Oct. 20, 1959 F. H. BLECHER 2,909,623

INTERLACED FEEDBACK AMPLIFIER

Filed June 27, 1957

FIG. 1

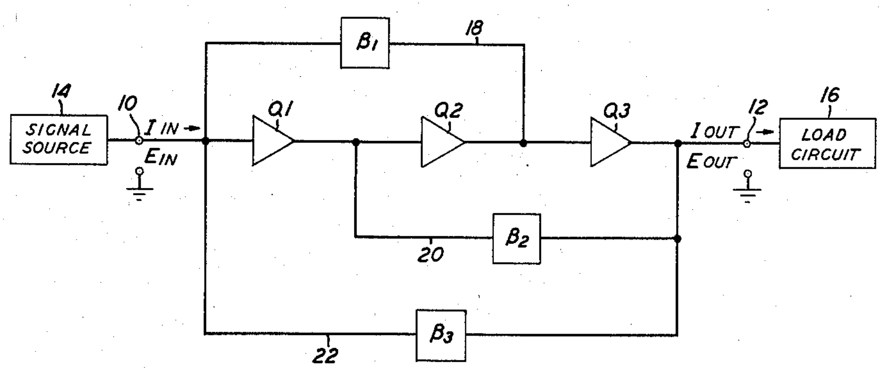
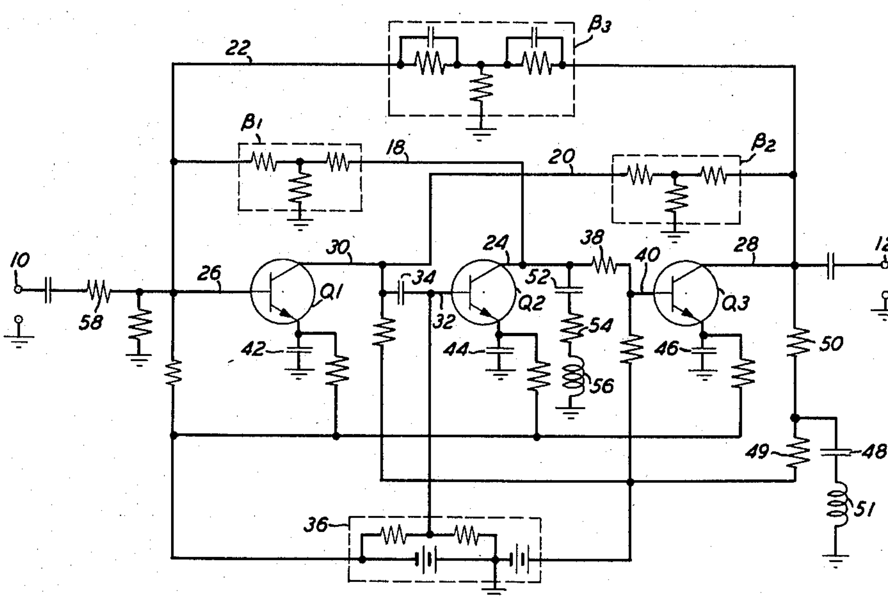


FIG. 2



INVENTOR
F. H. BLECHER
BY
ATTORNEY

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INTERLACED FEEDBACK AMPLIFIER

Franklin H. Blecher, Plainfield, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

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This invention relates to wave translating systems and more particularly to electric wave amplifying systems employing multiple-loop feedback amplifiers.

It is an object of the present invention to effect a pronounced improvement in the gain stability and to increase the length of life of a feedback amplifier system, while decreasing distortion.

A further object of the invention is to simplify the design and construction of such a system.

It is a more specific object of the present invention to provide an extremely reliable multi-stage amplifier system having a current or voltage gain which is not affected by a substantial failure in either the input or output stages of the system. A related object is to eliminate distortion due to the output stage of such an amplifier system while maintaining satisfactory gain stability.

The use of negative feedback in amplifiers to cause a reduction in the over-all gain while improving gain stability and reducing distortion, is well known and is taught, for example, in H. S. Black Patent No. 2,102,671, which issued December 21, 1937. The use of positive feedback in conjunction with negative feedback in multiple-loop feedback amplifiers is also known and is taught, for example, in F. B. Llewellyn Patent No. 2,245,598, which issued June 17, 1941, and Q. E. Greenwood Patent No. 2,281,238, which issued April 28, 1942. Both of the latter references concern feedback amplifier systems wherein each stage has an independent positive local feedback loop and wherein negative feedback is provided from the output of either the last or an intermediate stage to the input of the first stage. The positive feedback loops are independent in the sense that there is no interrelationship between them. As will become apparent below, the present invention concerns feedback systems having interrelated and, therefore, dependent positive feedback loops.

In an illustrative embodiment of the present invention, severe gain degradations in either the input or output stage of a three-stage cascaded feedback amplifier are compensated by introducing a critical amount of positive feedback into individual feedback paths coupling, respectively, the output of the second stage to the input of the first stage and the output of the last stage to the input of the second stage. Thus, the over-all gain of the amplifier is rendered substantially insensitive to such degradations.

A fuller understanding of the nature of the invention and other objects, features and advantages thereof may be had from a consideration of the illustrative embodiments now to be described with reference to the accompanying drawings.

In the drawings:

Fig. 1 is a diagrammatic representation of an interlaced feedback amplifier system embodying the invention; and

Fig. 2 is a circuit diagram illustrating a specific transistorized embodiment conforming with the diagrammatic representation of Fig. 1.

In Fig. 1, three amplifying stages Q_1, Q_2, and Q_3 having voltage or current gains A_1, A_2, and A_3, respectively, are connected in cascade and interposed between an input terminal **10** and an output terminal **12**. A signal source **14** is connected to the input terminal **10** to supply an input current I_{in} (or voltage E_{in}), and a load circuit **16** is connected to the output terminal **12** to receive an output current I_{out} (or voltage E_{out}). A positive feedback path **18** having a feedback fraction β_1 couples the output of stage Q_2 to the input of stage Q_1 (where "feedback fraction" is understood to mean that fraction of the output current or voltage of a stage which is fed back); a second positive feedback path **20** having a feedback fraction β_2 couples the output of stage Q_3 to the input of stage Q_2; and a negative feedback path **22** having a feedback fraction β_3 couples the output of stage Q_3 to the input of stage Q_1. The system is thus said to have interlaced positive feedback loops and over-all negative feedback and is identified as an interlaced feedback amplifier system. The loop gain of the loop consisting of the first and second stages Q_1 and Q_2 and the feedback path **18** may be written as $A_1A_2\beta_1$. Similarly, the loop gains of the loops formed by the feedback paths **20** and **22** may be written as $A_2A_3\beta_2$ and $A_1A_2A_3\beta_3$, respectively.

By recourse to the basic Kirchhoff equations, the over-all or external current or voltage gain of the amplifier system is found to be

$$A'=\frac{A_1A_2A_3}{1-A_1A_2\beta_1-A_2A_3\beta_2-A_1A_2A_3\beta_3} \qquad (1)$$

where ordinarily the gains of the individual stages are negative and the feedback fractions are positive.

In accordance with principles of the invention, the loop gains $A_1A_2\beta_1$ and $A_2A_3\beta_2$ are each made substantially equal to unity. The advantage of this may be seen from the over-all gain Equation 1, either by inspection or by partial differentiation. This advantage is that the over-all gain A' is 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 loop gain $A_1A_2A_3\beta_3$ other than the practical requirements 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. The allowable degradation in either of the gains A_1 or A_3 without affecting the over-all or external gain of the amplifier, is determined only by stability considerations. Thus, if the system of Fig. 1 is designed to have conservative gain and phase margins against instability without the β_1 and β_2 circuits, then either of the gains A_1 or A_3 may drop to a very small fraction (for example, one percent) of its initial value before causing oscillation.

It is desirable to eliminate distortion in the last stage of an amplifier, since most of the distortion in an amplifier is introduced by this stage. An advantageous property of the circuit shown in Fig. 1 is that output distortion introduced by the last stage Q_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 magnitude 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 practice of the invention closely approaches this theoretical ideal.

The use of both positive and negative feedback in an amplifier enables a designer to achieve transmission characteristics that are not obtainable in amplifiers using only negative feedback. However, such an amplifier is conditionally stable. Insofar as vacuum tubes require a substantial warm-up time, they are relatively unsuitable for use in conditionally stable amplifiers. For this reason, positive feedback usually is not employed in vacuum tube amplifiers (although it can be if adequate provision is made for warm-up time). Transistors, on the other hand, are particularly suitable for use in conditionally stable circuits, because they have substantially no warm-up time.

Fig. 2 shows in greater detail an illustrative embodiment of the invention in conformance with the diagrammatic representation of Fig. 1. The interlaced feedback amplifier shown comprises three cascaded N–P–N junction transistor stages Q_1, Q_2, and Q_3, each connected in a common emitter configuration. Positive feedback path **18**, including feedback circuit β_1, interconnects the collector output **24** of transistor Q_2 with the base input **26** of transistor Q_1. Positive feedback path **20**, including feedback circuit β_2, interconnects the collector output **28** of transistor Q_3 with the collector output **30** of transistor Q_1 which in turn is coupled to the base input **32** of transistor Q_2 through coupling capacitor **34**. Negative feedback path **22**, which includes feedback circuit β_3, interconnects the collector output **28** of transistor Q_3 with the base input **26** of transistor Q_1. Appropriate bias potentials for each of the stages Q_1, Q_2, and Q_3 are provided by bias circuit **36**.

It should be noted that although N–P–N transistors in the common emitter configuration are shown, other configurations and transistors of different conductivity types may be used. Moreover, each of the β circuits may be active as well as passive and unilateral as well as bilateral.

In the illustrative embodiment of Fig. 2 it is apparent that, but for the insertion of resistor **38** in the connections between the collector output **24** of transistor Q_2 and the base input **40** of transistor Q_3, degradation of transistor Q_3 would substantially affect the amount of current fed back through feedback path **18**. Consequently, the value of resistor **38** should be at least an order of magnitude greater than the input impedance of transistor Q_3.

An important consideration in the design of feedback amplifiers is that of shaping the gain characteristic, i.e., controlling the rate at which the current or voltage gain of the amplifier falls off at frequencies outside the useful fraquency band, in order to provide the maximum amount of negative feedback consistent with stability requirements. In the illustrative embodiment of Fig. 2, low frequency shaping of the loop current transmission is provided by capacitors **42**, **44**, and **46**, each of which is connected between the emitter of its respective transistor and ground. Low frequency shaping is also provided by capacitor **48** in conjunction with resistors **49** and **50**. High frequency shaping of the loop current transmission is provided by the β_3 circuit and an interstage shaping network comprising the series combination of capacitor **52**, resistor **54**, and inductor **56**, the combination being connected between the collector **24** of transistor Q_2 and ground. High frequency shaping is also provided by inductor **51** in conjunction with resistors **49** and **50**.

In order to stabilize the positive feedback in the amplifier, the negative feedback loop 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 must decrease at a rate which is equal to or greater than the rate at which the magnitude of the loop gain of the negative feedback loop decreases. The illustrative embodiment of Fig. 2 has a 45 degree phase margin at both the low and high frequency ends of the useful frequency band.

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, therefore, there is no need for shaping elements in the β_1 and β_2 circuits. Accordingly, the β_1 and β_2 circuits may be purely resistive.

Input resistor **58** is serially inserted in the connections between the input terminal **10** of the amplifier and the base input **26** of transistor Q_1, primarily to insure that currents fed back through the feedback paths **18** and **22** are substantially fed into the base input **26** of transistor Q_1. The relatively high output impedance presented by the collector-emitter path of transistor Q_1 insures that substantially all of the current fed back through feedback path **20** is fed into the base input **32** of transistor Q_2.

The illustrative embodiment of Fig. 2 has the advantageous property that if either the input transistor Q_1 or the output transistor Q_3 fails by a factor as large, for example, as one hundred (i.e., if the current gain of either transistor drops to as low, for example, as one percent of its normal value), the over-all or external gain nonetheless remains substantially unaffected. The compensation for degradations in either the input transistor Q_1 or the output transistor Q_3 is therefore substantially perfect over the transmission band for which the amplifier is designed. Moreover, simultaneous degradation of transistors Q_1 and Q_3 will have a lesser effect on the external gain of the illustrative amplifier of Fig. 2 than such degradation would have in the case of a single loop version of this amplifier (for the single loop version, β_1 and β_2 would be equal to zero).

Although the present invention has been described with reference to a specific embodiment, it should be considered as illustrative, for the invention comprehends also such other embodiments as come within its spirit and scope.

What is claimed is:

1. An amplifier comprising an odd number of tandem connected stages, a first positive feedback path extending around at least two of said stages, a second positive feedback path extending around at least two of said stages and interlaced with said first feedback path, each of said feedback paths forming a loop with its associated enclosed stages, the gains of said loops, each being substantially equal to unity, and a negative feedback path extending around all of said stages.

2. An amplifier comprising an odd number of tandem connected stages, each of said stages comprising a junction transistor having an input and an output and having base, emitter and collector electrodes interconnected in the common-emitter configuration, a first positive feedback path feeding back a fracition β_1 from the output of the second of said stages to the input of the first of said stages, a second positive feedback path feeding back a fraction β_2 from the output of the third of said stages to the input of the second of said stages, a negative feedback path feeding back a fraction β_3 from the output of the third of said stages to the input of said first stage, said first, second and third stages having gains, respectively, of A_1, A_2, A_3, wherein the products $A_1A_2\beta_1$ and $A_2A_3\beta_2$ are each substantially equal to unity and wherein the product $A_1A_2A_3\beta_3$ is negative and large in magnitude compared to unity.

3. In a wave translating system comprising cascaded first, second, and third amplifying stages each having an input and an output, first positive feedback means coupling the output of said second stage with the input of said first stage, second positive feedback means coupling the output of said third stage with the input of said second stage, and negative feedback means coupling the output of said third stage with the input of said first stage, the feedback loop comprising said first and second stages and said first positive feedback means and the feedback loop comprising said second and third stages and said second positive feedback means each having substantially unity loop gain.

4. In a wave translating system comprising cascaded

first, second, and third amplifying stages each having an input and an output, first positive feedback means coupling the output of said second stage with the input of said first stage, second positive feedback means coupling the output of said third stage with the input of said second stage, and negative feedback means coupling the output of said third stage with the input of said first stage, the feedback loop comprising said first and second stages and said first positive feedback means and the feedback loop comprising said second and third stages and said second positive feedback means each having substantially unity loop gain, and the feedback loop comprising said first, second, and third stages and said negative feedback means having a loop gain whose absolute magnitude is greater than unity.

5. An amplifier having an input and an output comprising cascaded first, second and third transistors each having an input and an output, first positive feedback means interconnecting the output of said second transistor with the input of said first transistor, second positive feedback means interconnecting the output of said third transistor with the input of said second transistor, and negative feedback means interconnecting the output of said third transistor with the input of said first transistor, the feedback loop comprising said first and second transistors and said first positive feedback means and the feedback loop comprising said second and third transistors and said second positive feedback means each having substantially unity loop gain.

6. An amplifier having an input and an output comprising cascaded first, second, and third transistors each having an input and an output, a signal source for supplying signal waves to said input of said amplifier, an output circuit for receiving waves from said output of said amplifier, means for supplying appropriate bias potentials for said transistors, positive feedback means interconnecting the output of said second transistor with the input of said first transistor, positive feedback means interconnecting the output of said third transistor with the input of said second transistor, and negative feedback means interconnecting the output of said third transistor with the input of said first transistor, the feedback loop comprising said first and second transistors and said first positive feedback means and the feedback loop comprising said second and third transistors and said second positive feedback means each having substantially unity loop gain.

7. An amplifier in accordance with claim 6 wherein the feedback loop comprising said first, second, and third transistors and said negative feedback means has a loop gain whose absolute magnitude is greater than unity.

References Cited in the file of this patent

UNITED STATES PATENTS

2,657,282	Te Winkel	Oct. 27, 1953
2,763,732	Rockwell	Sept. 18, 1956

FOREIGN PATENTS

164,807	Australia	Aug. 24, 1955

OTHER REFERENCES

Shea: "Principles of Transistor Circuits," September 1953, page 351. (Copy in Division 69.)

Langford-Smith: "Radiotron Designer's Handbook," fourth edition, 1952, pp. 354, 355. (Copy in Division 69.)