

RESERVE COPY PATENT SPECIFICATION

807,632



Date of Application and filing Complete

Specification: Nov. 20, 1956.

No. 35489/56.

Application made in United States of America on Jan. 10, 1956.

Complete Specification Published: Jan. 21, 1959.

Index at acceptance:—Class 40(8), T.

International Classification:—H03f.

COMPLETE SPECIFICATION

Transistor Amplifier With Frequency Bandwidth Stabilization

We, TEXAS INSTRUMENTS INCORPORATED, of 6000 Lemmon Avenue, Dallas, Texas, United States of America, a corporation organized and existing under the laws of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to transistor circuits and more particularly to an automatic gain controlled transistor radio frequency amplifier circuit exhibiting constant bandpass characteristics.

It is now well recognized that, although the circuit behaviour of transistors and vacuum-tubes is quite similar in many respects, the triode transistor is by no means fully analogous in its behaviour to the conventional vacuum-tube. Many of the unique problems in transistor circuit design not encountered in vacuum-tube circuit design have their origins in the coupling effect between the output and input circuits of the transistor, the relatively low input impedance of the device as compared with its output impedance and the fact that a transistor is primarily a current operated, rather than a voltage operated, device.

The above mentioned characteristics of transistors give rise to a problem in providing automatic gain control in a transistor cascade amplifier where the automatic gain control action is obtained by changing a d.c. bias voltage to one or more of the amplifier stages in accordance with the output level of some later stage. The automatic gain control voltage superimposed on the normal d.c. bias of the transistor affects the gain of the stage in two distinct ways. First, the gain of the transistor is directly dependent upon its d.c. bias currents and any change in these bias currents changes the gain. Secondly, changes in the bias currents of the transistor produce changes in both the resistive and reactive components of its input impedance causing impedance mismatches

[Price 3/6]

between the transistor input and the preceding stage. These impedance mismatches lower the gain of the stages affected but they also have the effect of de-tuning and unloading the inter-stage coupling circuits so that both the tuning and bandpass characteristic of the amplifier becomes a function of the automatic gain control applied or, in effect, a function of the input signal strength. Tuning or bandpass characteristics which vary with the input signal strength or with automatic gain control voltage are quite undesirable in amplifiers for a great many applications.

Accordingly, it is the principal object of the present invention to provide a transistor amplifier circuit for use at radio frequencies in which the tuning and bandwidth remains substantially constant over a wide range of automatic gain control voltages.

It is a further object of the present invention to provide a new transistor amplifier circuit for use in cascade amplifiers and other arrangements wherein the automatic gain control range is greatly extended over the control range of other known transistor amplifier circuits for a given bandwidth characteristic.

It is a still further object of the present invention to provide a transistor amplifier circuit in which the input impedance changes produced by automatic gain control are minimized.

These and other objects of the present invention will become more fully apparent from the following detailed description and the accompanying drawing in which:—

Fig. 1 is a partial schematic of a bandwidth stabilized transistor amplifier circuit showing the preferred embodiment of the present invention; and

Fig. 2 is a graphical chart showing the typical manner in which transistor input impedance varies with changes in emitter current for both an ordinary transistor amplifier and the bandwidth stabilized transistor amplifier of the present invention.

With reference now to Fig. 1, there is

illustrated by partial schematic diagram a typical n-p-n transistor amplifier automatic gain controlled stage comprising the transistor 10 with its emitter connected to ground through the emitter bias resistor 11, its collector connected to B+ voltage and to an impedance matching network 12 coupling the output signal of the circuit to the next stage and its base connected through the resistor 13 to an automatic gain control voltage derived from the output signal of a later stage of the amplifier. The usual a.c. bypass capacitor 9 is connected across the emitter resistor 11. The input signal is fed to the base of the transistor 10 from the preceding stage of the amplifier through the impedance matching and coupling circuit 14. The amplifier circuit, as thus far described, constitutes the essential parts commonly used in a transistor amplifier stage. The two coupling circuits designated generally as 12 and 14 may be of any of the many inter-stage impedance matching networks well-known in the art such as, for example, double or single tuned transformers or T or TT networks of the inductance coupled, capacitance coupled, or inductance and capacitance coupled types, tuned to the operating frequency and designed and adjusted for impedance match between the stages coupled. Since the coupling circuit is a reactance circuit, it is designed to have a certain desired bandpass characteristic when adjusted or tuned to match the input impedance of the transistor with which it is to be used. Because there is a unique adjustment of the coupling circuit for impedance match for each set of transistor bias conditions, that is, the adjustment can produce impedance match for only one transistor bias condition, adjustment of the coupling circuit is usually made for impedance match at some optimum bias condition of the transistor. However, to control the gain of the amplifier stage automatically, one of the d.c. bias currents must be changed and a change in any of these bias currents produces a change in both resistive and reactive components of the input impedance of the transistor. The impedance mismatch thus produced between the transistor input and the coupling circuit results in a different loading effect on the coupling circuit and the preceding stage and, consequently, an undesirable change in the amplifier bandpass characteristic. Further, the reactance change may result in serious detuning in addition to the changed bandpass characteristics.

The automatic gain control is accomplished in the circuit illustrated in Fig. 1 by varying the d.c. bias current flowing in the emitter-base circuit through changes in the base bias voltage of the transistor derived from the output signal level from some later stage in the amplifier and fed to the transistor base terminal through the resistor 13. The effects of the changes in the emitter current of a transistor

on the input impedance of the transistor are shown in the graph of Fig. 2 which is a plot of input impedance against emitter current for an n-p-n grounded emitter transistor circuit of the type shown in Fig. 1. On the graph, the horizontal line 15 represents the input impedance of the transistor when the d.c. bias currents are adjusted for optimum performance of the circuit. The input coupling circuit of the transistor is designed to have the desired bandwidth when "looking into" this value of impedance. The curve 16 represents the changes in the resistive component of transistor input impedance as the emitter current is varied by the automatic gain control voltage. The lines 17 define an input impedance of the transistor 15% to either side of the design center impedance and the limits within which the bandwidth will not change more than approximately 7½% with a double tuned input coupling circuit such as was used in testing the circuit. It is to be understood that the above mentioned specific values were arbitrarily chosen for illustrative purposes only and that the present invention is in no way limited thereto. Thus, it can be seen that the automatic gain control voltages of the stage must be held within the range in which the emitter currents produced by them do not effect an input impedance change of more than 15% of the design center impedance if objectional changes in the bandwidth characteristic of more than the arbitrarily chosen 7½% are to be avoided. This emitter current range is defined on the graph of Fig. 2 between the line 18, the emitter current with no automatic gain control voltage applied, and the line 29, the emitter current producing a 15% change in input impedance. In terms of gain, this range is only a few db.

Returning now to Fig. 1, it can be seen that the transistor amplifier circuit of the present invention has, in addition to the usual amplifier components, a diode element 19 with its cathode connected to the emitter of the transistor 10 through the resistor 20 and to ground through the capacitor 21 and its anode connected to the base of the transistor 10 through the capacitor 22 and to the junction of the resistors 23 and 24. The capacitors 9 and 22 are of such a value that no appreciable impedance is presented at the frequency to be amplified. Thus, when the diode 19 is conductive, the impedance "seen" by the coupling circuit 14 is made up of two parallel paths, one through the transistor itself from base through emitter to ground and the other from the base lead of the transistor through diode 19 and capacitor 21 in parallel with resistor 20 to ground. When the diode 19 is non-conductive, the circuit input impedance is the input impedance of the transistor only. By choosing the values of resistors 23 and 24, which form a voltage divider network between B+ voltage and ground, such that the voltage

at their junction point and therefore the voltage on the anode of the diode 19 is slightly less than the d.c. voltage at the emitter of the transistor, the diode is biased to a non-conductive state. The diode will remain non-conductive until the automatic gain control voltage to the base of the transistor reduces the emitter bias current to the point where the voltage drop across the resistor 11, which determines the voltage on the transistor emitter and the diode cathode, has decreased to a value less positive than the voltage at the anode of the diode. At this voltage, the diode becomes conductive and the input impedance of the circuit becomes a function of the parallel impedance paths between the base lead and ground as mentioned above. Because the impedance of the diode is a function of the current flowing in it, the input impedance of the amplifier stage will reach a maximum at some value of transistor emitter current and then decrease with a decrease in the emitter current. Since the input impedance of the transistor may consist of both a resistive and a capacitive component, capacitor 21 is proportioned to make the reactance at the input remain effectively constant, thus avoiding detuning with AGC as well as stabilizing bandwidth.

The effects of the bandwidth stabilization circuit, just described, on the input impedance of the amplifier stage is shown by curve 25 of Fig. 2. As can be seen, the curve 25 follows the curve 16 for the emitter current range through which the diode is non-conductive, that is, from normal emitter bias current at 26 down to the emitter bias current producing the arbitrarily chosen maximum impedance change occurring at the point 27. From the point 27 any decrease in the emitter current due, for example, to AGC voltage, produces a forward bias on the diode 19 of Fig. 1 causing it to become conductive. As indicated by the remaining portion of curve 25, further decreases in the emitter current cause the diode to become more conductive so that the input impedance of the circuit decreases as described in the preceding paragraph. By proper choice of the value of resistor 20 and capacitor 21 of Fig. 1, the input impedance can be held to within as little as $\pm 15\%$ of the input impedance for which the coupling circuit 14 was designed. In some instances, the resistance of diode 19 is sufficient, and resistor 20 may be replaced by a radio frequency choke coil having high impedance to the operating frequency but providing a d.c. path. The effective stabilizing path at the high frequency is then through diode 19 and capacitor 21. Thus, the automatic gain control range available in the circuit causing less than approximately 7% bandwidth change, to use the same criterion as in the previous example, has been extended to the line 28, a range of approximately 25 db or an increase in the automatic gain control range of approximately 20 db or more for the stabilized bandwidth

circuit over the unstabilized circuit.

Thus, there has been described means for increasing the range of automatic gain control available in transistor amplifier circuits without objectional changes in the tuning or bandwidth characteristic of the amplifier. It is to be understood, of course, that the n-p-n grounded emitter circuit shown is by way of specific example only and that the principles of the bandwidth stabilization system of the present invention are applicable as well to circuits using other transistor types such as, for example, p-n-p, p-n-i-p, n-p-i-n and others and to transistor circuit configurations such as grounded base or grounded collector.

WHAT WE CLAIM IS:—

1. A transistor amplifier stage having automatic gain control means and a bandwidth stabilization means which includes a unilaterally conductive device connected in parallel with the input electrodes of said transistor and responsive to the automatic gain control potential applied to said electrodes to diminish the apparent input impedance of said transistor responsive to increases in said gain control voltage.
2. A transistor amplifier stage as claimed in Claim 1, in which the unilaterally conductive device is biased to become conductive when the gain of the stage falls below a specified minimum level.
3. A transistor amplifier stage as claimed in Claim 1 or 2, wherein the stabilization means comprises an impedance network which includes the unilaterally conductive element and which is connected between the signal input terminals of the transistor.
4. A transistor amplifier stage as claimed in Claim 3, in which the conductive device is a diode and is connected in series with a resistor and a capacitor between the input terminals of the transistor.
5. A transistor amplifier stage as claimed in any one of the preceding claims, in which the stage comprises a transistor provided with an emitter electrode, a base electrode, and a collector electrode, an input circuit connected between said base electrode and said emitter electrode, and an output circuit connected between said collector electrode and said emitter electrode, and wherein the automatic gain control means is connected to said base electrode and the bandwidth stabilization means is connected between said base electrode and said emitter electrode and is arranged to become conductive when the voltage at said emitter electrode falls below a specified minimum value.
6. A transistor amplifier stage substantially as described and as shown in the accompanying drawing.
7. A multi-stage transistor amplifier circuit having at least one amplifier stage as claimed in any one of the preceding claims.

or are
plot of
for an
uit of
h, the 70
t im-
bias
mance
uit of
esired 75
lue of
s the
ristor
ent is
oltage. 80
of the
design
which
than
input 85
ug the
above
rarily
l that
nited 90
auto-
st be
nitter
ct an
% of 95
tional
ic of
re to
ge is
e line 100
gain
the
ge in
range
105
that
esent
lifier
its
the 110
id to
node
ro
tion
itors 115
able
o be
is
the
allel 120
from
ther
ugh
with
19 125
ance
only.
24,
veen
tage 130



are
t of
an
of
the 70
im-
bias
nce
of
red 75
of
the
tor
is
ge. 80
the
ign
ich
nan
out 85
the
ve
rily
hat
ed 90
to-
be
ter
an
of 95
nal
of
to
is
ne 100
in
he
in
ge 105
nat
ent
ier
its
he 110
to
de
ro
on
ors 115
ole
be
is
he
hel 120
m
er
gh
th
19 125
nce
ly.
4.
en
ge 130

at their junction point and therefore the voltage on the anode of the diode 19 is slightly less than the d.c. voltage at the emitter of the transistor, the diode is biased to a non-conductive state. 5 The diode will remain non-conductive until the automatic gain control voltage to the base of the transistor reduces the emitter bias current to the point where the voltage drop across the resistor 11, which determines the 10 voltage on the transistor emitter and the diode cathode, has decreased to a value less positive than the voltage at the anode of the diode. At this voltage, the diode becomes conductive and the input impedance of the circuit becomes a 15 function of the parallel impedance paths between the base lead and ground as mentioned above. Because the impedance of the diode is a function of the current flowing in it, the input impedance of the amplifier stage will reach a 20 maximum at some value of transistor emitter current and then decrease with a decrease in the emitter current. Since the input impedance of the transistor may consist of both a resistive and a capacitive component, capacitor 21 is 25 proportioned to make the reactance at the input remain effectively constant, thus avoiding detuning with AGC as well as stabilizing bandpass.

The effects of the bandwidth stabilization 30 circuit, just described, on the input impedance of the amplifier stage is shown by curve 25 of Fig. 2. As can be seen, the curve 25 follows the curve 16 for the emitter current range through which the diode is non-conductive, that is, 35 from normal emitter bias current at 26 down to the emitter bias current producing the arbitrarily chosen maximum impedance change occurring at the point 27. From the point 27 any decrease in the emitter current due, for 40 example, to AGC voltage, produces a forward bias on the diode 19 of Fig. 1 causing it to become conductive. As indicated by the remaining portion of curve 25, further decreases in the emitter current cause the diode to become 45 more conductive so that the input impedance of the circuit decreases as described in the preceding paragraph. By proper choice of the value of resistor 20 and capacitor 21 of Fig. 1, the input impedance can be held to within as 50 little as $\pm 15\%$ of the input impedance for which the coupling circuit 14 was designed. In some instances, the resistance of diode 19 is sufficient, and resistor 20 may be replaced by a radio frequency choke coil having high impedance to 55 the operating frequency but providing a d.c. path. The effective stabilizing path at the high frequency is then through diode 19 and capacitor 21. Thus, the automatic gain control range available in the circuit causing less than 60 approximately $7\frac{1}{2}\%$ bandwidth change, to use the same criterion as in the previous example, has been extended to the line 28, a range of approximately 25 db or an increase in the automatic gain control range of approximately 65 20 db or more for the stabilized bandwidth

circuit over the unstabilized circuit.

Thus, there has been described means for increasing the range of automatic gain control available in transistor amplifier circuits without objectional changes in the tuning or bandwidth 70 characteristic of the amplifier. It is to be understood, of course, that the n-p-n grounded emitter circuit shown is by way of specific example only and that the principles of the bandwidth stabilization system of the present 75 invention are applicable as well to circuits using other transistor types such as, for example, p-n-p, p-n-i-p, n-p-i-n and others and to transistor circuit configurations such as grounded base or grounded collector. 80

WHAT WE CLAIM IS:—

1. A transistor amplifier stage having automatic gain control means and a bandwidth stabilization means which includes a uni- 85 laterally conductive device connected in parallel with the input electrodes of said transistor and responsive to the automatic gain control potential applied to said electrodes to diminish the apparent input impedance of said transistor 90 responsive to increases in said gain control voltage.

2. A transistor amplifier stage as claimed in Claim 1, in which the unilaterally conductive device is biased to become conductive when 95 the gain of the stage falls below a specified minimum level.

3. A transistor amplifier stage as claimed in Claim 1 or 2, wherein the stabilization means comprises an impedance network which in- 100 cludes the unilaterally conductive element and which is connected between the signal input terminals of the transistor.

4. A transistor amplifier stage as claimed in Claim 3, in which the conductive device is a 105 diode and is connected in series with a resistor and a capacitor between the input terminals of the transistor.

5. A transistor amplifier stage as claimed in any one of the preceding claims, in which the 110 stage comprises a transistor provided with an emitter electrode, a base electrode, and a collector electrode, an input circuit connected between said base electrode and said emitter electrode, and an output circuit connected 115 between said collector electrode and said emitter electrode, and wherein the automatic gain control means is connected to said base electrode and the bandwidth stabilization means is connected between said base electrode 120 and said emitter electrode and is arranged to become conductive when the voltage at said emitter electrode falls below a specified minimum value.

6. A transistor amplifier stage substantially 125 as described and as shown in the accompanying drawing.

7. A multi-stage transistor amplifier circuit having at least one amplifier stage as claimed in any one of the preceding claims. 130

807,632

For the Applicants :—
F. J. CLEVELAND & COMPANY,
Chartered Patent Agents,
29, Southampton Buildings,
Chancery Lane,
London, W.C.2.

Printed for Her Majesty's Stationery Office by Wickes & Andrews, Ltd., E.C.4. 684/2.—1959.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies
may be obtained.



* C L N S *