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

REPLY TO ATTN OF: GP

November 6, 1970

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. : 3,501,712

Government or Corporate Employee : Hughes Aircraft Company International Airport Station Los Angeles, California

Supplementary Corporate Source (if applicable) : Jet Propulsion Laboratory

NASA Patent Case No. : XNP-06937

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [x] 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 . . ."

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Enclosure
Copy of Patent cited above

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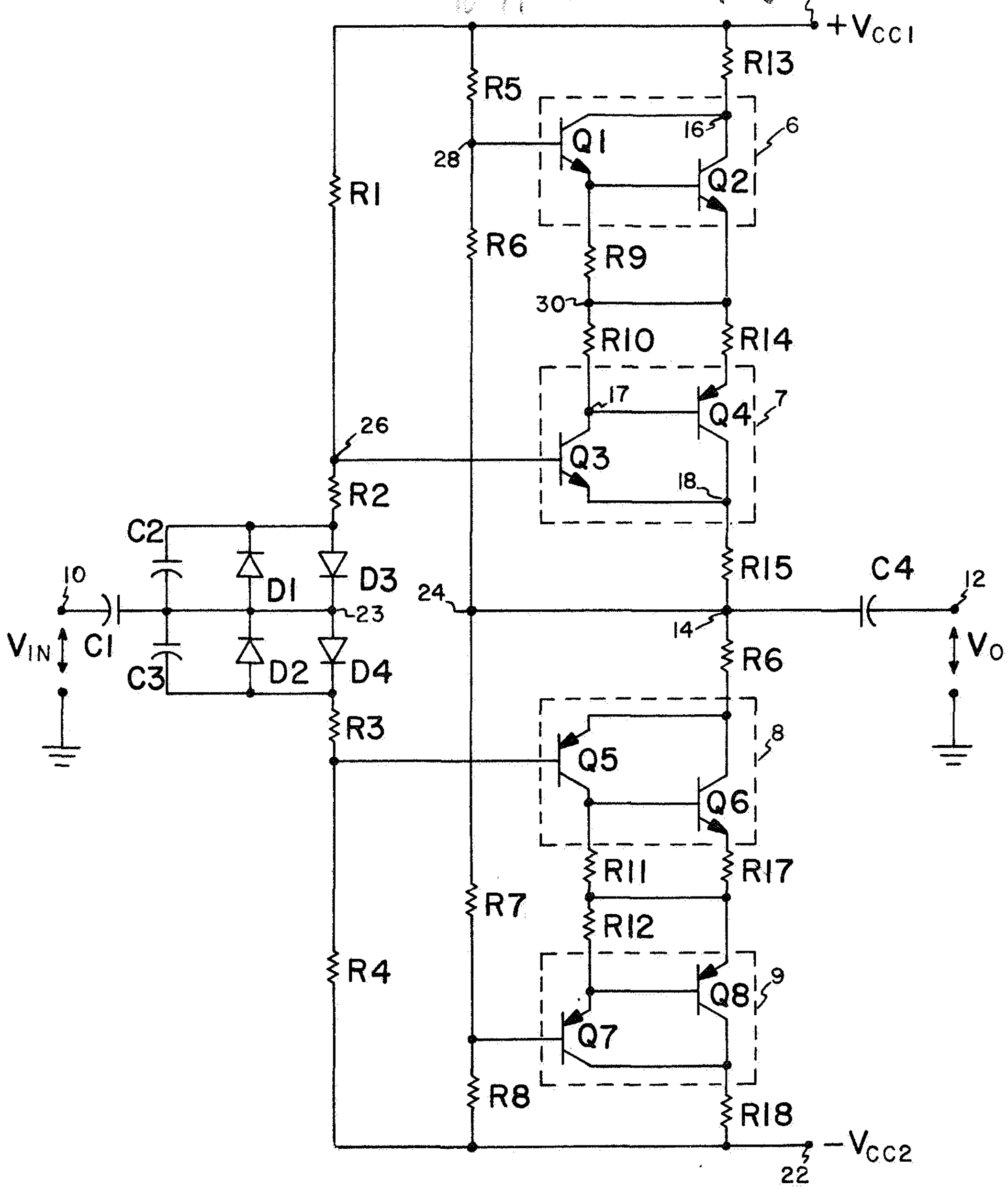
March 17, 1970 JAMES E. WEBB 3,501,712

ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HIGH VOLTAGE TRANSISTOR CIRCUIT

Filed May 17, 1967

N71-19516 408



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BY [signature]

ATTORNEYS

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HIGH VOLTAGE TRANSISTOR CIRCUIT

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of James S. Lee, Santa Barbara, Calif.

Filed May 17, 1967, Ser. No. 640,449
Int. Cl. H03f 3/68
U.S. Cl. 330—30 5 Claims

ABSTRACT OF THE DISCLOSURE

A transistor amplifier which has two series connected transistor subcircuits for sharing the output voltage and thus enabling higher voltage operation, wherein one subcircuit is of the Darlington type and the other is a complementary pair which eliminates a base-emitter in the feedback path; the amplifier providing a high input impedance, low output impedance, and low power dissipation.

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

This invention relates to semiconductor or transistor circuits.

In many electronics applications, a high-voltage high-frequency amplifier of simple construction is needed. However, the output voltage swing of transformerless transistor amplifiers is usually limited by the breakdown voltage of the transistors. The limitation is especially troublesome in high frequency applications because high frequency transistors typically have a low breakdown voltage. Transistor circuits have been designed which employ a series connected chain of transistors to distribute the output voltage, so that a high output voltage may be impressed across the entire chain. However, such circuits have generally required low resistance feedback and biasing resistors, and have resulted in relatively large power dissipation, high output resistance and low input resistance.

Accordingly, one object of the present invention is to provide an amplifier circuit for operation at high output voltage and high frequency, which is more efficient and more stable than amplifiers available heretofore.

Another object of the present invention is to provide an amplifier circuit utilizing semiconductor or transistor type elements which is capable of delivering high voltage outputs with less power dissipation, lower output impedance and higher input impedance than transistor circuits available heretofore.

Yet another object of the present invention is to provide a high voltage, low power-dissipation, complementary emitter follower amplifier of high voltage gain stability and high zero-signal idle current stability.

SUMMARY OF THE INVENTION

The foregoing and other objects of the invention are realized in one embodiment which is a complementary emitter follower type amplifier for class-A push-pull operation. Each complementary branch of the circuit has two series connected subcircuits, each subcircuit having about 50% of the branch voltage across it so that a high voltage can appear across the entire branch without breakdown of either subcircuit.

Instead of using a single transistor for each subcircuit, each subcircuit includes a pair of compound-connected

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transistors. One of the subcircuits is a Darlington connection which provides high current gain and high input resistance, thereby enabling the use of high value resistors in the feedback circuit from the amplifier output to the Darlington input, and greatly reducing power dissipation in the feedback resistors. The Darlington connection also reduces output impedance. The other subcircuit is similar to a Darlington connection but has the emitter and collector of the compound pair connected togethed instead of having the two collectors connected together. The modification from a Darlington connection results in there being only one base-emitter junction in the signal path. Two base-emitter junctions have a greater instability than a single junction, and as a result this arrangement provides better voltage gain stability and better zero-signal idle current stability than a Darlington connection, while retaining the desirable input and output impedance characteristics of the Darlington connection.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself will best be understood from the following description when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

The figure is a schematic diagram of a preferred embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The figure is a schematic diagram of a complementary emitter follower circuit for amplifying an alternating-current signal V_{in} received between input terminal **10** and ground, and delivering an alternating current signal V_o between output terminal **12** and ground. The circuit has two complementary branches to enable push-pull operation, a first branch connected between a positive voltage supply $+V_{cc1}$ and midterminal **14**, and a second branch connected between a negative voltage supply $-V_{cc2}$ and the midterminal **14**. The two branches are similar in construction and operation, so the circuit description of one applies to the other.

The first branch comprises a Darlington connected subcircuit **6** having transistors Q_1 and Q_2 with their collectors connected together at point **16** and with the emitter output of Q_1 directly connected to the base input of Q_2. This compound connection, commonly known as the Darlington connection, results in a high current gain or amplification of signals received at the base of Q_1, the amplified signals being delivered at the emitter of Q_2, and in a high input resistance to the base of Q_1. A second subcircuit **7** of the branch is a compound connection of transistors Q_3 and Q_4, wherein the emitter of Q_3 is connected to the collector Q_4 at point **18**. This connection of Q_3 and Q_4 also provides high current gain and high input resistance.

The circuit power is supplied by a voltage source $+V_{cc1}$ connected at the terminal **20** of the first complementary branch and a voltage source $-V_{cc2}$ connected at the terminal **22** of the second branch. A first series-connected group of resistors R_1, R_2, R_3 and R_4, and two diodes D_3 and D_4, all of which may be referred to as an input series connection of resistors or chain of resistors, connected between the two voltage sources at terminals **20** and **22**, provides biasing for the operation of input transistors Q_3 and Q_5. For $V_{cc1}=V_{cc2}$, the midpoint **23** of that group of resistors and diodes is generally at approximately zero average potential. The resistor R_2 is of small value compared to R_1; when the small voltage drop across R_2 is added to the voltage drop across diode

D_3 (*which is approximately equal to the base-emitter* voltage of Q_3) there is provided a potential at point **26** which is generally enough to raise the voltage of the base of Q_3 to a desired operating point.

A second series-connected group of resistors R_5, R_6, R_7 and R_8, which may be referred to as a feedback series connection or chain of resistors, connected between the two voltage sources at terminals **20** and **22**, provides biasing for the operation of input transistors Q_1 and Q_7. This group of resistors, because of its midpoint connection at **24** to the circuit output, also serves as part of a feedback loop. Resistor R_5 is of the same general magnitude as R_6 so the potential at point **28**, which is connected to the base of Q_1, is at a high potential. Thus, the emitter of Q_1 will be at a high potential since it will be only approximately 0.6 volt below the voltage at point **28**. The potential at **24** varies directly with the output voltage V_0, and the potential at **28** varies about half as much as point **24**, thereby providing feedback to Q_1.

The output transistors Q_2 and Q_4 are connected in series with the voltage sources $+V_{cc1}$ and $-V_{cc2}$ and resistors R_{13}, R_{14} and R_{15} of the first branch, and with the corresponding transistors Q_8 and Q_6 and resistors R_{18}, R_{17} and R_{16} of the second branch. The change in output voltage at **14**, or voltage swing caused by the first branch is due to the collector-emitter voltages across Q_2 and Q_4. The values of R_5 and R_6 are chosen so that the voltages across these transistors are nearly equal and therefore the voltage swing of the output signal at **14** can equal almost twice the breakdown voltage of either transistor Q_2 or Q_4.

Resistors R_9 and R_{10} are stabilizing resistors for Q_2 and Q_4, respectively. Stabilization is achieved by shunting the collector leakage current of Q_2 through R_9 and the leakage current of Q_4 through R_{10}. Resistor R_{13} provides short circuit protection for the first branch of the circuit and R_{18} provides short circuit protection for the second branch.

The input V_{in} passes through a capacitor C_1 at the input which prevents DC coupling. Positive excursions of V_{in} raise the potential of point **23** and therefore the potential at **26**, which increases the output voltage. Diode D_2 is provided to prevent emitter-base breakdown of Q_3 for input voltage swings that exceed the output voltage swing capability. For example, if V_{in} has an instantaneous negative voltage which is even more negative than $-V_{cc2}$, so that the output could not follow it, then current will flow from $-V_{cc2}$ through D_2 to limit the negative excursion at point **23** to a maximum of approximately $-V_{cc2}$. Diode D_1 prevents emitter breakdown for excessive positive inputs. Capacitor C_2 minimizes distortion on the positive peaks of high-frequency, large swing signals. Without C_2 the input capacitance of Q_3 would cause D_3 to become reverse biased during the positive peaks of high frequency, large swing signals, if the product of R_1 and the input capacitance of Q_3 were comparable to the period of the waveform. C_3 minimizes distortion on the negative peaks of high-frequency, large swing signals in an analogous way.

The second branch is constructed complementary to the first, with C_3, D_2, D_4, R_3, R_4, R_7, R_8, R_{11}, R_{12}, R_{16}, R_{17} and R_{18} being equal and connected similarly to C_2, D_1, D_3, R_2, R_1, R_6, R_5, R_{10}, R_9, R_{15}, R_{14} and R_{13} respectively. In the second branch subcircuits **9** and **8** correspond to the subcircuits **6** and **7**, respectively, of the first branch. The transistors Q_1, Q_2 and Q_3 are npn types with characteristics complementary to those of Q_7, Q_8 and Q_5 which are pnp types. Similarly, Q_4 is a pnp type with characteristics complementary to those of Q_6 which is an npn type.

Before a signal V_{in} is received, Q_2, Q_4, Q_6 and Q_8 are almost cut off and, assuming V_{cc1} equals V_{cc2}, points **14** and **24** are at zero potential. The voltage across each of the transistors Q_2, Q_4, Q_6 and Q_8 is one half V_{cc1} or V_{cc2}. Transistors Q_1, Q_3, Q_5 and Q_7 are also almost cut off.

When a positive V_{in} is received, the potential at **26** rises from a few tenths of a volt to nearly the V_{in} input voltage, the collector-emitter voltage across Q_3 falls while the Q_3 emitter voltage rises. When the collector-emitter potential of Q_3 falls, Q_4 is driven further "on" so that the emitter-collector voltage across Q_4 falls and the potential of the Q_4 collector rises. The rising voltage at the collector of Q_4 and hence the voltage at **14** is coupled back to the base of Q_1 through R_6. Since R_5 and R_6 form a voltage divider with a division of approximately one-half, the signal voltage at the base of Q_1 is approximately one half that at **14**. Thus, as point **14** rises, one half of this rise appears at the base of Q_1, and therefore at the emitter of Q_1. The rise at the emitter of Q_1 is coupled to the base of Q_2, and causes the emitter of Q_2 to rise. Since the emitter of Q_2 rises one half as much as point **14**, the collector-emitter voltages of Q_2 and Q_4 decrease by approximately the same percentages. As the output voltages (collector-emitter) of Q_2 and Q_4 decrease, the voltage at **14** rises and the output of the circuit, delivered through C_4 to terminal **12**, rises.

The circuit produces some cross-over distortion, as is generally found in complementary-symmetry transistor amplifiers. However, in the circuit of this invention only one base-emitter junction is in the signal path between point **14** and point **26**, so cross-over distortion is reduced to a minimum and zero-signal idle current is relatively small and constant. The amount of cross-over distortion and zero-signal current instability would be increased if a Darlington connection were employed (achieved by connecting an npn Q_4 with its emitter at point **18** and its collector connected to resistor R_{14}, connecting Q_3 so that its emitter were at **17** and it collector were at **30**, and changing resistors R_{10} and R_{14} to open and short circuits, respectively).

The input impedances of the subcircuits Q_1, Q_2 and subcircuits Q_3, Q_4 approximate the h_{FE} product of each of the two transistors times the load impedance at the output of each respective subcircuit. The output impedance of each is lower than that of a single transistor, since the output impedance of each subcircuit is the source impedance divided by the h_{FE} product. Higher input impedances enable the use of large resistors R_5 and R_6 which deliver current to Q_1 and a large R_1 which supplies current that flows to Q_3, and therefore the dissipation of power in these resistors is small.

One embodiment of the invention has been constructed utilizing the particular transistors and other components designated in the following table, all resistors being ½ watt, 5% tolerance types except R_1 and R_4 which are of 1% tolerance and R_{13} and R_{18} which are 1 watt types. All capacitors are of a non-polar type.

Component:	Characteristic
R_1	21.5K ohms—1% tolerance.
R_2	39 ohms.
R_3	39 ohms.
R_4	21.5K ohms—1% tolerance.
R_5	3.9K ohms.
R_6	4.7K ohms.
R_7	4.7K ohms.
R_8	3.9K ohms.
R_9	1K ohms.
R_{10}	1K ohms.
R_{11}	1K ohms.
R_{12}	1K ohms.
R_{13}	33 ohms—1 watt.
R_{14}	10 ohms.
R_{15}	10 ohms.
R_{16}	10 ohms.
R_{17}	10 ohms.
R_{18}	33 ohms—1 watt.

Component:	Characteristic
C_1	15 microfarads.
C_2	0.001 microfarads.
C_3	0.001 microfarads.
C_4	1000 microfarads.
D_1	Type 1N914.
D_2	Type 1N914.
D_3	Type 1N914.
D_4	Type 1N914.
Q_1	Type 2N2218A.
Q_2	Type 2N2218A.
Q_3	Type 2N2218A.
Q_4	Type 2N2904A.
Q_5	Type 2N2904A.
Q_6	Type 2N2218A.
Q_7	Type 2N2904A.
Q_8	Type 2N2904A.

The circuit was connected to voltage sources wherein $+V_{cc}=+40$ volts and $-V_{cc}=-40$ volts, and was operated with large input voltages such as 60 volts peak-to-peak. The circuit has been found to display low power dissipation and low output impedance, in addition to high input impedance and good stability. It should be understood, of course, that the specific component values are merely illustrative and should not be considered as limiting the scope of the invention.

While a particular circuit embodying the invention has been described in detail, various modifications will occur to skilled circuit designers which utilize the teachings of the invention. Accordingly, the invention is not limited to the particular embodiment described and illustrated, but only by a just interpretation of the following claims.

What is claimed is:

1. An amplifying circuit comprising:
an output terminal;
a plurality of output transistors having their emitters and collectors connected in series, said plurality of output transistors connected to said output terminal;
a plurality of input transistors, each having an output connected substantially directly to one of said output transistors;
biasing means connected to said plurality of input transistors for establishing operating points of said plurality of output transistors wherein approximately the same maximum voltage appears across each output transistor;
an input terminal;
means for connecting said input terminal to at least one of said input transistors, to form a high input impedance and at least one path between said input and output terminals with a single emitter base junction in said path;
the connection of a first of said input transistors to one of said output transistors includes the direct connection of the collector of the input transistor to the base of the output transistor and the direct connection of the emitter of the input transistor to the collector of the output transistor;
the connection of a second of said input transistors to one of said output transistors includes the direct connection of the collectors of said transistors and the direct connection of the emitter of the input transistor to the base of the output transistor; and
said biasing means includes a first chain of resistors at least one of which is connected between said input terminal and the base of said first of said input transistors, and a second chain of resistors at least one of which is connected between said output terminal and the base of said second of said input transistors, the resistors in said second chain being in the range of several thousand ohms.

2. A transistorized amplifying circuit comprising:
an input terminal for receiving an input signal;
an output terminal; and
at least one circuit branch coupled to said input terminal and to said output terminal to amplify the input signal and apply it at said output terminal, said circuit branch including;
first, second and third transistors of a first conductivity type and a fourth transistor of a second, opposite conductivity type, each transistor having base, collector and emitter electrodes,
first means for connecting said second and fourth transistors in series between a potential source and said output terminal, with the collector emitter junction of said second transistor in series with the emitter collector junction of said fourth transistor,
second means for directly connecting the collector and emitter of said first transistor to the collector and base of said second transistor respectively,
third means including resistive means for connecting the base of said first transistor to a potential which is a function of the potential difference between said source and the potential at said output terminal,
and fourth means for connecting said third transistor to said input terminal, to said output terminal, and to said fourth transistor to provide a high input impedance to said fourth transistor and to provide only a single emitter-base junction of said third transistor between the output and input terminals, said fourth means include a first resistor connected between said input terminal and the base of said third transistor, a second resistor connected at one end to said output terminal and at its opposite end to both the emitter and collector of said third and fourth transistors, respectively, and said circuit branch further including a third resistor connected between the base of said third transistor and said potential source.

3. The arrangement as recited in claim 2 wherein said third means include fourth and fifth resistors connected in series between said output terminal and said potential source, and means connecting the base of said first transistor to the junction point of said fourth and fifth resistors whose relative resistive values control the relative changes in the collector-emitter potentials of said second and fourth transistors, so as to control the maximum emitter potentials not to exceed the breakdown potential of either of said second and fourth transistors.

4. The arrangement as recited in claim 3 wherein the resistance of each of said fourth and fifth resistors is in the range of several thousand ohms, to minimize power losses therein.

5. The arrangement as recited in claim 4 wherein said circuit includes another circuit branch, complementary said one circuit branch, and including first, second and third transistors of said second conductivity type and a fourth transistor of said first conductivity type, said another circuit branch including a terminal connectable to a second potential source.

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