaced points.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In a wave transmission system of the type comprising a resonant wave input circuit and a succeeding resonant circuit, the method which includes tuning the resonant circuits to a common wave frequency, regenerating the succeeding circuit to a predetermined condition of regeneration, establishing a normally non-conductive direct current path between said input circuit and said succeeding regenerative circuit, applying wave voltage to the input and output points of said path, and introducing damping into said regenerated resonant circuit from said path by virtue of said path becoming conductive for direct current in response to an increase in regeneration of said succeeding circuit above said predetermined point.

2. In combination with a high frequency amplifier tube having regenerative coupling between its output and input electrodes, a resonant circuit coupled between the input electrodes of said amplifier tube, a wave input circuit preceding said amplifier input circuit and separated therefrom by at least one intervening resonant circuit, means for preventing an increase in regeneration of said amplifier above a predetermined magnitude, said means comprising an electron discharge device having an input electrode coupled to a point on said wave input circuit and an output electrode coupled to a point on said amplifier input circuit, means for normally rendering said electron discharge device non-conductive, and said device becoming conductive and permitting electron currents to flow through said amplifier input circuit in response to an increase in regeneration above said predetermined magnitude.

3. A regenerative signal amplifier tube provided with a resonant input circuit tuned to a desired signal frequency, a second resonant circuit preceding said input circuit, at least one resonant circuit located between said amplifier input circuit and said second resonant circuit, the three resonant circuits each being tuned to the desired signal frequency, a regeneration stabilizing circuit comprising an electron discharge device provided with an input electrode and an output electrode, a signal coupling connection between the input electrode of said device and said second resonant circuit, a signal coupling connection between said amplifier input circuit and the output electrode of said device, and means normally preventing electron current to flow in said stabilizer device in the absence of regenerative action in said regenerative amplifier above a predetermined magnitude.

4. A regenerative signal amplifier tube provided with a resonant input circuit tuned to a desired signal frequency, a second resonant circuit preceding said input circuit, at least one resonant circuit located between said amplifier input circuit and said second resonant circuit, the three resonant circuits each being tuned to the desired signal frequency, a regeneration stabilizing circuit comprising an electron discharge device provided with an input electrode and an output electrode, a signal coupling connection between the input electrode of said device and said second resonant circuit, a signal coupling connection between said amplifier input circuit and the output electrode of said device, means normally preventing electron current to flow in

said stabilizer device in the absence of regenerative action in said regenerative amplifier above a predetermined magnitude, said electron discharge device being a triode having a low mu, and said signal coupling connections applying signal voltages to the input and output electrodes respectively of the triode.

5. A regenerative signal amplifier tube provided with a resonant input circuit tuned to a desired signal frequency, a second resonant circuit preceding said input circuit, at least one resonant circuit located between said amplifier input circuit and said second resonant circuit, the three resonant circuits each being tuned to the desired signal frequency, a regeneration stabilizing circuit comprising an electron discharge device provided with an input electrode and an output electrode, a signal coupling connection between the input electrode of said device and said second resonant circuit, a signal coupling connection between said amplifier input circuit and the output electrode of said device, means normally preventing electron current to flow in said stabilizer device in the absence of regenerative action in said regenerative amplifier above a predetermined magnitude, said electron discharge device being a diode, and said intervening resonant circuit being reactively coupled to each of said amplifier input circuit and said second resonant circuit.

6. A regenerative signal amplifier tube provided with a resonant input circuit tuned to a desired signal frequency, a second resonant circuit preceding said input circuit, at least one resonant circuit located between said amplifier input circuit and said second resonant circuit, the three resonant circuits each being tuned to the desired signal frequency, a regeneration stabilizing circuit comprising an electron discharge device provided with an input electrode and an output electrode, a signal coupling connection between the input electrode of said device and said second resonant circuit, a signal coupling connection between said amplifier input circuit and the output electrode of said device, means normally preventing electron current to flow in said stabilizer device in the absence of regenerative action in said regenerative amplifier above a predetermined magnitude, a second electron discharge device connected in coupling relation between said second resonant circuit and said intervening resonant circuit, and said amplifier input circuit being reactively coupled to said intervening circuit.

7. In combination with a plurality of cascaded resonant circuits each tuned to a common signal wave frequency, means for regenerating the last of the cascaded resonant circuits, an electron discharge device having input and output electrodes, means connecting the output electrode of said device to said last resonant circuit, additional means for connecting said input electrode to one of the cascaded resonant circuit which precedes the last resonant circuit by at least one intervening resonant circuit, and means for normally preventing electron current flow to the output electrode of said electron discharge device.

8. In combination with a plurality of cascaded resonant circuits each tuned to a common signal wave frequency, means for regenerating the last of the cascaded resonant circuits, a tube having an input electrode and an output electrode, means connecting the output electrode of said tube to said last resonant circuit, additional means for connecting said input electrode to one of the cascaded resonant circuit which precedes the last resonant circuit by one resonant circuit, and means for biasing said input electrode for preventing electron current flow to the output electrode of said tube.

9. In a wave transmission system of the type comprising a resonant wave input circuit and a succeeding resonant circuit, the method which includes tuning both resonant circuits to a common wave frequency, establishing the succeeding circuit to a predetermined degree of regeneration, providing a normally non-conductive direct current path between said input circuit and said succeeding circuit, applying wave voltage to the input and output of said path, and damping said regenerated resonant circuit from said path by virtue of said path becoming conductive for direct current in response to an increase in regeneration of said succeeding circuit above said predetermined point.

10. In combination with a plurality of resonant circuits tuned to a common signal wave frequency, means for regenerating the last of the cascaded resonant circuits, an electron discharge device having input and output electrodes, means connecting the output electrode of said device to said last resonant circuit, means for connecting said input electrode to one of the cascaded resonant circuit which precedes the last resonant circuit, and means for normally rendering said device non-conductive thereby preventing direct current flow to the output electrode of said electron discharge device.

11. In a wave transmission system of the type comprising a resonant wave input circuit and a succeeding resonant circuit, the method which includes tuning the resonant circuits to a common wave frequency, decreasing the resistance of the succeeding circuit to a predetermined low value, establishing a normally non-conductive direct current path between said input circuit and said succeeding circuit, applying wave voltage to the input and output points of said path, and introducing resistance into said succeeding resonant circuit from said path by virtue of said path becoming conductive and passing direct current in response to a decrease in resistance of said succeeding circuit below said predetermined low value.

12. In combination with a wave amplifier tube having regenerative coupling between its output and input electrodes, a resonant input circuit coupled between the input electrodes of said amplifier tube, a wave input circuit preceding said amplifier input circuit, an electron discharge device having an input electrode coupled to a point on said wave input circuit and an output electrode coupled to a point on said amplifier input circuit, said electron discharge device being normally non-conductive, and said device becoming conductive and permitting electron currents to flow through said amplifier input circuit in response to an increase in regeneration above a predetermined magnitude.

13. In combination with a plurality of cascaded wave transmission circuits, means for regenerating the last of the cascaded circuits, an electron discharge device having an input electrode and an output electrode, means connecting the output electrode of said device to said last circuit, additional means for connecting said input electrode to one of the cascaded circuits which precedes the last circuit by at least one intervening circuit, and means preventing electron current flow to the output electrode of said

electron discharge device in the absence of regeneration at said last circuit being above a predetermined magnitude.

14. In a wave transmission system of the type comprising a resonant wave input circuit and a succeeding resonant circuit, the method which includes transmitting wave energy of a predetermined frequency through said circuits, establishing the succeeding circuit at a predetermined degree of regeneration, providing a normally non-conductive direct current transmission path between said input circuit and said succeeding circuit, applying wave voltage to the input and output terminals of said path, and damping said regenerated circuit by direct current from said path in virtue of said path becoming conductive in response to an increase in regeneration of said succeeding circuit in excess of said predetermined degree.

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