

May 30, 1961

F. H. BLECHER
PREVENTION OF OVERLOAD INSTABILITY IN
CONDITIONALLY STABLE CIRCUITS

2,986,707

Filed July 13, 1959

3 Sheets-Sheet 1

FIG. 1

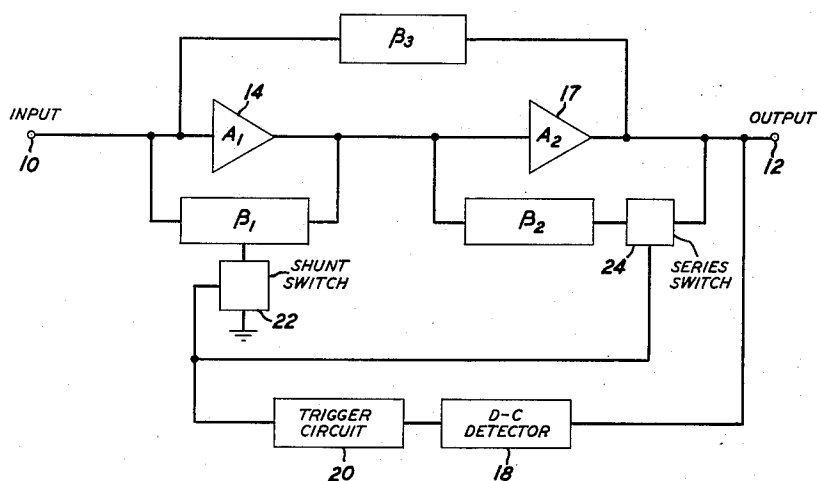
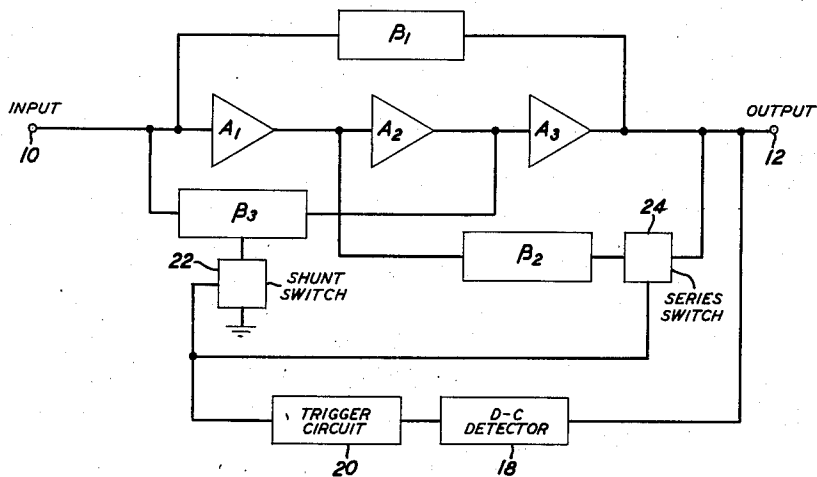


FIG. 2



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FIG. 3

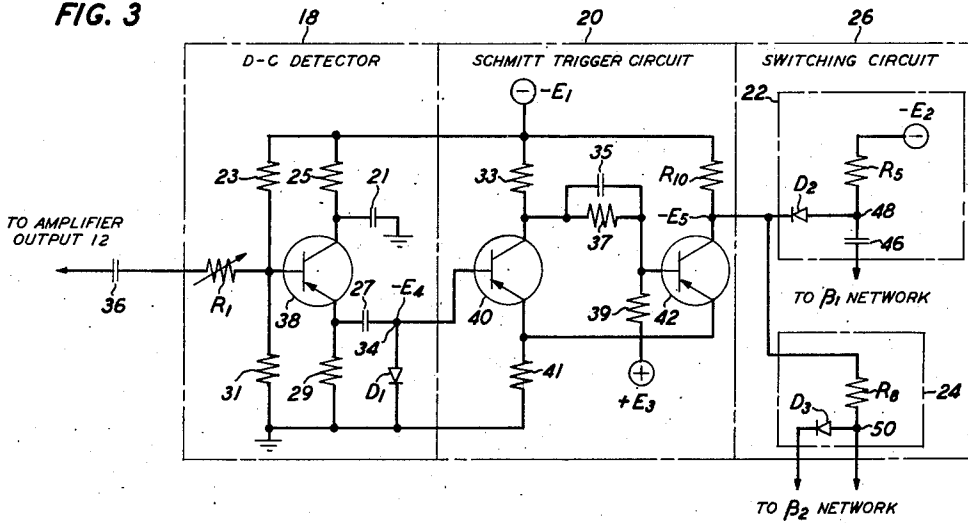
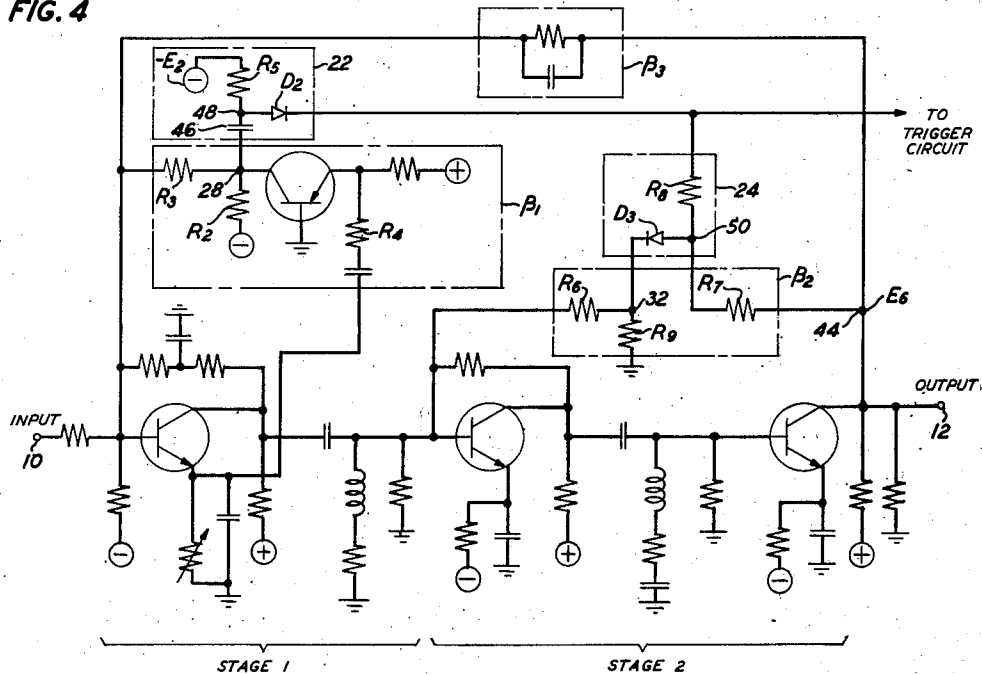


FIG. 4



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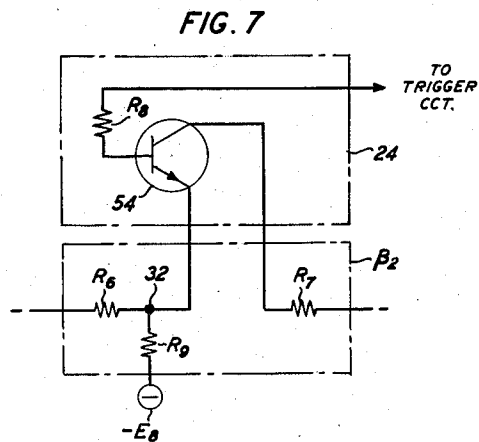
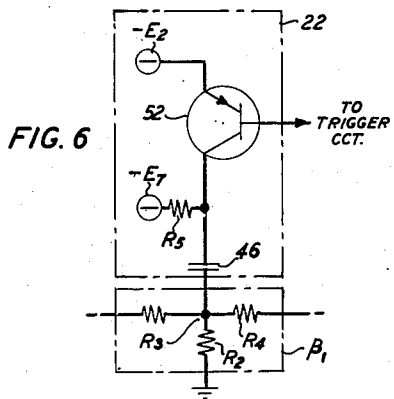
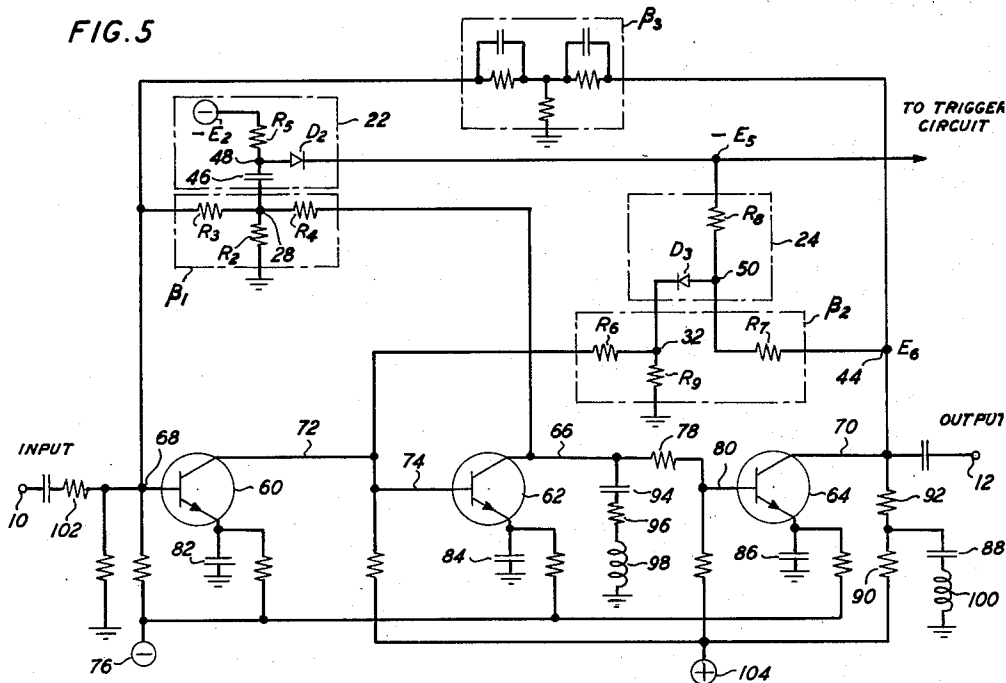
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3 Sheets-Sheet 3



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PREVENTION OF OVERLOAD INSTABILITY IN
CONDITIONALLY STABLE CIRCUITS

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13 Claims. (Cl. 330-86)

This invention relates to conditionally stable circuits. More specifically, it is concerned with the prevention of overload instability in multiple-loop feedback amplifiers.

The principles of the invention may be applied to any type of conditionally stable multiple-loop feedback system, regardless of its configuration. For purposes of illustration, these principles will be applied to two systems, currently of pronounced technical and commercial interest: the so-called "tandem" multiple-loop feedback amplifier, introduced by Q. E. Greenwood in Patent No. 2,281,238, which issued April 28, 1942, and the "interlaced" system disclosed in Patent No. 2,909,623 which issued to applicant on October 20, 1959.

The problem to which the present invention is directed, viz., overload instability in multiple-loop feedback amplifiers, will be firmly established if, at the outset, we consider it in connection with a particular system, say, that of Greenwood. If additional insight concerning the nature of the problem is desired, it is suggested that reference be made to the landmark work of H. W. Bode, "Network Analysis and Feedback Amplifier Design," pages 162-164, D. Van Nostrand Co., Inc., (1945); to an article by J. Oizumi and M. Kimura, entitled, "Design of Conditionally Stable Feedback Systems," which appears at page 157 of Transactions of the Institute of Radio Engineers, volume Ct-4, No. 3 (September 1957); and to an article entitled "Transistor Multiple Loop Feedback Amplifiers" by F. H. Blecher which appears in volume 13 of Proceedings of the National Electronics Conference, page 19 (1957).

For greater clarity and ease of narration, the Greenwood system will be limited, as it is in his patent, to two stages having respective forward gains A_1 and A_2 , two local positive feedback paths having respective feedback factors of β_1 and β_2 , and one negative over-all feedback path having a feedback factor of β_3 . The loop gains $A_1\beta_1$ and $A_2\beta_2$ are therefore positive, while the loop gain $A_1A_2\beta_3$ is negative. Note, further, that both $A_1\beta_1$ and $A_2\beta_2$ are constrained to equal unity.

Since the amplifier has two positive feedback loops whose gain magnitudes are constrained to equal unity, it is conditionally stable. Conditionally stable feedback amplifiers may become unstable by such disturbances as variations of supply potentials, variations in load, and saturation of amplifying elements by large input signals which overload the amplifier. It is the last-named cause of instability that is denominated "overload instability" and to which the invention is directed. If the negative feedback represented by the gain product $A_1A_2\beta_3$ should be diminished or discontinued, then the amplifier will burst into oscillation. The negative feedback loop will, in fact, as will later be explained, be effectively opened if an active element, contributing to the gain A_1 , should become overloaded. The amplifier will then go into oscillation for, while the gain product $A_1A_2\beta_3$ effectively will have been rendered impotent, the unity gain product $A_2\beta_2$ will continue with full vigor. Oscillation will also result if an active element contributing to the gain A_2 should

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become overloaded, for then, the unity gain product $A_1\beta_1$ would continue unopposed by the product $A_1A_2\beta_3$.

It is therefore an object of the present invention to automatically disable positive feedback in a multiple-loop feedback amplifier in the event that any amplifying element divulges the imminent prospect of becoming overloaded.

Reflection will show that if the prospective overload is not swiftly acted upon, the amplifier will go into oscillation notwithstanding the warning of impending overload. Accordingly, a further object of the invention is to ensure fast-acting and effective response to the overload warning.

In accordance with the invention, the alternating-current output signal of the amplifier is detected and converted to a direct-current signal. The latter signal controls the state of a trigger circuit to which it is supplied. If this control signal is below a certain critical level, the trigger circuit is unaffected and remains in its normal state. If, however, the critical level is surpassed, the trigger circuit will be "flipped" to its abnormal state. Provision is made in the detector circuit so that the critical level of the trigger circuit corresponds to a prescribed maximum output level of the amplifier, which imports imminent instability due to the rapidly approaching overload point of one of the amplifier's active elements. The trigger circuit, in turn, controls switches which effectively interrupt all regenerative propagation whenever the trigger circuit is flipped to its abnormal state.

Perhaps the most outstanding feature of the invention is the utter simplicity by which the perplexing problem of overload instability is overcome. The invention will doubtless be welcomed wherever extremely reliable transmission is desired, to say nothing of applications where reliability is the pre-eminent consideration: e.g., trans-oceanic cable systems, and the many military applications in which failures due to instability cannot be tolerated.

The following description, when read in conjunction with the drawings, will offer a more comprehensive understanding of the invention. In the drawings:

Fig. 1 is a block schematic diagram of the "tandem" feedback amplifier, referred to above, and very generally, of a circuit, arranged in accordance with the invention, for preventing overload instability;

Fig. 2 illustrates, also very generally, application of the principles of the invention to the "interlaced" feedback amplifier spoken of above;

Fig. 3 is a detailed circuit diagram of a preferred embodiment of the invention;

Figs. 4 and 5 show the manner in which the control switches may be connected in the tandem and interlaced feedback amplifiers, respectively; and

Figs. 6 and 7, respectively dealing with shunt and series control switches, concern alternative configurations of the control switches shown in Figs. 3 to 5, transistors being used in lieu of diodes.

Fig. 1 broadly shows, in block schematic form, the detailed circuit of Fig. 4. As stated above, Fig. 1 is a so-called "tandem" multiple-loop feedback amplifier of the type disclosed in the Greenwood patent. The stages 14 and 16 have gains of A_1 and A_2 , respectively. The amplifier has probably come to be known as one of the "tandem" multiple-loop variety because of the successive local feedback paths, here represented by the β_1 and β_2 circuits, which provide local feedback respectively around the stages 14 and 16. Over-all negative feedback is provided by the β_3 circuit which interconnects the output 12 and the input 10. The β_1 and β_2 circuits provide positive feedback.

If it were not for the β_3 circuit, which contributes to the stabilizing loop gain $A_1A_2\beta_3$, the amplifier of Fig. 1 would be normally unstable, i.e., the amplifier would continually oscillate. If the magnitude of the external

feedback provided by β_3 is large compared to the internal feedback provided by β_1 and β_2 , the internal feedback does not affect the stability of the amplifier under normal conditions. Proof of this is given in an article entitled "Design Principles for Single Loop Transistor Feedback Amplifiers," by F. H. Blecher which appears in Transactions of the Institute of Radio Engineers, volume Ct-4 (September, 1957). The loop gain $A_1A_2\beta_3$ is therefore chosen to offset the regenerative loop gains $A_1\beta_1$ and $A_2\beta_2$, in order to render the amplifier stable under normal conditions of operation. But in view of the positive feedback loops and the possibility of abnormal operating conditions, the amplifier is only conditionally stable. Thus, should an active element in stage 14 become overloaded, that is to say, saturated, the negative feedback loop will be effectively opened and the amplifier will oscillate.

It will be instructive to elaborate upon the last statement. It should first be understood that the overloading of a stage vitally affects its amplifying capability. Its gain is, in fact, drastically reduced. This fact can be discerned from a consideration of the characteristic curves of a typical amplifying element. Since the active element, which was assumed to have become overloaded, contributes to the negative feedback represented by the loop gain $A_1A_2\beta_3$, the negative feedback will decrease as a consequence of the decrease in A_1 due to the overload. The positive feedback represented by $A_1\beta_1$ will also decrease. The positive feedback represented by $A_2\beta_2$ will, however, continue unabated. The phase and gain margins of the amplifier will therefore be reduced and, since the Greenwood system ideally calls for an $A_2\beta_2$ of unity, oscillation will result. The above analysis can also be used to show that oscillation will occur, as well, if an active element in stage 16 should become overloaded.

But in accordance with the principles of the invention, whether or not active elements in stage 14, or 16, or in both stages become overloaded, the "tandem" multiple-loop feedback amplifier will remain stable. To be sure, the advantages of positive feedback will not be available so long as the overload condition persists, but the amplifier will, nevertheless, continue operation as a stable, single loop, negative feedback amplifier. Stability is insured by the protection circuit consisting of detector 18 Schmitt trigger circuit 20, and the switches 22 and 24.

In Fig. 1, as in Fig. 2, switch 22 is shown as a shunt switch, whereas switch 24 is shown to be of the series variety. The difference is only meant to show that alternate methods of switching may be used. Thus, the switches 22 and 24 may both be of the same type or, if desired, respectively of the series and shunt varieties. The protection circuit will be explored in much greater detail when the description of Fig. 3 is given.

Fig. 2 is a block diagram of an interlaced feedback amplifier of the type described in the above-cited co-pending application. For ideal performance, the loop gains $A_1A_2\beta_1$ and $A_2A_3\beta_2$ are each constrained to equal unity. The β_1 and β_2 circuits are positive feedback paths. The unity gain constraint is advantageous in that the over-all gain of the amplifier is thereby rendered insensitive to changes in the gain A_1 , so long as the gains A_2 and A_3 have not varied, and to changes in the gain A_3 so long as the gains A_1 and A_2 have not varied. To obtain this result, there are no restrictions on the normally-stabilizing loop gain $A_1A_2A_3\beta_3$, other than the practical requirement that the feedback be negative and that its absolute magnitude be greater than unity by an amount sufficient to render the system stable in the sense that it will not oscillate.

Another advantageous property of the interlaced amplifier shown in Fig. 2 is that output distortion introduced by the last stage A_3 is drastically reduced if the loop gain $A_1A_2\beta_1$ is constrained to equal unity. Moreover, this reduction of distortion is effectively independent of the loop gains $A_2A_3\beta_2$ and $A_1A_2A_3\beta_3$, except that the magni-

tude of the latter gain, as mentioned above, should be greater than unity by an amount sufficient to render the system stable. Theoretically, it should be noted, the output distortion is completely eliminated, but it is impracticable to constrain $A_1A_2\beta_1$ to exactly unity at all times. Nevertheless, reduction of output distortion in the interlaced feedback amplifier closely approaches this theoretical ideal.

The overload protection circuit of Fig. 2, shown very generally in block schematic form, is identical to that of Fig. 1. Again, it should be noted that it is not necessary to use the shunt and series switches as they are shown in the diagram. A shunt or a series switch may be used in conjunction with either feedback network, depending upon the specific design of the network.

It is well to note that the use of both positive and negative feedback in an amplifier enables a designer to obtain transmission characteristics that are not obtainable in amplifiers using only negative feedback. Such amplifiers, however, are only conditionally stable, as we have seen. Since a vacuum tube requires a substantial warm-up period, it is, in a very real sense, persona non grata so far as conditionally stable amplifiers are concerned. Positive feedback, therefore, is usually not employed in vacuum tube amplifiers; although it should be understood that it can be, if adequate provision is made for warm-up time. Transistors, on the other hand, do not present this warm-up problem and are, consequently, particularly suitable for use in conditionally stable circuits. Thus, the reader will note that the feedback amplifiers and overload protection circuits presently under discussion employ transistors exclusively.

Fig. 3 shows in detail the overload protection circuits shown very generally in Figs. 1 and 2. Ultimately, as we have seen, the regenerative portions of Figs. 1 and 2 switch (change states) whenever an imminent overload condition is forecast. The method used to accomplish this end has been broadly treated above. The means for doing so will now be elaborated upon.

The overload protection circuit consists of a direct-current detector 18, a Schmitt trigger circuit 20, and a switching circuit 26. The symbols E_1 , E_2 , . . . E_5 represent absolute magnitudes of direct-current voltages at various points in Fig. 3. Of these, $-E_1$, $-E_2$ and $+E_3$ are power supply voltages; $-E_4$ is the direct-current voltage developed at the output 34 of the direct-current detector; and $-E_5$ is the direct-current output voltage of the Schmitt circuit.

The direct-current detector circuit 18 is coupled through capacitor 36 to the output 12 of the multiple-loop feedback amplifier of either Fig. 1 or Fig. 2. The detector circuit 18 consists of a level control, an emitter follower (otherwise known as a common collector stage), and a peak detector.

The level control is the potentiometer R_1 . It is adjusted so that the maximum alternating-current output voltage of, say, the amplifier of Fig. 2, after which an overload condition is imminent, is converted by the detector to the threshold or "flipping" voltage of the Schmitt circuit.

The emitter follower 38 is preferred for at least two reasons. First, it has a high input impedance and, consequently, the output of the feedback amplifier, to which it is connected, will not be "loaded down." Second, and more important, it has a low output impedance which makes it possible for the peak detector, the diode D_1 and capacitor 27, to respond to sudden increases in the level of the feedback amplifier output voltage. It is not sufficient that the Schmitt circuit 20 and the switching circuit 26 be fastacting, since a forecasted overload condition will have been in vain if detector circuit 18 cannot quickly convey this information to the Schmitt circuit 20. The rapid responsive capability of detector circuit 18 to abrupt increases in the feedback amplifier output level

is therefore necessary in most cases, if overload instability is to be avoided.

The Schmitt trigger circuit 20 has two stable modes of operation, i.e., two states of equilibrium, and will be in one or the other, depending upon the magnitude of the detector output voltage $-E_4$. In its normal state, i.e., when the feedback amplifier has forecast no danger of imminent overload, the Schmitt circuit has its first stage 40 nonconductive and its second stage 42 conductive. Conversely, stages 40 and 42 are respectively rendered conductive and nonconductive when the output level of the feedback amplifier has informed the detector circuit 18 that an overload is immediately prospective and, in turn, voltage $-E_4$ has been brought to the "flipping" level of Schmitt circuit 20. The amplifier output voltage at which an overload is imminent thus corresponds to a specified level of $-E_4$, beyond which Schmitt circuit 20 changes state. So long as the magnitude of $-E_4$ does not fall below this level, the Schmitt circuit output voltage $-E_5$ will be at a constant peak value substantially equal to $-E_1$, as we shall see.

When the Schmitt circuit 20 is in its normal state, then, its output voltage $-E_5$ has a relatively small negative value since transistor 42 is conductive. In its abnormal state, however, Schmitt circuit 20 has a negative output voltage of relatively high value, since transistor 42 is then cut off (has zero collector current) and $-E_5$ is very nearly equal to the supply voltage $-E_1$. Thus, in the face of an imminent prospect of amplifier overload, the output voltage $-E_5$ of Schmitt circuit 20 will be relatively large, negatively, and very nearly equal to the supply voltage $-E_1$.

The Schmitt circuit has been the subject of many papers, beginning with "A Thermionic Trigger" by O. H. Schmitt, which appeared in The Journal of Scientific Instruments, volume 15, page 24 (1938), published by the Institute of Physics, London, England. The vacuum-tube analog of trigger circuit 20, is shown at page 468 of Reference Data for Radio Engineers (4th ed. 1956).

In discussing switching circuit 26, it will be helpful to do so with reference, at appropriate times, to the β_1 and β_2 networks of, say, Fig. 5. While Schmitt circuit 20 is in a state of normalcy—no overload in the feedback amplifier is imminent—the diode D_2 of the shunt switch 22 is reverse-biased by the negative supply voltage $-E_2$. It is apparent, therefore, that the voltage $-E_2$ is more negative than the Schmitt output voltage $-E_5$ when transistor 42 is conductive. The diode D_2 has an extremely high impedance when it is reverse-biased, since, in practice—presently at least— D_2 is a silicon junction diode. Thus, the overload protection circuit has no effect on the make-up of the β_1 circuit while the multiple-loop feedback amplifier operates at normal signal levels. The β_1 circuit of Fig. 5, for example, normally comprises two series resistors, R_3 and R_4 , and two shunt resistors, R_2 and R_5 .

When, however, an overload condition is immediately prospective, diode D_2 of shunt switch 22 is forward-biased by the change-of-state of Schmitt circuit 20, since the voltage $-E_5$, now very nearly equal to $-E_1$, is greater, negatively, than the supply voltage $-E_2$. The shunt resistance in the β_1 network now includes, in addition to resistors R_2 and R_5 , the resistor R_{10} which interconnects diode D_2 and the source of potential $-E_1$. The resistance of R_{10} is sufficiently small so that the positive feedback due to the β_1 network is now negligible enough to be ignored. That is to say, $A_1 A_2 \beta_1 < 1$. Regeneration by way of the β_1 network thus effectively ceases.

Again, while Schmitt circuit 20 is in a state of normalcy, the diode D_3 of the series switch 24 is forward-biased by the voltage E_6 , which is manifest at juncture 44 of Fig. 5. The voltage E_6 is the positive direct-current voltage component of the feedback amplifier output signal. Regenerative propagation through the β_2 circuit is thus unaffected by diode D_3 while the feedback amplifier is operating at permissible signal levels. While D_3 is

forward-biased, it can be seen that the β_2 circuit consists of the series resistors R_6 and R_7 and the two shunt resistors R_8 and R_9 . In practice, R_{10} is small compared to R_9 .

When, however, in response to an imminent amplifier overload, Schmitt circuit 20 changes state, rendering transistor 42 nonconductive, diode D_3 becomes reverse-biased. The reverse-biasing of D_3 is insured by proportioning E_1 (it will be recalled that E_5 very nearly assumes this value when transistor 42 is cut off) E_6 , R_7 and R_8 so that $E_1/R_8 > E_6/R_7$. The series impedance of the β_2 now additionally includes the extremely high impedance of the reverse-biased diode D_3 . Consequently, $A_2 A_3 \beta_2 < 1$ and, in fact, regeneration by way of the β_2 circuit is effectively interrupted.

In all of what has been said above, it should have been apparent that when the overload condition is removed, the feedback amplifier returns to normal operation.

Figs. 4 and 5, already referred to in the above discussion, show the manner in which the switching networks 22 and 24 may be connected to typical β networks. The connections are self-explanatory. Suffice it to say that capacitor 46 of the shunt switch 22 interconnects juncture 28 of the β_1 network and juncture 48 of the switch. Also, as can readily be seen, diode D_3 of the series switch 24 interconnects juncture 32 of the β_2 network and juncture 50 of the switch. Juncture 50, in turn, is connected to resistor R_7 . The operation of the switching networks 22 and 24 has already been described in connection with Fig. 3. The amplifying portions of Figs. 4 and 5 are similar. It will be sufficient, therefore, in pointing up the interplay between the β circuits and the amplifying elements, to briefly describe one of these figures, namely Fig. 5.

Fig. 5, as has been mentioned above, is an interlaced multiple-loop feedback amplifier. As shown, it comprises three cascaded NPN junction transistors 60, 62, and 64, each connected in the common emitter configuration. The β_1 circuit interconnects the collector output 66, of transistor 62 and the base input 68 of transistor 60. The β_2 circuit interconnects the collector output 70 of transistor 64 and the collector output 72 of transistor 60 which, in turn, is coupled to the base input 74 of transistor 62. The β_3 circuit interconnects the collector output 70 of transistor 64 and the base input 68 of transistor 60. Appropriate bias potentials for each of the transistors 60, 62 and 64 are provided by the negative voltage power supply 76 and the positive voltage power supply 104.

It should be noted that resistor 78 is inserted between the collector output 66 of transistor 62 and the base input 80 of transistor 64 so that the amount of current fed back by way of β_1 circuit is effectively independent of any degradation that may occur in the output stage 64. Consequently, the value of resistor 78 should be at least an order of magnitude greater than the input impedance of transistor 64.

Shaping of the gain characteristic, i.e., controlling the rate at which the current or voltage gain of the amplifier falls off with frequencies outside the useful frequency band, is an important consideration in the design of feedback amplifiers. Low frequency shaping of loop current transmission is accomplished by capacitors 82, 84 and 86, each of which is connected between the emitter of its respective transistor and ground. Low frequency shaping is also provided by capacitor 88 and its associated resistors 90 and 92. High frequency shaping of the loop gain transmission is accomplished by the β_3 circuit and the inter-stage network which comprises the series combination of capacitor 94, resistor 96, and inductor 98. High frequency shaping is also provided by the network consisting of inductor 100 and resistors 90 and 92.

The aforementioned shaping circuits serve to shape the loop gain of each of the positive feedback loops as well as the negative feedback loop and, consequently,

there is no need for shaping elements in the β_1 and β_2 circuits. Accordingly, the β_1 and β_2 circuit may be purely resistant, as they are in Fig. 5.

In order to stabilize the positive feedback provided by the β_1 and β_2 circuits, the β_3 circuit is designed for relatively large phase and gain margins. In addition, at frequencies outside the useful frequency band, the magnitude of the loop gain of each of the positive feedback loops should decrease at a rate which is greater than or at least equal to the rate at which magnitude of the loop gain of the negative feedback loop decreases. The interlaced amplifier illustrated in Fig. 5 is advantageously designed to have a 45-degree phase margin at both the low and high ends of its useful frequency band.

The input resistor 102 is serially inserted in the connections between the input terminal 10 and the base input 68 of transistor 60, primarily to insure that substantially all of the current fed back through β_1 and β_3 circuits finds its way into the base input 68 of transistor 60. This precaution is not needed in the output circuit of transistor 60, since the relatively high output impedance of this transistor insures that substantially all of the current fed back through the β_2 circuit finds its way into base input 74 of transistor 62.

Fig. 6 illustrates an alternative arrangement for the shunt switch 22 of Fig. 1. PNP transistor 52 here serves as the fundamental switching element. The collector junction of the transistor is reverse-biased by the negative voltage $-E_7$. $-E_7$ is more negative than the voltage $-E_2$. The relationship between the negative voltages $-E_2$ and $-E_5$, the Schmitt circuit output voltage shown in Fig. 3, remains the same as before. That is, so long as transistor 42 is conductive $E_2 > E_5$, but when the Schmitt trigger circuit changes state and transistor 42 is rendered nonconductive, $E_2 < E_5$. With this relationship in mind, it can be seen that so long as the emitter junction of transistor 52 is reverse-biased by the voltage $-E_2$, propagation through the β_1 network will be unaffected, for the collector-emitter path of transistor 52 presents a very high impedance. But when an impending amplifier overload has caused transistor 42 to be cut off and, consequently, the voltage $-E_5$ to become substantially equal to $-E_1$, the emitter junction of transistor 52 becomes forward-biased. Since transistor 52 is then driven into current saturation, its collector-emitter path presents a very low impedance. Under this state of affairs, the positive feedback due to the β_1 network is negligible and $A_1\beta_1$ (Fig. 1) or $A_1A_2\beta_1$ (Fig 2) is very much less than unity. Stability of the respective feedback amplifiers, pending cessation of the overload condition, is thus insured.

The series switch 24, shown in Fig. 7, employs an NPN transistor 54. This is in lieu of the diode D_3 which is included in the series switch 24 as it is shown, for example, in Fig. 5. In Fig. 7, resistor R_9 is connected to a negative supply voltage $-E_8$ instead of directly to ground, as it is in Fig. 5. The magnitude of the voltage $-E_8$ is chosen so that it is greater than the normal value of the output voltage $-E_5$ of the Schmitt circuit 20 (see Fig. 3). During normal operation of the feedback amplifier with which it is associated, the voltage $-E_8$, being more negative than $-E_5$, thus forward-biases the emitter junction of transistor 54, driving it into saturation. The collector-emitter path of the transistor is, therefore, normally a very low impedance to current passing through the β_2 network. But when, in response to an impending overload condition, transistor 42 of Fig. 3 is cut off and the voltage $-E_5$ increases negatively to the value of $-E_1$, which is more negative than $-E_8$, the emitter junction of transistor 54 becomes reverse-biased. The collector-emitter path of transistor 54 is then a very high impedance. Positive feedback by way of the β_2 circuit is therefore effectively discontinued so long as the overload condition persists.

Countervailing factors will, in various applications of the invention, determine the designer's choice of switch-

ing element for the switches 22 and 24 of Fig. 1. Diode switches have the advantages of relative circuit simplicity, speed of operation, and extremely high reverse impedance. Transistor switches, on the other hand, are advantageous in view of their sensitivity (they require a relatively small amount of driver power) and their extremely low forward impedance.

While specific embodiments have been shown and described, they should not be construed as circumscribing the scope of the invention.

What is claimed is:

1. In combination, a multiple-loop feedback amplifier comprising at least one regenerative feedback loop and an overall negative feedback loop, said regenerative feedback loop having associated therewith a switching circuit for disabling the regenerative loop; and a protection circuit for preventing overload instability in said multiple-loop feedback amplifier, said protection circuit including and interconnecting said switching circuit with the output of said amplifier, and further including a direct-current detector for detecting signals at the output of said amplifier and converting them to direct current; bistable means responsive to the amplitude of said detected current to change state at a certain critical amplitude level of said current, at which level an overload in said multiple-loop feedback amplifier is imminent, said bistable means being in its normal state of equilibrium while said detected current is below said critical level and in its abnormal state of equilibrium while said detected current is above said critical level; means for supplying said detected current to said bistable means; and means interconnecting said bistable means and said switching circuit, said switching circuit disabling its associated regenerative feedback loop when said bistable means is in its abnormal state of equilibrium and enabling said associated loop when said bistable means is in its normal state.

2. The combination, in accordance with claim 1 in which said switching circuit comprises a diode.

3. The combination in accordance with claim 1 in which said switching circuit comprises a diode serially inserted within its associated regenerative feedback loop.

4. The combination in accordance with claim 1 in which said switching circuit comprises a diode connected in parallel circuit relationship with its associated regenerative feedback loop.

5. The combination in accordance with claim 1 in which said switching circuit comprises a transistor.

6. In combination, a multiple-loop feedback amplifier and a protection circuit for preventing overload instability in said amplifier, said amplifier comprising an overall negative feedback loop and a plurality of regenerative feedback loops, each of said regenerative loops having associated therewith a switching circuit for interrupting positive feedback whenever an overload in said amplifier is immediately prospective, said protection circuit including and interconnecting each of said switching circuits with the output of said amplifier and further including a direct-current detector for converting said output of said amplifier to direct current, a bistable circuit responsive to the amplitude of said direct current and changing from its normal to its abnormal state of equilibrium at a predetermined amplitude level of said direct current, at which level said amplifier overload is immediately prospective, said detector including a level control for correlating the amplifier output level at which said overload is immediately prospective and said predetermined direct-current level at which said bistable circuit changes from its normal to its abnormal state of equilibrium, said bistable circuit reverting to its normal state when said direct-current output of said detector falls below said predetermined amplitude level, and means for supplying the output of said bistable circuit to each of said switching circuits, each of said switching circuits including means for interrupting regenerative propagation in its associated feed-

back loop whenever said bistable circuit is in its abnormal state.

7. The combination in accordance with claim 6 in which said amplifier is a tandem multiple-loop feedback amplifier having a local regenerative feedback loop around each stage of said amplifier. 5

8. The combination in accordance with claim 6 in which said amplifier is an interlaced multiple-loop feedback amplifier having a plurality of regenerative feedback loops, each including more than one stage of said amplifier. 10

9. The combination in accordance with claim 6 in which said bistable circuit is a Schmitt trigger circuit.

10. In combination, a multiple-loop feedback amplifier comprising a plurality of regenerative feedback loops each having unity loop gain; means to detect the imminent prospect of an overload condition in said amplifier; bistable circuit means, responsive to said detector means, and changing state when an imminent overload has been detected; and switching means, responsive to said bistable circuit means and associated with each of said regenerative feedback loops, to interrupt regeneration in said feedback loops upon said change of state of said bistable circuit means. 20

11. In combination, a conditionally stable circuit in-

cluding at least one regenerative feedback loop and having a prescribed maximum output voltage beyond which said circuit will tend to become unstable, detector means to detect the output voltage of said conditionally stable circuit, bistable circuit means responsive to said detector means and changing from a normal to an abnormal state when said prescribed voltage has been surpassed, and switching means responsive to said bistable circuit means to interrupt regeneration in said feedback loop when said bistable circuit means has assumed its abnormal state.

12. The combination in accordance with claim 11 in which said detector means comprises a level control, an emitter-follower stage, and a peak detector, interconnected in the order named.

13. The combination in accordance with claim 11 in which said bistable circuit comprises a Schmitt trigger circuit having a pair of emitter-coupled transistor stages.

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