NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

January 19, 1971

REPLY TO
ATTN OF: GP/43005

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No.	: 3,466,560
Government or Corporate Employee	: Government
Supplementary Corporate Source (if applicable)	: N. A.
NASA Patent Case No.	: XGS-02812

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☐ No ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Dorothy J. Jackson

Dorothy J. Jackson
Enclosure
Copy of Patent cited above

FACILITY FORM 602

N71-19466 (ACCESSION NUMBER)
5 (PAGES)
(NASA CR OR TMX OR AD NUMBER)
(THRU)
00 (CODE)
09 (CATEGORY)

N71-19466

X65-02812

Sept. 9, 1969 L. L. KLEINBERG 3,466,560

STABLE AMPLIFIER HAVING A STABLE QUIESCENT POINT

Filed Oct. 22, 1965

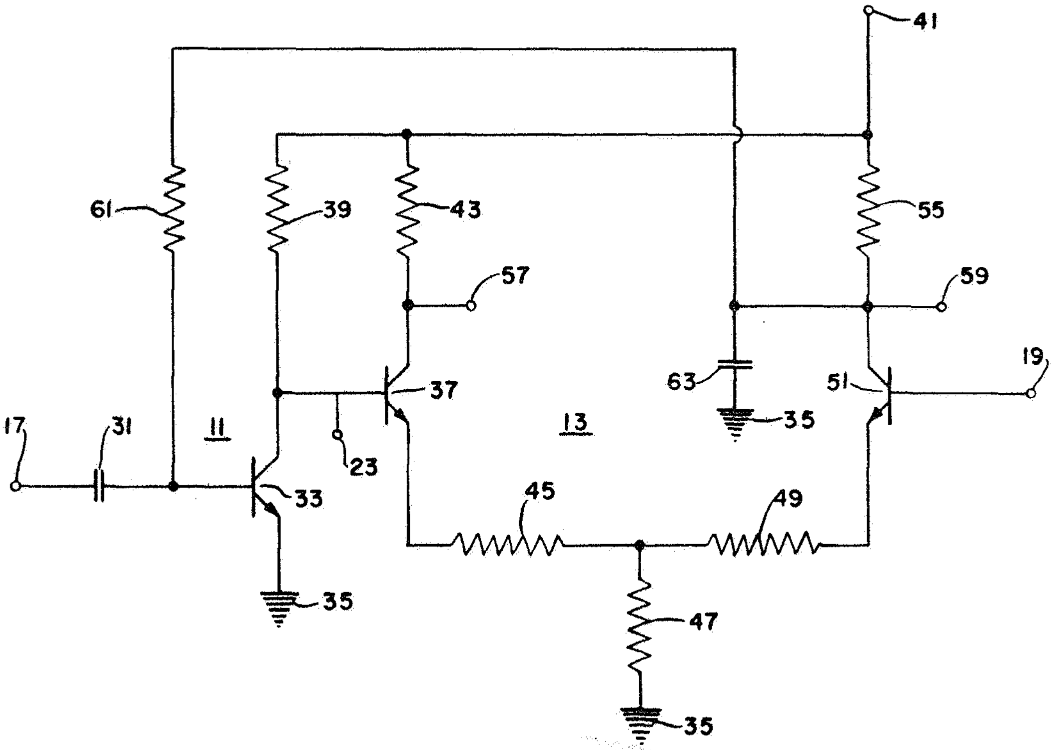
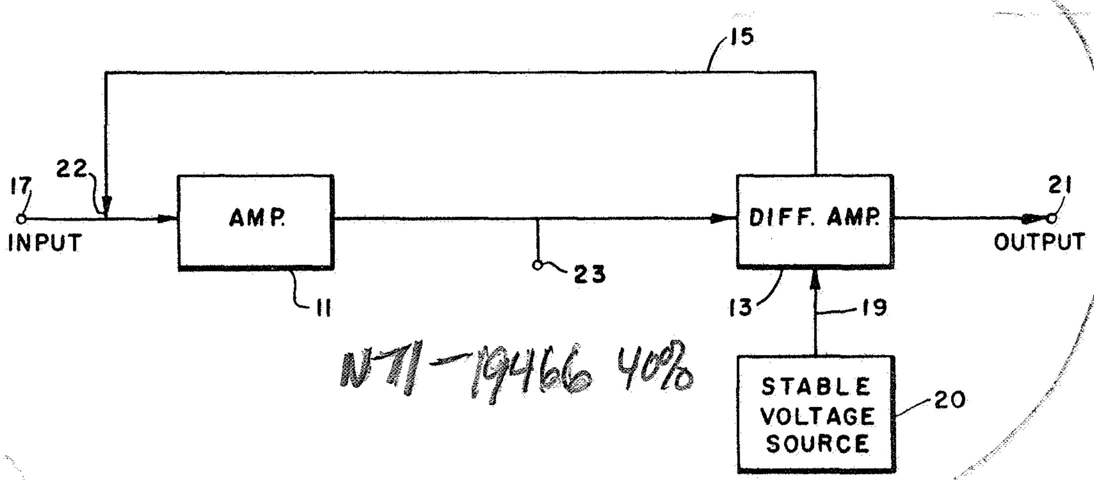


FIG. 2.



N71-19466 40%

FIG. 1.

INVENTOR
Leonard L. Kleinberg

BY [signatures]
ATTORNEYS

1127

United States Patent Office

3,466,560

Patented Sept. 9, 1969

1

3,466,560

STABLE AMPLIFIER HAVING A STABLE QUIESCENT POINT

Leonard L. Kleinberg, Greenbelt, Md., assignor to the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

Filed Oct. 22, 1965, Ser. No. 502,750

Int. Cl. H03f 3/68

U.S. Cl. 330—30 1 Claim

ABSTRACT OF THE DISCLOSURE

An amplifier utilizing a novel feedback system providing both stability and high gain which is particularly adaptable for monolithic and thin film construction. The quiescent point of the amplifier circuit is maintained at a constant voltage level through the use of feedback from a differential amplifier which amplifies the DC difference between the amplifier output and a stable reference.

The invention described herein may be manufactured and used by or for the government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to amplifier circuits and more particularly to stabilized high gain amplifier circuits.

Amplifiers in general are utilized in electronic circuitry to amplify either AC or DC signals. Conventional amplifier networks normally include a means to control the gain of the amplifier. This means may consist of a variable resistor connected in either a bias or feedback circuit. If the gain of the amplifier changes, due to the aging of components, for example, the operator may change the variable resistance setting and compensate for the change in gain. It will be appreciated that while this means for obtaining a stable amplifier gain is satisfactory in some environments it is unsatisfactory in others. For example, for ease of measurement, instrumentation amplifiers are used in electronic measurements circuits for amplifying a low level signal to a higher level. It will be similarly appreciated that an amplifier which is to be utilized in this environment for continuous measuring must have either a stabilized or a continuously observed gain. In other words, to eliminate the problem of frequent recalibration, the amplifier must have stable gain.

The gain of an amplifier, particularly a transistor amplifier, varies with the age of its components. Temperature rise in the amplifier due to the internal heat generation as well as changes in environment also affect the gain of an amplifier. These variations are important when the amplifier is utilized in a laboratory and are critically important when the amplifier is utilized with instrumentation located at a remote point as, for example, in a missile or spacecraft. In recent years there has been an increasing effort to measure the earth's environment by utilizing instrumented spacecraft such as orbiting satellites and sounding rockets. Many of the desired measurements are made by instruments whose outputs are at low signal levels. Instrumentation amplifiers are required, therefore, to amplify the output signal to a higher magnitude prior to transmission to receive stations located on the earth. It is in situations of this type that the invention finds particular utility, but it will be appreciated that laboratories and satellites are only two examples of where a stable gain amplifier is useful. Other uses, for example, include instrumentation or relay amplifier networks utilized under the sea or at remote locations on the earth's surface.

Prior art apparatus for obtaining stabilized amplification has included electronically controlled servo systems

2

to vary the control resistance of the amplifier, similar to manual control, to compensate for gain drift. However, this approach requires the use of complicated and comparatively bulky apparatus.

Other previously developed amplifiers have attempted to resolve the foregoing problems by electronically providing multiple stage amplifier systems having feedback to improve the stability thereof. However, in many cases this feedback has introduced resistance or reactance in the feedback loop which limits the degree of drift compensation that can be obtained. Further, to obtain a high closed loop gain, prior art feedback amplifiers require a very high open loop gain. High open loop gain is difficult to achieve, particularly with DC coupled amplifiers. In addition high gain requires high resistance, the value of which becomes increasingly prohibitive.

Still others have a relatively fixed emitter to base bias in a compensation transistor, however, this prevents operation of the amplifier in a high impedance mode. The problem has also been approached by carefully choosing components to obtain drift compensation as the components age. All of these devices require highly stable components that are too delicate, requiring frequent replacement.

It is an object of the invention to provide an improved stabilized high gain amplifier.

It is a further object of the invention to provide a more simple stabilized high gain amplifier.

It is a still further object of the invention to provide an improved signal amplifier network which utilizes transistors to furnish a highly stable output signal which is unaltered by the aging of components and is generally free of dependence on the careful choice of the network's electronic components.

The foregoing and other objects are accomplished by the provision of a unique feedback amplifier network. Specifically, in accordance with a principle of the invention the signal to be amplified is first applied to a conventional amplifier circuit. The output from the standard amplifier is then fed into one of the inputs of a differential amplifier while the second input to the differential amplifier is provided by a stable voltage source; and finally an output from the differential amplifier is fed back to bias the input of the conventional amplifier stage. This simple electronic network provides a signal amplification apparatus which has high gain as well as a stable output signal. Further, the system is easily controlled since the input from the stable power source can be selectively varied to provide a desired variation in the amplification of the system. Similarly, a selective variation of the supply voltages on the system's amplification elements also results in a variation in the gain of the amplifier. It will therefore be appreciated that in addition to its other features, another advantage of the invention is its ease of control. Still another advantage is that the feedback bias can vary over a wide dynamic range and still accomplish the purpose of the invention.

It will be appreciated that, due to the feedback bias mode of operation, the invention has the additional advantage of being susceptible to micro circuit construction.

The foregoing objects and many of the attendant advantages of the invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description taken in conjunction with the accompanying drawing wherein:

FIG. 1 is a block diagram of the overall system of the present invention; and

FIG. 2 is a schematic diagram of an electronic network in accordance with the invention.

FIG. 1 discloses generally a first amplifier stage **11**, a differential amplifier stage **13**, and a feedback bias connection **15**. The input to the first amplifier's stage **11** is connected to an input terminal **17**. The output from the first amplifier stage **11** is connected to one input of the differential amplifier **13**. The differential amplifier has a second input **19** adapted for connection to a stable source of electric power **20**. The output from the differential amplifier **13** is connected to a first output terminal **21**. Also connected to the differential amplifier **13** is the feedback bias connection **15** which is connected to the input of the first amplifier at **22**. In addition, a second output terminal **23** is connected directly to the output from the first stage amplifier **11**. This second output terminal **23** provides an output which is more stable, but of lower gain than the output from the first output terminal **21** as hereinafter described.

The circuit illustrated in FIG. 1 will operate upon the application of an input signal to the input terminal **17**. This signal is amplified by the first amplifier stage **11** and applied to the differential amplifier **13** as one of its inputs. The differential amplifier amplifies the DC difference between the input signals from the amplifier stage **11** and the stable source **20**. As hereinafter described, in one embodiment of the invention, the differential amplifier **13** has two outputs. One output is DC and is applied to the feedback bias connection **15** for stabilization. The second output is the amplified input signal and is applied to the first output terminal **21** for further application to additional electronic circuitry as desired by a network utilizing the herein described system.

As understood, the system operates on the principle that an amplifier will maintain stability if the DC operating point of the system is maintained stable. The invention performs this function by utilizing the differential amplifier to sense a shift in this operating or quiescent point and provide a DC feedback to compensate for the shift. This feedback varies the bias on the input to maintain the amplifier at the quiescent point. Consequently, when the output is taken from the first stage amplifier **11** it is extremely stable over a wide range of variation in circuit components due to temperature, aging or other factors. When the output is taken from the differential amplifier the stability is not as good due to the variation in parameters of the elements included in the differential amplifier. However, due to the second stage of amplification, the gain is increased. Consequently although both outputs have high gain and stability, the one has a higher gain while the other has superior stability. It will be appreciated, therefore, that the foregoing network provides a simple amplifier that is stable over a wide range of system variations due to the utilization of a differential amplifier in conjunction with a stable voltage source to maintain stabilization.

FIG. 2 illustrates a schematic diagram of a circuit which operates in accordance with the present invention. The input signal is applied to the input terminal **17** and coupled through a capacitor **31** to a first transistor **33** which preferably has a high current amplification factor of over 100. The emitter of the first transistor is connected to ground **35**. Hence, this first transistor constitutes a grounded emitter amplifier stage. The output from the first transistor is taken from its collector and applied to the base of a second transistor **37**. The collector of the first transistor is connected through a resistor **39** to a supply source **41**. The collector of the second transistor is also connected through a resistor **43** to the supply source **41**. The emitter of the second transistor **37** is connected through a pair of resistors **45** and **47**, connected in series, to ground **35**. The interconnection between the last two described resistors **45** and **47** is connected through a further resistor **49** to the emitter of a third transistor **51**. The base of the third transistor **51** is connected to the input terminal **19** adapted for connection to the stable voltage source **20** (FIG. 1). The collector of the third transistor **51** is connected through still another resistor **55** to the supply source **41**.

The second and third transistors **37** and **51** in the

above described configuration correspond to the differential amplifier **13** described in connection with FIG. 1. The output from the differential may be taken at the collector of the second transistor **37** at a terminal **57**, or at the collector of the third transistor **51** at a terminal **59**. FIG. 2 illustrates one output **59** being taken at the collector of the third transistor **51** and fed back through a feedback resistor **61** to the base of the first transistor **33**. To provide an AC by-pass this feedback output is coupled through a capacitor **63** to ground **35**.

In accordance with the invention the circuit illustrated in FIG. 2 operates by amplifying the signal applied at the input terminal **17** of the first stage **11** which comprises the first transistor **33** in the grounded emitter configuration. The output taken from the collector of the first transistor **33** is applied as one input to the differential amplifier **13**. The third transistor has its base connected to a stable source of voltage at terminal **19**. The differential amplifier amplifies the DC difference between the two input signals and generates an output at the collector of the third transistor **59**, which is fed back through the feedback resistor **61** to stabilize the input to the overall network. As stated above the differential amplifier senses changes in the quiescent point of the first stage of amplification and through the feedback arrangement varies the input bias to maintain the first stage at said operating point. Hence, the foregoing described system is an electronically simple feedback amplifier which is stable over a wide range of variations in circuit components due to aging, environmental or other causes.

As set forth above the outputs for application to other systems can be obtained at various points, if a highly stable output is desired it can be obtained from the collector of the first transistor **33**. If somewhat lower stability but increased gain is desired the output can be taken from the collector of the second transistor **37**.

In the preferred embodiment of the invention the first amplification stage constitutes a transistor having a high beta (the current amplification factor of the transistor) however, any transistor having a beta value over about 100 will operate in a satisfactory manner.

To more fully understand the overall concept of the invention the following mathematical analysis of the embodiment of the invention illustrated in FIG. 2 is presented wherein:

K_v=voltage amplification of the first transistor **33** at the second output terminal **23**;
R_l=load on the first transistor **33**;
r_e=emitter resistance of the first transistor **33**;
i_c=collector current of the first transistor;
E_c=value of the supply voltage **41**;
e_c=voltage on the collector of the first transistor at its quiescent operating point; and

$$F=\frac{E_c-e_c}{E_c}$$

where F is a constant determined by the values of E_c and e_c.

For a high beta transistor:

$$K_v \approx \frac{R_l}{r_e} \tag{1}$$

also,

$$r_e \approx \frac{1}{39 i_c} \tag{2}$$

and,

$$i_c=\frac{E_c F}{R_l} \tag{3}$$

therefore,

$$r_e \approx \frac{R_l}{39 E_c F} \tag{4}$$

and $$K_v \approx 39FE_c \qquad (5)$$

Equation 5 shows that the voltage gain of the first transistor **33** is independent of load resistance and depends upon the quiescent and supply voltages. If the quiescent voltage is maintained constant the gain will be stable regardless of any change in the load resistance. This function is performed by the differential amplifier and its feedback bias connection as hereindescribed.

Further the amplification at the output at the collector of the second transistor **37** is represented by approximately

$$39FE_c\left(\frac{R_{43}}{R_{45}+R_{49}}\right)$$

Where R_{43} equals the value of the resistance **43** between the collector of the second transistor **37** and the supply source **41**; and $R_{45}+R_{49}$ equals the value of the resistance **45** and **49** between the emitters of the second and third transistors **37** and **51**. In this case, the amplification of the signal is increased. However, as stated above, the stability is decreased due to the amplification now depending on the additional resistance factors.

The foregoing has been a brief mathematical analysis of the invention to illustrate how the invention meets the objects of the invention and provides a stable high gain amplifier. Although the analysis has been applied to the circuit illustrated in FIG. 2, a similar analysis can be performed for other specific circuits meeting the broader concept of the invention as illustrated in FIG. 1.

It will be appreciated that the foregoing detailed description sets forth an embodiment of the invention which mets all of the foregoing objects and provides a simple, stable high gain amplifier. However, it should be understood that the invention may be practiced otherwise than as specifically herein disclosed. For example, the principle of the invention has been disclosed with a grounded emitter amplifier, however, a grounded base amplifier falls within the scope of the invention. Similarly, a voltage divider can be coupled to the supply source to provide the stable source rather than an external source. Consequently, it is to be understood that, within the scope

of the appended claim, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. In a stabilized high gain amplifier network consisting of resistors, capacitors and semiconductive devices, the improvement comprising:

an input terminal;

a supply power source;

a first high beta transistor, the base of said first transistor connected to said input terminal;

the collector of said first transistor connected to said supply power source;

a second transistor;

the base of second transistor connected to the collector of said first transistor; the collector of said second transistor connected to said supply power source; a third transistor; the base of said third transistor adapted for connection to a stable source of electronic signals; the collector of said third transistor connected to said supply power source; a first resistor; a second resistor; said first and second resistors connected in the series between the emitters of said second and third transistors; a third resistor; said third resistor connected between the junction of said first and second resistors and the emitter of said first resistor; a fourth resistor; said fourth resistor connected between the collector of said third transistor and the base of said first transistor; a pair of output terminals connected to the collector of said first transistor.

References Cited

UNITED STATES PATENTS

3,304,512 2/1967 McMillan ---------- 330—26 X

ROY LAKE, Primary Examiner

L. J. DAHL, Assistant Examiner

U.S. Cl. X.R.

330—26